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Representations of Nature of Science in High School Physics Textbooks

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Abstract

Nature of science (NOS) is a vital component of scientific literacy that refers to the science's epistemology. Students must possess the NOS conception to address socio-scientific issues using the reasoning and justification patterns like scientists. This qualitative research assessed the representation of NOS quantitatively and qualitatively in the grade XII senior high school physics textbooks. The quantitative representation of NOS was described by the percentage of appearance of each element of NOS, while the delivery approach was used to describe NOS qualitatively. The analysis was conducted on two textbooks focused on electromagnetic radiation, special relativity theory, and quantum phenomena chapters. The NOS framework instrument has been conceptually and empirically valid. The results show that the empirical and scientific theories were addressed with the highest percentage of appearance, while the social and cultural embeddedness of science and scientific methods were poorly addressed. All elements of NOS were represented implicitly. The empirical findings of this study are expected to be able to stimulate the improvement of the representation of NOS in science textbooks in Indonesia.

Keywords: nature of science, senior high school physics textbooks, science education

INTRODUCTION

Nature of science (NOS) refers to the epistemology of science, which is a way of knowing, or the values and beliefs inherent in science and its development (Lederman, 1992; Abd-El-Khalick & Lederman, 2000). NOS can also be defined as a set of dimensions on how to achieve reliability in building science as knowledge (Allchin, 2011). In general, NOS is a set of scientific characteristics that distinguishes it from other disciplines (Sadler, Chambers, & Zeidler, 2004). NOS can be summed up as the basis of the epistemology of science and its development which forms a set of characteristics of science.

NOS as a characteristic of science consists of specific aspects that have not been generally agreed by experts. The absence of consensus on the definition and aspects of NOS led to the emergence of various aspects of NOS proposed by these experts. The formulation of NOS aspects proposed by Lederman (2007) is quite widely used as a framework in science education research, which Abd-El-Khalick, Waters, & Le (2008) then summarized into ten aspects, including: 1) empirical, 2) inferential, 3) creative, 4) theory-driven, 5) tentative, 6) scientific method, 7) scientific theories, 8) scientific laws, 9) social dimensions of science, as well as 10) social and cultural embeddedness of science.

NOS is a fundamental component of science education that has been confirmed in various science standard documents and curricula in various countries, including the United States, Australia, England, New Zealand, and Canada (McComas & Olson, 1998). With the provision in the form of the NOS conception, students are expected to be able to respond to socio-scientific issues (Millar, 1997). In other words, NOS is an

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essential component in scientific literacy (Holbrook & Rannikmae, 2009).

NOS can be taught to students either implicitly or explicitly. However, some research results confirm that teaching NOS in an explicit-reflective manner is the best strategy (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). In an explicit approach, NOS is assumed to be cognitive content that can be achieved by students through direct learning.

Ideally, NOS should not only be presented in standards and/or curriculum, but should also be represented in textbooks as learning resources that help teachers plan and implement science learning to achieve the goals set by the local curriculum. This is noteworthy considering that students' conception of NOS is influenced by the representation of NOS in the science textbooks used (Chua, Tan, & Ramnarain, 2018). Meanwhile, the distribution of research that focuses on analyzing the representation of NOS in science textbooks is still centered on certain countries, such as the United States (Abd-El-Khalick et al., 2008), China (Li et al., 2018), Singapore (Chua et al., 2018), Thailand (Chaisri & Thathong, 2014), and Turkey (Izci, 2017). There is no empirical study that analyzes the representation of NOS in Indonesian science textbooks. To overcome this gap, this study aims to describe the representation of NOS in the physics textbook for class XII SMA / MA Curriculum 2013. The empirical findings of this study are expected to contribute to efforts to improve the representation of NOS in science clusters textbooks in Indonesia.

METHOD

This research is a qualitative research with a document analysis approach. The analysis of the NOS representation was carried out on two physics textbooks for class XII SMA / MA Curriculum 2013 which dominate the textbook market share in the Province of DIY (Table 1). The analysis of each textbook focuses on three chapters containing the historical content of the development of science, namely electromagnetic radiation, the theory of special relativity, and quantum phenomena. The history of scientific development is one of the contents that can be used to reflect NOS effectively (Abd-El-Khalick & Lederman, 2000).

The NOS representation is analyzed systematically and structured according to the instrument in the form of the NOS framework (Table 2) which is conceptually and empirically valid. The instrument was obtained by adapting the NOS construct proposed by Abd-El-Khalick et al. (2008) & Chua et al. (2018). The adaptation process is carried out by synthesizing the dimensions of each aspect of NOS from two sources in order to obtain operational indicators for each aspect. The steps to analyze the NOS representation in this study are described as follows: 1) dividing the chapter presentation into units of analysis; 2) identify the NOS aspects contained in each unit of analysis according to Table 2; 3) identify the quality of the NOS representation based on the presentation approach used (explicit or implicit); then 4) calculate the percentage appearance of NOS aspects according to equation (1) and identify the dominance of the representation approach.

$$\text{The appearance of the NOS aspect} = \frac{\text{The number of units of analysis containing the NOS aspect}}{\text{The total unit of analysis containing the NOS aspect}} \times 100\% \quad (1)$$

Table 1. Specifications textbook of physics class XII SMA / MA as the object of analysis

Text Book Code	Titles	Authors	Publisher	Number of Pages Analyzed
A	Fisika untuk SMA/MA Kelas XII	M. Kanginan	Erlangga	22%
B	Kajian Konsep Fisika 3 untuk Kelas XII SMA dan MA	M. F. Rosyid; E. Firmansah; R. Resmiyanto; A. Yasrina	Tiga Serangkai Pustaka Mandiri	25%

Table 2. Description of the NOS framework in textbook analysis

NOS aspects	Dimensions	Indicators in Textbook Analysis
Empirical	Scientific claims originate from and / or are consistent with observations of natural phenomena. However, scientists do not have direct access to most natural phenomena. These observations are made using tools based on these assumptions.	1) Emphasize that scientific claims come from observations of natural phenomena so that this claim is empirical. 2) Presenting the process of observing natural phenomena, both with and without observation supporting instruments.
Inferential	Observation produces descriptive statements about natural phenomena that can be accessed by the senses so that consensus on these natural phenomena can be easily reached by the observer. Meanwhile, inference produces statements about natural phenomena that can only be measured through their manifestations or effects. The body of scientific knowledge and scientific explanation is a form of inference.	Presents a scientific explanation of the results of observations of natural phenomena.
Creative	The process of formulating scientific explanations and theoretical entities by scientists in order to produce scientific knowledge by involving creativity.	Emphasizes the creative and innovative thinking of scientists in interpreting theoretical entities and producing scientific knowledge.
Theory-driven	Commitments, beliefs, or theoretical perspectives held by scientists influence the process of observation and investigation.	Shows the effect of differences in scientists' theoretical assumptions on the process of observation and investigation.
Tentative	Scientific knowledge (facts, theories, laws, etc.) is reliable and durable, but never absolute. Scientific knowledge can change when new evidence is found due to conceptual and technological advances.	Demonstrate the process of improving scientific knowledge as a result of finding new evidence.
Scientific Method	There is a mistaken belief that science has a gradual procedure like a recipe for the scientific method. In scientific work,	Emphasizing that the scientific method consists of various activities that are not procedurally sequential,

NOS aspects	Dimensions	Indicators in Textbook Analysis
	scientists observe, compare, measure, test, speculate, hypothesize, debate, create conceptual ideas and devices, and construct scientific theories and explanations.	including observing, comparing, measuring, testing, speculating, hypothesizing, arguing, making conceptual ideas and devices, and building scientific theories and explanations.
Scientific Theories	Scientific theory has the following characteristics: 1) theory is based on assumptions; 2) proposing the existence of entities that cannot be observed; 3) only circumstantial evidence can support and validate the theory. Match between predictions and observations increases the reliability of the theory.	1) Presenting a scientific theory as a scientific explanation based on certain assumptions. 2) Emphasize the conformity between the results of predictions and the results of observations based on certain theories.
Scientific Laws	Laws are descriptive statements that contain mathematical relationships of natural phenomena. Theory and law are not hierarchically related so that the theory does not become law if sufficient supporting evidence is obtained.	1) Presenting scientific laws as descriptive statements of mathematical relationships of natural phenomena. 2) Emphasizing that scientific theory and law are not hierarchically related.
Social Dimensions of Science	There are patented procedures available to facilitate communication and criticism in order to increase the objectivity of scientific knowledge that is collectively researched.	Describes the processes of communication, criticism, confirmation, and negotiation of scientists in order to increase the objectivity of scientific knowledge.
Social and Cultural Embeddedness of Science	Science influences and is influenced by various socio-cultural elements, such as ideology, religion, politics and economics.	Shows the influence of the social and cultural context on the investigative process carried out by scientists.

RESULTS AND DISCUSSION

The results of the quantitative and qualitative NOS representation analysis are shown in Table 3. The sections of statements in textbooks containing NOS representations are shown in Table 4. All aspects of NOS in textbooks A and B are presented implicitly, even some of them contain misconceptions of representation (misrepresented). The findings of this study are relatively consistent with the results of the analysis by Li et al. (2018) on junior high school physics textbooks at the 8th grade in China which shows that the representation of NOS in the textbook is not dominated by explicit statements. Izci (2017) also describes the results of a similar NOS representation analysis, in which five of the ten aspects of NOS (empirical, inferential, tentative, scientific theories, and social and cultural embeddedness of science) are implicitly conceptualized in the IPA textbook (teacher edition) SMP in 7th grade in Turkey. This should be used as a major evaluation consideration considering that several research results suggest the use of an explicit approach as an effective strategy in building the conception of NOS (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). NOS needs to be assumed as cognitive content like learning material so that it can be presented clearly in textbooks.

Table 3. Representation of NOS quantitatively and qualitatively

Aspects of NOS	Textbook A		Textbook B	
	Percentage of Occurrences (%)	Presentation Approach	Percentage of Occurrences (%)	Presentation Approach
Empirical	25.22	Implicit	25.61	Implicit
Inferential	9.57	Implicit	7.32	Implicit
Creative	10.43	Implicit	6.09	Implicit
Theory-driven	6.09	Implicit	7.32	Implicit
Tentative	7.83	Implicit	17.07	Implicit
Scientific Method	4.35	Implicit	1.22	Implicit
Scientific Theories	14.78	Implicit	24.39	Implicit
Scientific Laws	11.30	Implicit	6.09	Implicit
Social Dimensions of Science	9.57	Implicit	4.88	Implicit
Social and Cultural Embeddedness of Science	0.87	Implicit	0	Implicit

The percentage of occurrences of NOS aspects in textbooks A and B is quite varied, but shows a similar trend. The empirical aspect is represented predominantly in the two textbooks, namely 25.22% in textbook A and 25.61% in textbook B. Nnatural phenomena which are observed empirically, either through direct access or with the help of certain scientific instruments. The dominance of the empirical aspect can also be found in most science textbooks because this NOS aspect is indeed easier to represent (Aydin & Tortumlu, 2015).

The essence of scientific theories is an aspect of NOS with the second highest percentage of representation quantitatively, both in text book A at 14.78% and textbook B at 24.39%. This finding relates to the way the material is presented in the two textbooks which refers to the historical development approach.

The historical development approach is used to present important concepts in the matter of electromagnetic radiation, the theory of special relativity, and quantum phenomena. It contains descriptions of various experimental projects of scientists who have contributed to improving scientific theory so that the tentative, theory-driven, creative, and social dimensions of science cannot be separated from the representation of scientific theories aspects.

Improvements in scientific theory after the discovery of new empirical evidence due to advances in technology suggest that science is tentative. In the process of finding new empirical evidence, scientists conduct research based on theoretical backgrounds and beliefs that are always held firmly individually (theory-driven). The process of translating the reality of empirical evidence cannot be regarded as a rational and systematic activity because creativity is also needed in it. Scientific theory is not established by the contribution of a scientist alone. Criticism, cooperation, and negotiation among scientists are social dimensions in science that characterize the nature of science. In a more precise analysis method, the representation of these aspects of NOS which are interrelated and consistent shows better quality of representation than a single presentation (Abd-El-Khalick et al., 2008).

Table 4. Section of statements containing NOS representations

Aspects of NOS	Textbook A	Textbook B
Empirical	“The precision instrument designed by Michelson and Morley has the ability to detect shifts in fringe patterns as small as 0.01. But in this experiment both detected no shifts in the fringe patterns. " (Page 277)	"This elongation of time can be observed in various natural phenomena. An example is the process of forming and decaying elementary particles (particles) called muons. " (Page 201)
Inferential	"He observed that a spark would jump rapidly between two electrically charged metal balls precisely when the surface of the metal sphere was illuminated by light coming from the other spherical spark. Here the light shining on the surface of the metal sphere facilitates the release of charged particles. . . " (Page 330)	"At that time Rontgen was studying the electron beam from the cathode tube. The metal plate located near the cathode tube emits a fluorescent light as the electrons are flowed. Based on these events, Rontgen concluded that the resulting rays were caused by radiation from an atom. " (Page 236)
Creative	"From working hard with his colleagues, Einstein dared to break the rules by taking a different approach to understanding the ether problem." (Page 277)	"Against this difficulty, Max Planck proposed an idea that was considered quite radical at that time, namely the quantization of the energy possessed by electromagnetic vibrations." (Page 223)
Theory-driven	"Einstein, like Faraday, prefers simple descriptions, so he assumes that the ether does not exist. From this assumption, he then attempted to explain physical phenomena in accordance with facts (including the zero result in the Michelson-Morley experiment). " (Pages 277−278)	"Classical theory does not recognize the concept of quantization of a quantity. Classical theory holds that all physical quantities are continuous. Bohr's atomic model defied this assumption by including the quantization of angular momentum. As a result, the power levels of the electrons are obtained in the atom. " (Page 230)
Tentative	"Meanwhile, scientists using new instruments are constantly developing new experiments, the results of which cannot be satisfactorily explained by the laws of classical physics. Revolutionary new laws were developed in the 20th century. These laws we now call quantum physics. " (Page 319)	"Some of the experimental results have forced people to begin to doubt the correctness of Newtonian mechanics. Several other experiments led us to doubt classical electromagnetics. " (Page 217)
Scientific Method	"The ability to control variables	"In 1924, L. de Broglie tried to see the possibility of dualism applicable to particles such as electrons, protons, neutrons, and so on. He put forward the hypothesis (Page 232)
Scientific Theories	“The magnitude of the relativistic momentum of a particle is given by the equation:…. Which of the following has	“Classical physics, namely physics before the twentieth century, was dominated by Newtonian mechanics and classical

Aspects of NOS	Textbook A	Textbook B
	the greatest relativistic momentum? . . . " (Page 307)	electromagnetics described by Maxwell's equations. This is not surprising, since the natural phenomena observed by man at that time can be satisfactorily explained and (predicted) accurately by the two theories. " (Page 217)
Scientific Laws	"In 1893, Wilhelm Wien proposed a general form of the black body distribution law J (f, T) which gives λ_{max} and T relationships that match the experimental results. This relationship is known as Wien's law of shift and is written as follows. . . " (Page 324)	"Maxwell's equation at the top is also called Gauss's law which explains the relationship between the distribution of electric charge and electric intensity (electric force per unit charge it causes)." (Page 160)
Social Dimensions of Science	"Five years later, impressive confirmation of the electromagnetic wave theory of light was obtained when Boltzmann derived Stefan's law from a combination of thermodynamics and Maxwell's equations." (Page 322)	"An advanced stage of de Broglie's thinking was the birth of wave mechanics" brainstormed "by Erwin Schrödinger and matrix mechanics" brainstormed "by Werner Heisenberg." (Page 232)
Social and Cultural Embeddedness of Science	Arthur H. Compton (1892−1962), American physicist. . . . He is a pioneer in research with X-rays and cosmic rays. Before World War II, he led part of the US atomic bomb research project. " (Page 339)	-

The following is a section of statements in textbook A which contains a representation of related aspects of comprehensive NOS (scientific theories, tentatives, theory-driven, creative):

“Wien’s theory fits the spectrum of black body radiation for short wavelengths and deviates for long wavelengths. In contrast, the Rayleigh-Jeans theory fits the spectrum of black body radiation for long wavelengths and deviates for short wavelengths. It is clear that classical physics failed to explain black body radiation. In 1900, Planck began his work by making a new assumption about the nature of the vibrations of molecules in the cavity walls of black bodies (at that time electrons had not been discovered). This new assumption is very radical and contrary to classical physics, namely as follows. . . “ (Pages 326−327)

The excerpts of statements in textbook B containing representations of related aspects of NOS (scientific theories, creative, empirical) are described as follows:

"In 1865, he (James Clerk Maxwell) announced his work with the title A Dynamics Theory of the Electromagnetic Field, a work that unites (combines) the laws of electricity and magnetism into a revolutionary theory. The work postulated displacement currents and predicted the existence of electromagnetic waves traveling as fast as light. . . . This prediction can be proven empirically (experimentally) by Heinrich Hertz with the discovery of radio waves. The discoveries of Maxwell and Hertz in turn support the truth (that light is a wave) and at the same time suppress (for quite a while) the controversy about the nature of light " (Pages 159−160).

Misconceptions about scientific theories were found in several representations in textbooks A and B, regardless of the high percentage of occurrences of these aspects of NOS. This misstatement stems from ambiguity in the position of scientific theories and scientific laws, as the following statement excerpts:

"The orderly motion of the planets around the center of a solar system (the sun for our solar system) was formulated empirically by Kepler through his laws. The three Kepler laws were built based on the data that had been collected by Brahe. Kepler's laws are fundamentally explained by Newton's laws of motion and gravity. . . . Human belief in the truth of the two theories raises the status of the two theories to become the basic laws of physics. " (Textbook B, page 217)

"Let us discuss the classical theory of black body radiation which views black body radiation as waves, namely Wien's law of radiation and Rayleigh-Jeans's law." (Textbook A, page 325)

According to Lederman (2007), scientific theories and laws are not related hierarchically. This means that scientific theories cannot be turned into scientific laws, and vice versa. They are separate components of the body of scientific knowledge. Scientific theories are inferential explanations of a natural phenomenon or order in these phenomena, whereas scientific laws are descriptive statements about the mathematical relationships of natural phenomena. The NOS aspect which has the lowest level of quantitative representation in both textbooks is the social and cultural embeddedness of science, which is only 0.87% in textbook A and does not appear in textbook B. In the context of comparison, the social and cultural aspects of embeddedness of Science also has a low level of representation in high school chemistry textbooks in the United States, because the substance of this NOS aspect is considered incompatible with the cognitive development of high school students (Abd-El-Khalick et al., 2008).

The social and cultural aspects of the embeddedness of science at the level of education in the United States, which refer to the view that certain social and cultural contexts affect the process of acceptance and interpretation of science and scientific discoveries, conceptualized at the tertiary level. The integration of NOS gradually according to the age level of students has indeed been implemented in the United States, guided by Appendix H Next Generation Science Standards (Harrison, Seraphin, Philippoff, Vallin, & Brandon, 2015).

The NOS aspect with the next low frequency of occurrence is the scientific method, which is 4.35% in textbook A and 1.22% in textbook B. The low percentage of quantitative representation in this aspect of NOS is related to the use of the historical development approach to presenting learning material which is abstract conceptualization. Although the two textbooks emphasize the empirical side of the experimental projects of scientists, this empirical aspect does not aim to stimulate students to collect empirical evidence through the scientific method. Ideally, the representation of the scientific method aspect aims to change the paradigm regarding the sequence of steps of a patent scientific method like a recipe book. Abd-El-Khalick et al. (2008) emphasized that the nature of the scientific method is reflected in the actions of scientists who observe, compare, measure, test, formulate speculations, formulate hypotheses, debate, create conceptual ideas and devices, and build theories and explanations. These strategies are the essence of scientists' actions in exploring nature (Kurt & Doğan, 2020).

CONCLUSION

NOS in the physics textbook for class XII SMA/MA 2013 curriculum in this study is represented by an implicit approach. The aspects of NOS that have the highest level of quantitative representation in both textbooks are empirical and scientific theories. Meanwhile, the aspects of NOS that have the lowest level of quantitative representation are the social and cultural embeddedness of science and the scientific method. Reformation of NOS representation explicitly in science clump textbooks is something that needs to be pursued. Variations in the presentation of learning materials need to be considered in order to facilitate the proportional representation of all aspects of NOS. Empirical, inferential, and scientific method aspects can be represented through experimental approaches. Furthermore, creative, theory-driven, tentative,

scientific theories, scientific laws, social dimensions of science, as well as social and cultural embeddedness of science can be represented through an approach to historical development.

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