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A Comparative Study on the Various Perspectives on the Nature of Science through Textbook Analysis Centering on the Consensus View, Features of Science, and Family Resemblance Approach

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A R T I C L E I N F O

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A B S T R A C T

This study intends to delineate the characteristics of various perspectives on the nature of science (NOS) through the textbook analysis. Thus, centering on a science textbook called Science Laboratory Experiments, this study analyzes the elements of the NOS from three different perspectives: the consensus view, features of science (FOS), and family resemblance approach (FRA). While the consensus view highlights the similar elements of the NOS across the topics, the FOS is concerned about empirical ways for doing science. The FRA rather focuses on socio-cultural aspects of science activities. While the consensus view is useful to reify the features of the NOS, the FRA helps to understand science from various viewpoints. Regarding the philosophical account for three perspectives, all of them are ambiguous to some extent. The consensus view holds contradictory dispositions e.g., relativism vs. (post-)positivism, and critical realism and instrumentalism. The FOS supports empirical tradition but cannot effectively cope with the anomalous situation. The FRA is useful to show up the ways of science in both microscopic (personal) and macroscopic (social) viewpoints. However, the broader concept about science may mislead understanding of the NOS. Consequently, this study provides some implication for improving the framework of the NOS and teaching the NOS in the classroom.

I. Introduction

One of the overarching goals in science education is to understand how science works (McComas, 1998). The nature of science (NOS) has been much heeded in the community of science education since 1990s, and many educators have delineated its concept in theoretical and empirical ways (Abd-El-Khalick *et al*., 1998; Bianchini *et al*., 2002; Clough, 2006; Irzik and Nola, 2014; Lederman, 1992; Matthews, 2012). The NOS is crucial in teaching and learning science. This is because it is regarded as a key component of scientific literacy for the informed citizenship (Abd-El-Khalick and Lederman, 2000; Millar and Osborne, 1998; Ratcliffe and Grace, 2003), and it may play a significant role in learning science contents and world view of science (Deng *et al*., 2011; Liu and Tsai, 2008; McComas, 1998). Thus, international policy reports and national curriculum documents in many countries think highly of the role of the NOS (American Association for the Advancement of Science, 1993; National Research Council, 1996, 2012; Organisation for Economic Co-operation and Development, 2016).

As a means to assess understanding of the nature of science, many educators tried to evaluate views of students, teachers, and scientists on the NOS (Abi-El-Mona and Abd-El-Khalick, 2011; Aydeniz and Bilican, 2014; Bayir *et al*., 2014; Schwartz and Lederman, 2008), and subsequent materials for teaching and learning the NOS have been developed and implemented in the classroom. Among them, a prevailing approach is so-called the consensus view which suggested seven elements of the NOS, advocated by Lederman *et al*. (2002), and his idea is now widely accepted in the communities of science education. They developed the questionnaire to survey the views of students and teachers on the NOS(Lederman *et al*., 2002).

In spite of abundant studies on the NOS over three decades, there is little agreement about the meaning of the nature of science (Jho, 2018; Lederman, 1992; McComas, 1998; Smith and Scharmann, 1999). A number of studies addressed the limitations of the consensus view in terms of philosophical dispositions: Tsai and Liu (2005) suggested the NOS consisting of five dimensions as role of social negotiation, invented and creative nature of science, theory-laden exploration, cultural impacts, and changing and tentative feature of

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science knowledge (Tsai and Liu, 2005); Collette and Chiappetta (1989) categorized it into four themes (science as a body of knowledge, science as a way of investigation, science as a way of thinking, and interaction of science, technology and society) for scientific literacy; and features of science added at least three elements to the consensus view as listed: experimentation, idealization, and modeling (Matthews, 2012).

Moreover, it is disputable whether the nature of science is domain-general or domain-specific (Lee and Tsai, 2012). The consensus view simplifies the NOS but does not illustrate the detailed process and actions in science. For example, myth of scientific method implies that there is no single recipe for doing science. However, this argument does not explain what can be counted as an appropriate way for doing science. In terms of empirical basis, different fields of science may rely on the different methods. Mechanics tries to infer the mathematical solutions to explain the given situation while systematic botany concentrates on observation rather than prediction or explanation. Theoretical physics in a quantum level is often based on the mathematical formulation or simulation rather than the experimentation, and observation in astronomy is different from that in chemistry. This indicates that the consensus view does not encompass the peculiar nature of various fields of science. As an alternative way to solve these issues, family resemblance approach (FRA) to the NOS stresses the socio-cultural dimensions of the NOS (Irzik and Nola, 2014). Figure 1 illustrates the processes of inquiry as D, I, E, P, and H, and shows the inclusive features in various fields of science (Erduran and Dagher, 2014). Intriguing is that some procedures are more influential to certain fields of science. For, medicine and particle physics think highly of experimentation to get the empirical evidence while astronomy seldom examines the experiments but observe the celestial movements. Even, the same term is in different use according to the context. In physics, prediction usually means motion of bodies (position, velocity and acceleration) based on the laws and theories as a causal relationship, while prediction in medical science means the effect of treatment on humans as a statistical relationship.

It is controversial that scientists'view on the NOS is often regarded as a naïve one according to the consensus view. The consensus view argues that science knowledge is tentative and supports that science knowledge is socially and culturally embedded, similar to constructivism. However, scientists tend to hold a traditional view of science that science knowledge is a set of objective statements (Aydeniz and Bilican, 2014; Peters-Burton and Baynard, 2013; Pomeroy, 1993). In addition, scientists concentrate more on the experimentation and modeling depending on the realism and materialism (Bayir *et al*., 2014; Bianchini *et al*., 2002). In other words, science deals with physically existing ones, and scientific theories and laws are to be placed behind the natural world. Even scientists hesitate to accept Kuhnian theory that science is not developed but changed, so-called paradigm shift (Schwartz *et al*., 2004). The theory-laden nature upholds the tentativeness of science knowledge, however, scientists are much concerned about the accurate measurement and rigorous experimentation, which is connected with post-positivism. This indicates that there is a gap between the contemporary view in science education and that of scientists on the NOS. Another clash between science and science education is related to modeling. Scientists use models to explain and predict the natural phenomena and tend to figure out the optimal one which fits for the experimental data. However, the consensus view does not mention about how to construct or assess scientific knowledge. To cope with such controversies, features of science (FOS) theorizes experimentation and models in scientific inquiries through the history and philosophy of science (Irzik and Nola, 2014; Matthews, 2012).

The another issue about the NOS is related to the ambiguous distinction between science and technology. It is usually assumed that science is useful in a daily basis. However, in this sentence, science does not mean simply traditional "pure" science, but technology like smart phone, TV, and new kind of energy. In the past, science was narrowly defined as a discipline to pursuit the truth or patterns in the natural world, but now science is widely used as a synonym of science and technology (DiGironimo, 2011). The consensus view explains the reciprocal relationship between science and technology based on the distinction of the two. However, since the twentieth century, science enterprise is interested in the development of new techniques and improvement of efficiencies in the inquiries. Science and technology investigate similar topics, deal with similar topics, and share the outcome each other. For example, in condensed matter physics, scientists test various materials to find out the appropriate matters for a semi-conductor as material engineers do. It is hence very difficult to distinguish pure science and applied science (technology). Recently, science educators are interested in the nature of technology or engineering aligned with the nature of science (Bell and Lederman, 2003; Constantinou *et al*., 2010; Liou, 2015; Waight, 2014; Waight and Abd-El-Khalick, 2012). After all, the meaning of

Astronomy = [D, I, P, H]
Particle Physics = [D, I, E, P, H]
Medicine = [D, I, P', E, T]
- Scientific process: data collection (D), inference making (I), experimentation (E), prediction (P), hypothetico-deductive testing (H), and blind randomized trails (T)
- P' indicates the differences in predictive power

Figure 1. The exemplar uses of family resemblance approach to the nature of science

the NOS as well as the meaning of science are provisional. When students and teachers take into account the NOS, they include science as well as technology. Even, the word, scientific, is broadly used in many disciplines afar from natural science. The subtle relationship between science and technology may be applied to the relationship between science and non-science. The border of science is not clear-cut but waiving as ocean tides. In this light, FRA was introduced to bridge the gap between the two and tie up diverse fields of science (Irzik and Nola, 2014).

The above disputes about the NOS address the necessity of new vehicles to encompass the various purposes and goals in relation to science. Thus, this study tackles the consensus view and the alternatives which are frequently discussed, the FOS and the FRA. The purpose of this study is to examine the pros and cons of different perspectives on the NOS through the textbook analysis and to give some clues to resolve the controversies in the NOS studies. This study amy suggest the more appropriate solution to cope with the problems in the NOS research.

II. Theoretical background

1. Consensus view

The notion of the NOS encompasses various disciplines of science. In the 1960s, the NOS meant scientific methods but later, process skills, science knowledge, ways of science, and context in science were taken into account as the NOS (Deng *et al*., 2011). The NOS has been discussed by many educators (Aikenhead and Ryan, 1992; Bady, 1979; Cooley and Klopfer, 1961; Kimball, 1968; Klopfer and Cooley, 1963; McComas, 1998; Rubba and Anderson, 1978). In the 1990s, Lederman synthesized the NOS in the literature review and developed a questionnaire to examine students' and teachers' understanding of the NOS (Lederman, 1992; Lederman *et al*., 1998, 2002). In his framework, the NOS is comprised of seven elements as shown in Table 1.

Based on the seven elements on the NOS, Lederman and his group developed a series of questionnaires to evaluate the conceptions of students, teachers and scientists about the NOS, and their questionnaires are useful to show up the effect of implemented teaching for the NOS. The NOS with seven elements is often called as the consensus view because of its frequent citation and wide use.

2. Features of science (FOS)

While the consensus view highlights the general aspects of science, the FOS concentrates more on the empirical aspects of science by taking into account what scientists actually do. The FOS is grounded to the empiricist viewpoint such as Whewell's essentialist thinking and Dewey's pragmatism. To elaborate experimental ways for doing science, the FOS added some elements to the consensus view: experimentation, idealization, and modelling (Matthews, 1994, 1998, 2012).

Experimentation is significant in a science enterprise. For example, many scientists in the scientific revolution applied the observed results to the new situation or developed theories based on the natural phenomena. Galileo illustrated the uniformly acceleration motion of free fall while using the inclined experiment, Newton proved his theory of color using prism experiment, and Hooke explained capillary motion with manipulation of glass tubes (Cooper and Hunter, 2006; Hunter and Schaffer, 1989; Levere and Shea, 1990; Newton, 1952; Shapin, 1996).

Idealization is crucial in developing scientific theories. Although scientific knowledge is to investigate the natural phenomena, scientific knowledge does not seem to account for nature because of the gap between theory and practice and many erroneous situations. After all, scientists should neglect some point or to focus more on some parameters. Apart from the natural world, idealization is helpful to understand the natural world and experimentation presents the adequacy of idealization. For instance, Galileo dismissed the Aristotelian

Table 1. Elements of the nature of science from the consensus view (Erduran and Dagher, 2014)

Element	Description
Tentativeness	Scientific knowledge, although reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change.
Observation and inference	Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the sense). By contrast, inferences are statements about phenomena that are not directly accessible to the senses.
Theory-ladenness	Scientific knowledge is theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work.
Creativity and imagination	Science is empirical. Nonetheless, generating scientific knowledge also involves human imagination and creativity.
Socio-cultural embeddedness	Science as a human enterprise is practiced in the context of a larger culture and its practitioners are the product of that culture.
Scientific theories and laws	Scientific theories are well-established, highly substantiated, internally consistent systems of explanations. Laws are descriptive statements of relationships among observable phenomena. Theories and laws are different kinds of knowledge and does not become the other.
Myth of scientific method	The myth of scientific method is regularly manifested in the belief that there is a recipelike stepwise procedure that all scientists follow when they do science. This notion was explicitly debunked.

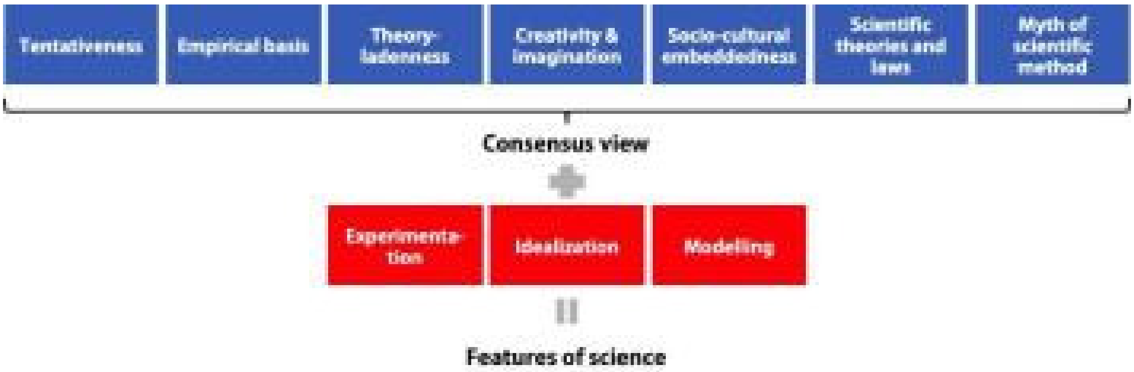

Figure 2. Comparison between the consensus view and features of science

thinking about free fall motion with thought experiment (Jho, 2014; Levere and Shea, 1990). In order to establish scientific theories, scientists should be able to simplify parameters, to abstract the situation, and to build up generalized conclusions.

Last, models are important artifacts to predict and explain the natural world. Both experimentation and idealization bring about a kind of model as a consequence, and it is seldom possible to think about science without models. Models can make the invisible visible such as the structure of an atom, figure out the hidden patterns such as periodic table, progress debates on science like ether vortices of electromagnetic field, and abstract the natural phenomena with simple mathematical forms as ideal gas law and the Schrödinger equation (Clement, 2008; Clement and Rea-Ramirez, 2008). Even students use various models as graph, equation, concept map and table while learning science. Models are really significant as processes and outcomes of science.

3. Family resemblance approach to the NOS

The term, family resemblance approach, originates from the book of Wittgenstein, *The Philosophical Investigations* (Wittgenstein, 1978). Wittgenstein is renowned as a philosopher of language, and his book tackles the relationship between word and meaning. In his earlier days, he pointed out that many of linguistic problems was caused by logical fallacies of propositions, and claimed that use of simple statements could avoid misunderstanding of semantics of words (Wittgenstein, 2001). The meaning of a word was predetermined, he argued, and he tried to find out the ostensive definition. Thereafter, he was aware that it was hardly impossible to figure out the innate meaning of a word and that the meaning was decided in the context while it was in use. He insisted on the absence of the ostensive definition and stressed the context used in a word. The meaning in language is not fixed but determined by the context. In this light, there is nothing common in use of a word in terms of semantics, and this indicates that the rules of a language are prescribed while using and that the rules may not be appropriate in the different context. Hence, the meaning should not be generalized but grouped by various application. This is called as family resemblance. While the consensus view tries to find out the commonalities among various fields of science, FRA rather encompasses the contextualized meaning of the NOS and focuses more on social activities and communicative ways in constructing science knowledge.

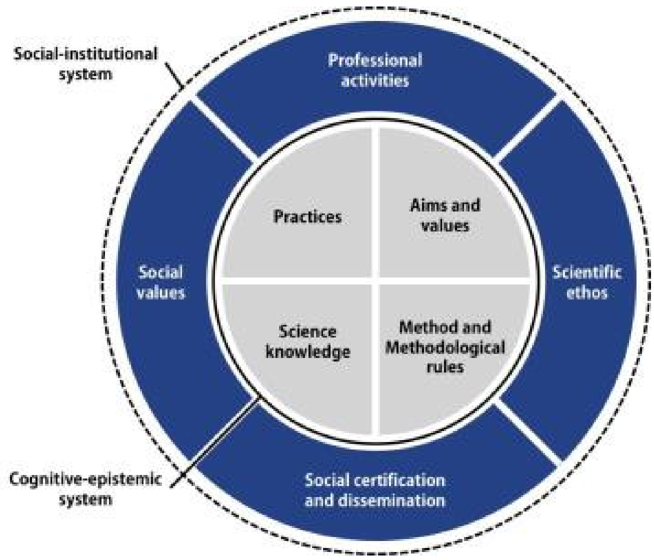

Figure 3. A systematic framework of family resemblance approach to the NOS

The family resemblance approach to the NOS conceptualizes science in respect to a cognitive-epistemic and a social-institutional system (Erduran and Dagher, 2014), as shown in Figure 3. Science knowledge is established through the cognitive process as an individual level. For example, scientific theories are developed by a cognitive way of a human mind and by empiricism of sensory organs, including in-direct observation. But also, they are constructed and certified by social norms and processes, peer reviews and science ethics. Each of system reflects the two dimensions. Science as a cognitive-epistemic system entails aims and values, methods and methodological rules, scientific knowledge, and (scientific) practices while science as a social-institutional system contains professional activities, scientific ethos, social certification and dissemination, and social values. Regarding a cognitive-epistemic system, aims and values refer to a set of aims in the sense that products of scientific activities are expected to achieve them. For example, viability, testability, and replicability can be regarded as aims while simplicity and consistency can be conjoined as values. Practices refer to types of activities used in the process of inquiries: posing questions, making observations, collecting data, and formulating hypotheses. Methods and methodological rules refer to the variety of systematic approaches and the rules that scientists use to make sure that they produce reliable knowledge such as inductive and deductive reasoning. Scientific knowledge refers to the final products of scientific activities that culminate in laws, theories, models, and experimental data. Within the conception of science as a social-institutional system, professional activities refer to activities that scientists perform to communicate their research. Scientific ethos refers to the set of norms that scientists follow in their own work and their interactions with one each other: universalism, disinterestedness, and ethical norms. The social certification and dissemination of scientific knowledge refers to the peer review process, as a way of social quality control. The social values of science refer to the values shared in the communities as listed: freedom, contribution to the economic development, and utilitarianism.

Ⅲ. Research methods

In order to figure out the differences of various perspectives on the NOS, this study determines to analyze science textbooks in secondary schools. Usually, curriculum is divided into four categories: intended, enacted, learned and assessed curriculum (Porter, 2006). The national curriculum document reflects the intended curriculum and textbooks refers to the enacted curriculum that is taught to students in the classroom, and the learned and assessed curriculum is based on what textbooks say. That is to say, science textbooks play a rudder role in teachers’ planning the instruction and students’ learning science. Even in Korea, the ministry of education publishes the curriculum guideline for teaching and learning to align with the national curriculum. Textbook analysis is helpful to understand how science is taught in the classroom.

This study takes into account several standards to select the textbooks to be analyzed. First, the objectives of the textbook should be connected to the NOS explicitly. Second, the textbook should deal with contents for all students, not a specific group. This study tries to give some implications for teaching and learning the NOS in the classroom. International documents of comparative assessment also intend to evaluate the learning outcomes of ordinary students who completed the compulsory education. Third, the textbook should deal with various fields of science in order to examine whether the NOS is domain-general or domain-specific.

To satisfy the standards above, this study selects a science subject talking about scientific inquiry, entitled as Science Laboratory Experiments. First of all, the subject explicitly intends and enacts to learn the NOS. In Korea, 2015 revised national curriculum, the latest version of science curriculum, aims at improving the capabilities of key competences for the future society: scientific inquiry, scientific communication, scientific reasoning, scientific problem solving, scientific participation, and lifelong learning (Ministry of Education, 2015). To accomplish such a goal, the new curricular subjects in science are developed for all tenth graders as follows: Integrated Science and Science Laboratory Experiments. The goal of Science Laboratory Experiments is to provide students with experiences of inquiry-based experiments in order to enhance their abilities of scientific inquiry. The subject consists of three chapters: scientific inquiry in the history of science, scientific inquiry in the everyday life, and scientific inquiry of state-of-the-art. The first chapter deals with two core ideas, the nature of science and inquiry method of scientists. Regarding the NOS, it is expected that students understand the various elements of the NOS through the history of science and scientific inquiries. Second, this textbook is supposed to be taught to all tenth graders. According to the national curriculum in Korea, this subject ought to be taught for all high school students (15～16 years old) before they decide higher-level subjects. International comparative assessments such PISA and TIMSS intends to evaluate science achievement of secondary students (Mullis and Martin, 2013; Organisation for Economic Co-operation and Development, 2016). The subject of Science Laboratory Experiments is designed for 15-year-old students to learn the nature of science and scientific inquiry. Last, it is comprised of various fields of science. According to the national curriculum (Ministry of Education, 2015), the first chapter of Science Laboratory Experiments contains four inquiries: comparing free fall and horizontally projectile motion, completing Mendeleev’s periodic table, investigating the process of Pasteur’s biogenesis, and examining the cause and effect of mass extinction in the geological era. Each topic belongs to physics, chemistry, biology, and earth science respectively. As well, the curriculum guideline articulates four learning outcomes: reproducing and explaining the crucial experiment which came about the paradigm

Table 2. The content of textbook of Science Laboratory Experiments according to 2015 revised national curriculum

Chapter	Core idea	Goal	Inquiry Content
Scientific inquiry in history of science	Nature of science	To understand the nature of science through the historical cases of scientists to experience the nature of science while doing scientific inquiries	· Free fall and projectile motion (physics) · Periodic table (chemistry) · Biogenesis (biology) · Mass extinction (earth science)
	Inquiry method of scientists	To apply various inquiry methods according to the given contexts	

shift in the history of science, experiencing accidental discoveries and explaining the NOS related to the activities, doing scientific inquiries and inductive reasoning, and performing the hypo-thetico deductive experiments. Therefore, the subject of Science Laboratory Experiments is fruitful to discuss the philosophical aspects of the NOS as mentioned before.

Each of inquiry topic is comprised of two activities. First, comparing free fall and horizontally projectile motion begins with thought experiment to fall bodies tied up each other. This had been already done by Galileo to refute Aristotelian natural motion. Then, another experiment includes observation of the motion of ball and measurement of the displacement per unit time when falling a ball at rest and throwing a ball horizontally. Second, Mendeleev's periodic table asks students to arrange 17 cards written on chemical elements and their characteristics, and to find out any patterns. Then, students investigate the achievement of scientists who contributed to develop the periodic table before Mendeleev. Third, the review of biogenesis by Pasteur replicates Redi's experiment putting two pieces of banana into an open jar and a wrapped jar respectively and observing the caterpillars. Then, it introduces Pasteur's experiment and guesses the hypothesis he wanted to prove. Last, the mass extinction deals with investigation to predict the cause of mass extinction by observing some photos of strata made from different ages (Paleozoic, Mesozoic, and Cainozoic) and some pieces of rocks to prove that meteors were fallen down at that time. Then, students predict what changes were brought to bio-system by drawing a picture.

This study follows content analysis with two domains (Jenner and Titscher, 2000). The researcher divides science contents into the four inquiry topics according to the national curriculum: free fall and horizontally projectile motion, periodic table, biogenesis, and mass extinction. Each of content are analyzed from three perspectives on the NOS: the consensus view, the FOS, and the FRA. The consensus view is composed of seven elements of the nature of science (empirical basis, scientific theories and laws, imagination and creativity, theory dependence, cultural embeddedness, scientific method, and tentativeness); the FOS is extended to experimentation, idealization, and models; and FRA is mainly divided into cognitive-epistemic system (aims and values, scientific practices, methods and methodological rules, and scientific knowledge) and social-institutional systems (professional activities, scientific ethos, social certification and dissemination, and social values). The elements of the NOS can be re-categorized into empirical, theoretical, socially embedded, and methodological. In this study, the researcher analyzed only one kind of textbook even though there are almost ten kinds of textbook for Science Laboratory Experiments. This is because the aim of this study is not at showing up the elements of the NOS in the textbooks, but at comparing different perspectives on the NOS through the textbook, as an example.

For the inter-rator reliability, two science educators were asked to analyze a chapter of one of the textbooks, and discussed together about the incongruent coding. Figure 4 shows an example of coding according to the various perspectives on the NOS. This figure illustrates the objectives of this section and historical changes in regard to the natural motion (later called as inertial motion). This section introduces thought experiment by Galileo as the crucial experiment for the paradigm shift as aims and values in the FRA and pleads students to respect peers' opinions and keep science ethics as scientific ethos. In the body, the argument generated by thought experiment is regarded as scientific knowledge in the FRA. In terms of the FOS, Aristotelian physics according to the four elements and their natural motion is viewed as a model (Maudlin, 2010, 2012). Last, the change of concepts about the cause of free fall motion shows the tentative nature of science in the consensus view.

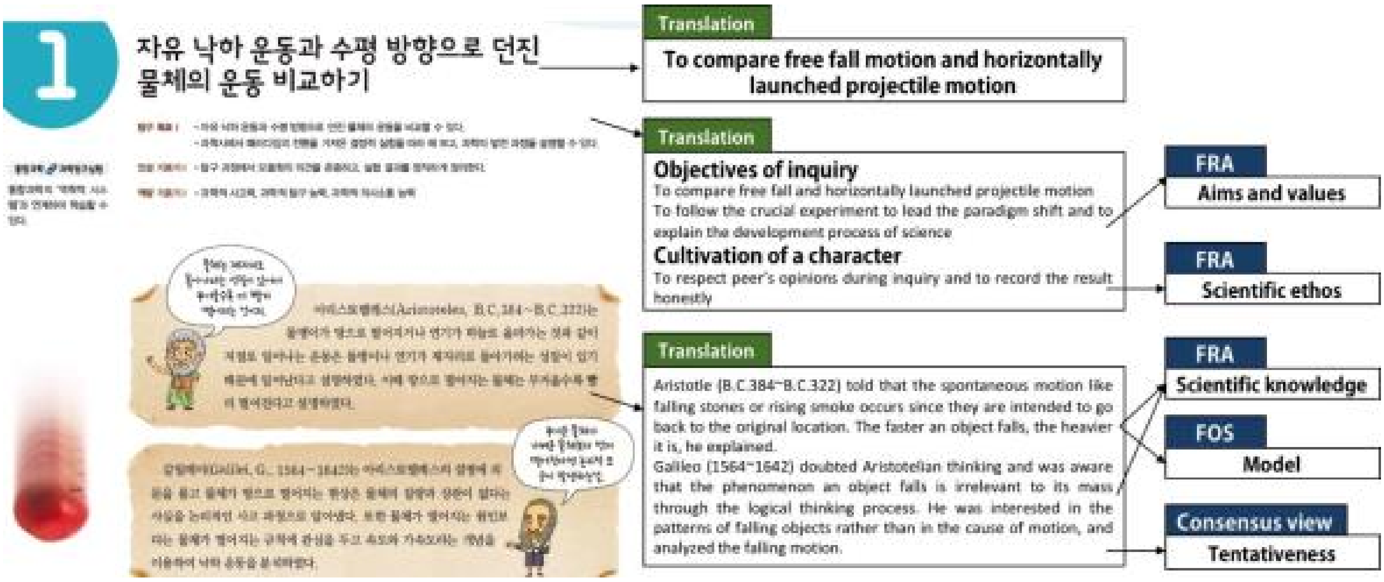

Figure 4. A coding example of textbook analysis on the NOS (Shim *et al*., 2017)

Ⅳ. Results

1. The elements of the NOS according to three different perspectives

This study analyzes what elements of the NOS are presented in the textbook from the three perspectives. The result shows that the NOS is inclined to the empirical and epistemic aspects. Empirical basis in the consensus view may correspond to experimentation in the FOS, and scientific practices and methods and methodological rules in the FRA. Figure 5 shows that each perspective has different interpretation about experimentation. While the consensus view does not illustrate the nature of experimentation elaborately, the FOS shows that only two topics in the textbook contain experimentation while the others are not related to direct observation and measurement. On the one hand, idealization and models are seldom stated in the textbook, and the single case is just presented in the introduction of free fall motion. This indicates that the experiments in the textbook neither take into account the idealization to confirm the theories nor draw conclusions using models. For example, when a ball at rest is falling down, its velocity is not linearly increasing due to the drag force and rotation of ball. In case of the horizontally projectile motion, there are two directions of velocity (horizontal and vertical) and drag force may influence the relationship between time and displacement because drag force depends on velocity. To confirm the same vertical motion in the gravitational field, there should be an idealization of ignoring drag force and friction. However, the textbook encourages students to observe two different motions by video camera and to compare the two in respect to the vertical position. Although it is expected to come about the same results regardless of the trajectories of balls, the observed result shall be definitely different. On the one hand, in case of free fall motion, the FRA shows that the textbook introduces the inquiry procedure (collecting and interpreting data) and methods (video analysis of falling bodies and measurement of displacement during the time interval). The textbook encourages students to explain two different motions with gravity and evaluate peer’s ideas. This is connected to the professional activities as scientists communicate with each others. The FRA takes into account the social aspects of science activities rather than the consensus view and the FOS.

Scientific theories and laws, imagination and creativity, and theory dependence in the consensus view may be connected to idealization and models in the FOS, and scientific knowledge in the FRA. The consensus view addresses the distinction between theories and laws and intertwined relationship between theoretical and empirical nature of science. Most cases includes the empirical nature of science while other elements of the NOS are seldom referred. Theory dependence is only found in the mass extinction. The textbook introduces cross-sectional areas of strata in Gubbio of Italy and asks for inferring the cause of mass extinction of dinosaurs (see Figure 6). On the next page, a graph shows that the proportion of iridium in K-T boundary is much higher than other two strata in the Mesozoic and the Cenozoic era. Iridium is usually contained in the meteors rather than the crust of the Earth. Other photos show some impact marks on the surface of quartz in Yucatan peninsula, Mexico. A series of observations and data try to show that the meteoric collision really happened in the past. Another photos show that the size and number of foraminifer were decreased by comparing the strata of the Mesozoic and the Cenozoic era. It is likely that the textbook intends students to understand the mass extinction through a inductive inquiry (empirical basis of the NOS).

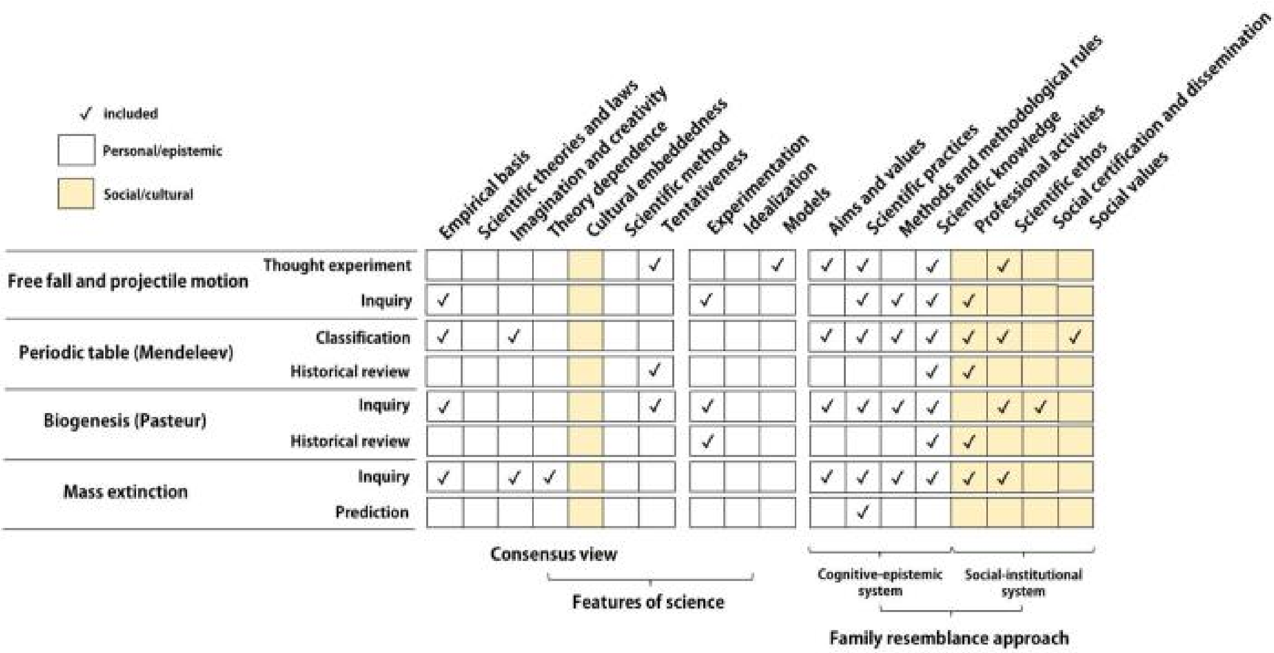

Figure 5. The NOS analysis according to the various perspectives: consensus view, FOS and FRA

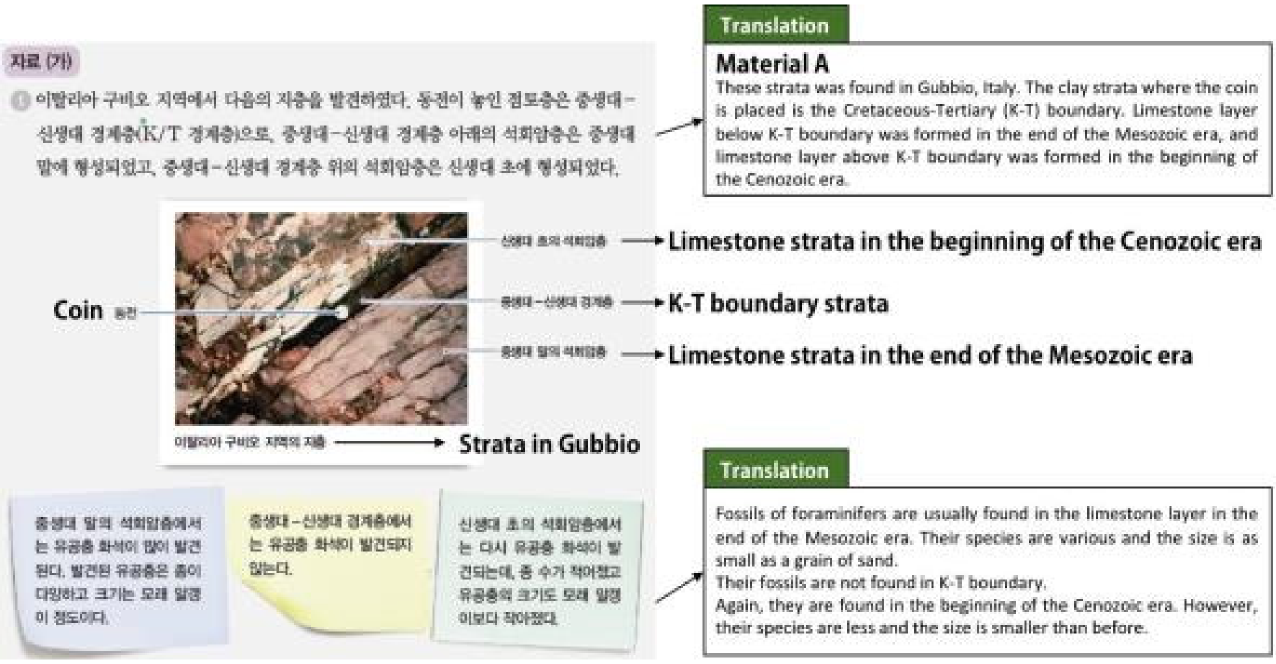

Figure 6. Observation of strata in the geological era for the investigation of mass extinction

However, such an interpretation relies on the Alvarez hypothesis. In fact, it is very difficult for students to reach the conclusion due to many hidden assumptions. First, students should know about Iridium. Iridium (Ir) is transition metal of platinum group and one of the least abundant elements in the Earth's crust. It is most corrosion-resistant and oxidation-resistant. This indicates that the ratio of Ir in the crust will seldom change. Following the results, textbook may conclude that the meteoritic collision emerged to the Earth but Ir may come form the volcanic origin because the core of the Earth is rich in Ir. Second, students ought to recognize the environmental conditions for foraminifer. It usually lived in the ocean and were placed on the bottom of food web. Hence, the decrease of foraminifer might cause to the decrease of predators. Third, they need to understand the law of superposition of strata and the law of faunal succession which play a significant role in guessing the age of three strata. Such knowledge is a combination of facts, laws and theories, which are linked to the scientific theories and laws of the NOS. On the other hand, some assumptions in geology are connected to models used. The theories of uniformitarianism and faunal succession are based on the law of superposition of strata. This is usually exemplified in the textbook by piling different colors of clay. The stable and continuous change in crustal movement is one of the ideal assumptions in geology. The idiosyncratic characteristics of the FOS is not presented in the textbook neither. However, such an activity to make an hypothesis based on the small amount of data is stereotypical to show up the nature of geology. It is impossible to see what is actually inside the core of Earth and what really happened to the Earth millions years ago. That is why many fields of science do experiments using models and compare the real data and experimental results. This show the nature of science knowledge in a specific field, endorsed in scientific knowledge in the FRA.

The socio-cultural embeddedness of the NOS is relevant on the social-institutional system in the FRA. According to the consensus view, the textbook does not have any statement about socio-cultural influence on science at all. However, the FRA shows social activities of science communities. In Figure 5, the colored cells indicate socio-cultural elements while the white cells indicate the personal and epistemic elements. The figure shows that more ticks are found in the white cells. In the introduction of each topic, respect and science ethics are stressed as the objectives of inquiry and the textbook intends to discuss the experiment results to each other:

Students should respect other's opinion during inquiry and keep track of results honestly.

Students should share the roles with other group members to respect others and value other's opinion.

Although the subject of Science Laboratory Experiments is based on the history of science, it is rare to show how scientists make judgment on different ideas. Such an aspect is relevant on social-institutional system in the FRA, which is not recognizable in the consensus view and the FOS. Only in case of biogenesis, the textbook introduces different ideas about biogenesis, e.g., Redi, Needham, Spallanzani, and Pasteur, and a series of experiments to confirm and falsify their thinking. In this case, the FOS and the consensus view count this part as experimentation and empirical basis respectively while the socio-cultural influence is ruled out. Scientists try to confirm their ideas by publish a paper in the peer-reviewed journal, presenting their ideas in the conference and collaborating others, so-called social certification and dissemination in the FRA.

The dominating idea in the epistemology of science knowledge is tentativeness of the NOS. It is not absolute but durable and stable.

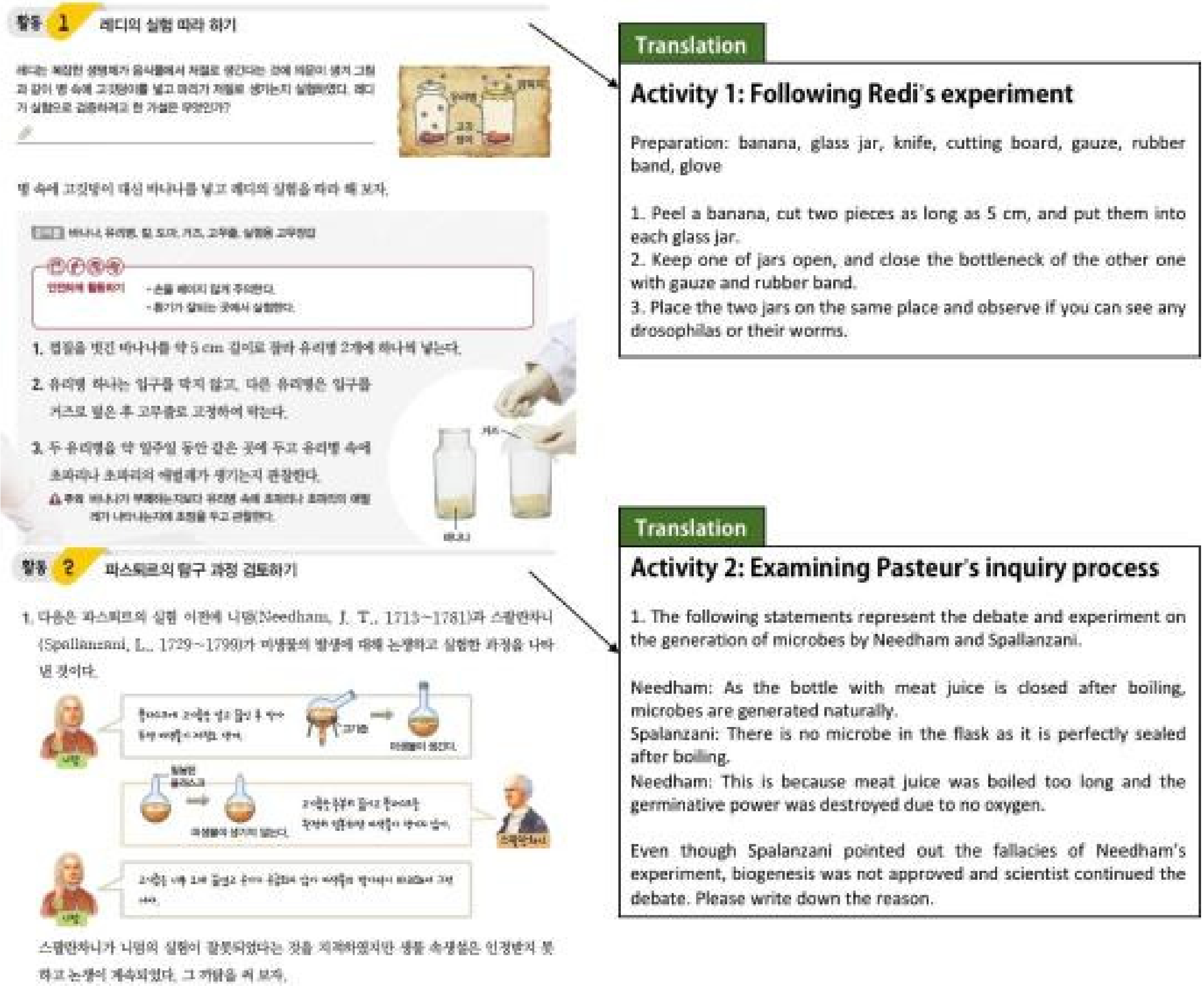

Figure 7. Activities on the biogenesis in the textbook (Shim *et al.*, 2017)

The textbook shows that the ideas about science have been changed overtime by introducing different ideas of scientists in the different times. While explaining the periodic table, it reviews the arrangement of chemical elements from Lavoisier to Moseley. The textbook explicitly upholds Kuhnian theory in science by a statement of the objective, "following a crucial experiment contributing to the paradigmatic shift and explaining scientific progression." According to Kuhn (2012), science knowledge is a complex output produced by values, methods and results shared in the science community and is subjective and does neither approach to the truth nor have any progression at all. The textbook does not illustrate how scientists suggested such ideas and modified the periodic table. To understand the tentativeness of the NOS, it is necessary to understand the historical context of scientific discoveries. Mendeleev and Meyer independently composed their periodic tables in the latter half of nineteenth century (Bensaude-Vincent and Stengers, 1996). At that time, atomic numbers were not significantly appraised because proton and neutron were found later in the twentieth century. Mendeleev made his table with groups of similar elements in columns. After the development of quantum mechanics, rows in the table are related to the filling of a quantum shell of electrons (Aldersey-Williams, 2011). Discoveries of new elements and the particles such as protons, electrons and neutrons in the twentieth century confirmed the adequacy of periodic table and Seaborg, Moseley, and other scientists contributed to complete the contemporary periodic table (Aldersey-Williams, 2011; Newman and Ypsilantis, 1996). This indicates that understanding the tentative nature of science is essentially combined to the detailed experimentation (in the FOS) and contributions to the scientific achievement by many scientists (social certification and dissemination in the FRA).

In terms of methodology, the consensus view highlights that there is no concrete way to propound "certain" knowledge in science (Lederman, 1992; Lederman *et al.*, 2002). It does not make any judgment about the adequacy of scientific methods, in spite of many scientific methods. The textbook contains a variety of methodological ways: thought experiment, collecting and representing data, making hypothesis, and inferring conclusion. As for such activities, the consensus view simply divide them into theoretical and empirical ways, while the FOS subdivides empirical nature of science into experimentation, idealization, and models. Instead, the FRA regards them as scientific practices and methods. Rather, the FRA highlights social process to guarantee the scientific knowledge. The FOS prioritizes the empirical process in doing science while the FRA concentrates more on how the obtained argument is proved as true in the community. However, the FRA is disputable to define what science is. The FRA also values minorities of science, such as feminist science, indigenous science, and religious science. Science knowledge is personally recognized and socially shared, there is no exception to rule them out as far as they follow the appropriate rules. As for this, the consensus view proposes clear standards to be viewed as science. At least, the FOS makes judgment the given theories in terms of experimentation.

To summarize, the consensus view may not assume the domain-specificity of the NOS. As shown in Figure 5, empirical, creative/imaginative and tentative NOS are found across the topics. Even, it has a limitation to show up the context of scientific achievement. The FOS is useful to understand how a scientist reached his/her own conclusion, but insufficient to understand how one's argument is approved as scientifically appropriate in the community of science. The FRA helps to understand the sociology of science as an alternative way of the FOS. Even, the FRA shows philosophical aspects of science such as aims and values, and scientific ethos. However, the FRA is problematic to define the nature to be regarded as science. After all, there are some points to be improved so that the NOS can appreciate scientific inquiry and essence of science as a world view of scientific mind.

2. Philosophical positions of the NOS

In this section, I am going to discuss the issue raised in the introduction and the results of textbook analysis. Different epistemology may stem from different world view. In the previous results, the FOS is likely to show the empirical nature of science more elaborately. Although the consensus view lists the relationship between theory and law, and between observation and inference, it does not articulate clear explanation about what can be counted as science. Science is based on observation of the natural world, and scientific theories are derived from observation and measurement. On the contrary, experiment and observation are affected by background theories. Actually, theories affect designing experiments and determine parameters to be measured. The entanglement of the two is connected with the tension between rationalism and empiricism, following Plato's and Aristotle's thoughts (Cushing, 1998). Such a feature stands for the complexity of epistemological belief in science. It is inevitable to see the gap between theoretical prediction and experimental results in the real world. The essence of kinematics, $F=ma$, does not explain motion of a ball rolling on the table well. Science takes use of idealization to find out any patterns from the entangled nature, and collects and interprets data from the laboratories, not from the natural world directly. That is to say, science explains and predicts data reduced from nature (Giere, 1997). In this light, it is doubtful if science is to discover something behind the curtain, or to create something from nothing. Such a dispute is related to the ontological issues of science concepts, realism vs. instrumentalism (Hodson, 2008).

In terms of epistemology of science, the consensus view hold a complicated position. Regarding the theory ladenness, it is likely that the consensus view supports Kuhn's idea (Lederman, 1998). Many examples to explain the theory ladenness, different conclusions based on the same phenomena, is a typical case to explain the competition of different theories before the stage of normal science. The argument that observation is filtered through perceptual senses and prior knowledge is accorded with the incommensurability. Even, this idea invokes Piaget's idea of conceptual change (Duschl and Grandy, 2013; Duschl & Hamilton, 2011). What is accepted as true in Kuhn's theory is determined by approval of members in the community. However, the consensus view does not address the social certification of science knowledge. In this light, the consensus view may follow Popper's idea (Popper, 1963) because it stresses the accordance between theory and experiment and the significance of empirical basis. However, the consensus view does not point out how to deal with the anomalous data which does not fit for the theoretical prediction. According to Popper, a law should satisfy every instance of the phenomenon but may be falsified if new evidence is found. Once an discrepant result is found, a principle or a theory should be falsified. However, as mentioned in the textbook as well, many studies on the NOS postulates better understanding or better performance in science and the NOS (Cho *et al*., 2018; Cofré *et al*., 2019; Jho, 2018). Even the textbook states the development in science which does not coincide with paradigmatic shift.

On the one hand, the consensus view argues that observation is filtered through perceptual apparatus or prior belief/knowledge and supports the distinction between observation and inference (Lederman, 1992; Lederman *et al*., 1998, 2002). This indicates that the consensus view takes critical realism that the world exists out of our perception and cognition. From critical realist viewpoint, experiment is not solely record of perceived, but an interactive process with events surrounding us (Collier, 1994). However, it is problematic about the acceptance of socio-cultural embeddedness in the consensus view (Lederman *et al*., 2002). Science knowledge as a compound of social fabric, power structures, politics, socioeconomic factors, philosophy, and religion is linked to the interpretivism or constructivism which argues that world is understood not found (Kukla, 2000). Social constructivism highlights the significance of context and construction of knowledge embedded in the society and culture. In this light, science knowledge is not discovered but made through human perception and social experience. However, this is problematic because the ontological commitment of realism that the world exists out of perception does not coincide with that of social constructivism that the world does not necessarily exist but is just constructed. Scientists tend to think that the entities of science exists and science approaches the truth, whose idea is not accorded with constructivist position (Aydeniz and Bilican, 2014; Bayir *et al*., 2014; Hodson and Wong, 2014; Schwartz and Lederman, 2008). In terms of epistemological view of science, the consensus view may not depicts the whole aspect of theoretical science. On occasion, scientists made a bold decision without empirical evidence. For example, Newton thought that the intensity of gravitational force is inversely proportional to the square of distance based on the analogy of light, and Cavendish confirmed his ideas one hundred years later (Cushing, 1998; Jho, 2014). Planck advocated quantum hypothesis to explain the radiation of black body with extrapolation of mathematical formula, and just clung to a solution fit for the experimental data in spite of any theoretical reasons (Jammer, 1989).

Contrary to the consensus view, the FOS clearly advocates the empiricist tradition (Khine, 2012). The FOS starts with experimentation to build up science theories and laws. While experimentation, it simplifies some conditions and posits imagery system through idealization, and especially, models are crucial in the whole process of scientists' activities (Matthews, 2012). The FOS argues that a theory is made from experimentation and is empowered by prediction and explanation about other experimentation. As well, the FOS illustrates theorization without empirical evidence, e.g., inertial motion of Newton and swings of Galileo (Shapin, 1996). The FOS regards science as a human and thus historically-embedded truth- seeking enterprise with many features: cognitive, social, commercial, cultural, political, structural, and ethical (Matthews, 1994, 1998, 2012). In this light, feminist or religious view can affect scientific knowledge. In fact, FOS holds various philosophical positions of science. The emphasis on experimentation and essential notions of science such as law, theory, model, cause and others is connected to the scientific realism that objects in science exists irrespective of our perception or thoughts, and that science aims at producing the truth (Ladyman, 2002; Sankey, 2008). On the other hand, the entanglement of science with culture, society and religion is related to constructivism. Although FOS is multi-faceted in the philosophy of science, it does not explain how science changed over time. For example, the competition between heliocentric and geocentric theories is construed as socially embedded, but FOS does not give any explanation about the transition of Copernican astronomy, such as the paradigm shift by Kuhn, falsification by Popper, and anarchist approach by Feyerabend (Feyerabend, 2010; Kuhn, 2012; Popper, 2002). Moreover, FOS cannot set the demarcation between science and pseudo- or non-science.

The FRA mostly fits the modern ideas about sociology of science. According to the FRA, the NOS is divided into cognitive-epistemic and social-institutional systems (Erduran and Dagher, 2014). The elements in a cognitive-epistemic system reflect psychological and epistemological notion of science. Even, social-institutional system encompasses social negotiation of science knowledge. The FRA can include broader views on the NOS. In appearance, the FRA upholds similar viewpoint to Kuhn's (Erduran *et al*., 2019). However, such a view does not tell anything about what science is and how science works. Social science as well as pseudo-science can be displayed from the framework of the FRA. The term, family resemblance, is borrowed from the argument of Wittgenstein. The meaning of word is not pre-determined, but in use (Wittgenstein, 1978). Due to the absence of ostensive definition, meaning of science is also decided by use in the context. The contextualized use is linked to the socio-cultural embeddedness in the FOS or the consensus view. If any disciplines are named as science, for instance, social science and human science, they can be also counted as science. This is because they share many elements of the NOS and they are also called as science. It is quite difficult to distinguish "the real science" from other disciplines which are desired to coin the term, scientific. It seems inappropriate to make judgment if a discipline is under the umbrella of science in spite of satisfaction of many elements of the NOS. The issue of domain-specificity of the NOS is also involved in definition of science.

V. Discussion and implications

This study intends to delineate the characteristics of various perspectives on the NOS through the textbook analysis: the consensus view, the FOS, and the FRA. Each of perspective sheds light on diverse aspects of the NOS. While the consensus view highlights the similar elements of the NOS across the topics, the FOS is concerned about empirical ways for doing science. The FRA rather focuses on socio-cultural aspects of science activities. While the consensus view is useful to reify the features of the NOS, the FRA helps to understand science from various viewpoints. Regarding the philosophical account for three perspectives, all of them are ambiguous to some extent. The consensus view holds contradictory dispositions e.g., relativism vs. (post-)positivism, and critical realism and instrumentalism. The FOS supports empirical tradition but cannot effectively cope with the anomalous situation. The FRA is useful to show up the ways of science in both microscopic (personal) and macroscopic (social) viewpoints. However, the broader concept about science may mislead understanding of the NOS.

The results of this study give us some implications for the NOS research. What perspective to follow in the educational setting is closely connected to the philosophical positions. If a teacher think highly of the role of experiment in science, the FOS is more proper to his/her view. The elaborate categories in the FRA will be useful for him/her to design and implement science inquiries as a means of teaching the NOS. On the one hand, if he/she wants to tell students about simple guidelines, he/she would like to choose the consensus view. The FRA would be pleased with one who expects to show the complex nature of science activities. Each of perspective points to the different faces of science and science educators ought to consider what extent to be taught and who is learned. It is much difficult for primary students to understand the philosophical aspects of the NOS, such as aims and values, and scientific ethos.

Teaching the NOS in the classroom may rely on the subjects to be taught. As mentioned before, the stress points in the NOS are different from topics to be tackled. In the biogenesis, the textbook shows how scientists develop their ideas by experimentation whereas the mass extinction intends to make inferences based on the premises. The content and context of the NOS to be taught ought to be considered.

When teaching the NOS, the demarcation of science should be more cautious. Nowadays, as science and technology are intertwined and the public pays more attention to socio-scientific issues, it is disputable whether science can be disentangled from others (Bauer *et al*., 2007; Hodson, 2008; Ratcliffe and Grace, 2003). For example, Bush medicine, lay-expert controversy, and eccentric science are connected with the demarcation of science and they are inevitable outcomes derived from the popularization of science (Bauer *et al*., 2007; Irwin and Wynne, 1996; Sismondo, 2010). Even though the FRA intends to show various aspects of the NOS and to bind them in one science, meaning in use is not effective to distinguish science from others. Many kinds of disciplines are used to call 'scientific' and even many points are shared with science: making hypothesis, collecting data, inferring patterns, and generalizing conclusion. The demarcation of science has been changed over time. In the past, technology and engineering was regarded as applied disciplines from science, but nowadays, the role and activities of science and technology is indistinctive. In this way, some kinds of studies may be counted as a family of science in the future. Then, how can we clarify the meaning of science and express the notion of the nature of science? Another problem is explanation about the history of science. Kuhn, Popper, Lakatos and others provide various explanation about competing theories and the change of scientific mind, whereas the nature of science does not delineate the change. Actually, naïve understanding of the nature of science is related to the tentativeness in science in the previous studies (Abd-El-Khalick and Lederman, 2000; Bell and Lederman, 2003; Bianchini *et al*., 2002). Many of textbooks including the one in this study provide contemporary understanding of science without history and philosophy of science, and it may cause difficulties in understanding of science (Matthews, 1994). To understand the path of science in the past will be helpful to predict the direction of science in the future.

The results of this study implicate that different perspective on the nature of science may bring about different understanding of the NOS. As shown in Figure 5, understanding the NOS is affected by the adopted framework. As well, the framework may be useful to represent students' difficulties in understanding the NOS as it is useful to show up the problems in the textbook. Even though the FOS and the FRA have shown more sophisticated and diverse positions in terms of philosophy of science, students or teachers may not be able to understand them. Therefore, it is significant to establish expected learning outcome corresponding to the ability of learners.

For the further studies, the notion of the NOS needs to be re-conceptualized so that it can encompass more diverse views on science and provide a guideline for appropriate understanding of science. There should be an investigation about the NOS according to the different fields of science so that we can distinguish the domain-general and domain-specific NOS. Besides, we need to take into account various philosophical positions to overcome three perspectives on the NOS. According to Foucault, discourse refers to "ways of constituting knowledge, together with the social practices, forms of subjectivity and power relations which inhere in such knowledges and relations between them" (Artières, 2011; Weedon, 1996). Discourse is formed through interdict from the external, partition and rejection, and opposition between truth and untruth (Foucault, 1972, 1977; Huh, 2012). Discourse, as the aggregation of statements sharing similar values, contexts, and meanings, is contextualized under the specific epistemological conditions or fields, which is called Episteme (Huh, 2012). From his viewpoint, the paradigm shift implies the change of Episteme, and the demarcation of science can be understood as the formation of discourse by interdiction. In the reality, scientists communicate with each other, gathers a meeting or a conference, and establish an academic society. They try to delineate the rights and responsibility with membership and take use of many kinds of interdicts and rigorous rules as similar to Foucauldian discourse. Besides Foucault, there are many philosopher's ideas about science such as Laudan, Latour and Lakatos. Various perspectives on science helps us to understand what role of the NOS play in understanding science in science education.

References

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. Science Education, 82, 417-436.

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of the nature of science: A critical review of the literature. International Journal of Science Education, 22(7), 665-701.

Abi-El-Mona, I., & Abd-El-Khalick, F. (2011). Perceptions of the Nature and 'Goodness' of Argument among College Students, Science Teachers, and Scientists. International Journal of Science Education, 33(4), 573-605.

Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: 'Views on science-technology-society' (VOSTS). Science Education, 76(5), 477-491.

Aldersey-Williams, H. (2011). Periodic tales: A cultural history of the elements, from Arsenic to Zinc. New York: Harper Collins.

American Association for the Advancement of Science (1993). Benchmarks for science literacy: A project 2061 report. New York: Oxford University Press.

Artières, P. (2011). Michel Foucault. Paris: Herne.

Arya, A. P. (1998). Introduction to classical mechanics. Upper Saddle River, NJ: Prentice Hall.

Aydeniz, M., & Bilican, K. (2014). What do scientists know about the nature of science? A case study of novice scientists' views of NOS. International Journal of Science and Mathematics Education, 12(5), 1083-1115.

Bacon, F. (1994). Novum organum: With other parts of the great instauration. Chicago: Open Court.

Bady, R. J. (1979). Students' understanding of the logic of hypothesis testing. Journal of Research in Science Teaching, 16(1), 61-65.
Bauer, M. W., Allum, N., & Miller, S. (2007). What can we learn from 25 years of pus survey research? Liberating and expanding the agenda. Public Understanding of Science, 16(1), 79-95.
Bayir, E., Cakici, Y., & Ertas, O. (2014). Exploring natural and social scientists' views of nature of science. International Journal of Science Education, 36(8), 1268-1312.
Bell, R. L., & Lederman, N. G. (2003). Understandings of the nature of science and decision making on science and technology based issues. Science Education, 87, 352-377.
Bensaude-Vincent, B., & Stengers, I. (1996). A history of chemistry. Cambridge, MA: Harvard University Press.
Bianchini, J. A., Whitney, D. J., Breton, T. D., & Hilton-Brown, B. A. (2002). Toward inclusive science education: University scientists views of students, instructional practices, and the nature of science. Science Education, 86(1), 42-78.
Cho, E, Kim, C., & Choe, S. (2018). A study on the plurality of nature of science in science education. Journal of the Korean Association for Science Education, 38(5), 721-738.
Clement, J. J. (2008). Creative model construction in scientists and students: The role of imagery, analogy, and mental simulation. Dordrecht: Springer.
Clement, J. J., & Rea-Ramirez, M. A. (2008). Model based learning and instruction in science (Models and modeling in science education). New York: Springer.
Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. Science Education, 15, 463-494.
Cofré, H., Núñez, P., Santibáñez, D., Pavez, J. M., Valencia, M., & Vergara, C. (2019). A critical review of students' and teachers' understandings of nature of science. Science & Education, 28(3-5), 205-248.
Collette, A. T., & Chiappetta, E. L. (1989). Science instruction in the middle and secondary schools. Columbus, OH: Merrill Pub. Co.
Collier, A. (1994). Critical realism : An introduction to Roy Bhaskar's philosophy. London: Verso.
Constantinou, C., Hadjilouca, R., & Papadouris, N. (2010). Students' epistemological awareness concerning the distinction between science and technology. International Journal of Science Education, 32(2), 143-172.
Cooley, W. W., & Klopfer, L. E. (1961). Test on understanding science. Princeton, NJ: Educating Test Service.
Cooper, M., & Hunter, M. (2006). Robert Hooke: tercentennial studies. Burlington, VT: Ashgate.
Cushing, J. T. (1998). Philosophical concepts in physics: The historical relation between philosophy and scientific theories. New York: Cambridge University Press.
Deng, F., Chen, D.-T., Tsai, C.-C., & Chai, C.-S. (2011). Students' views of the nature of science: a critical review of research. Science Education, 95, 961-999.
DiGironimo, N. (2011). What is technology? Investigating student conceptions about the nature of technology. International Journal of Science Education, 33(10), 1337-1352.
Duschl, R. A., & Grandy, R. (2013). Two views about explicitly teaching nature of science. Science & Education, 22(9), 2019-2139.
Duschl, R., & Hamilton, R. (2011). Learning science. In R. Mayer & P. Alexander (Eds.), Handbook of research on learning and instruction (pp. 78-107). New York: Taylor & Francis Group.
Erduran, S., & Dagher, Z. R. (2014). Reconceptualizing the nature of science for science education: scientific knowledge, practice and other family categories. Dordrecht: Springer.
Erduran, S., Dagher, Z. R., & McDonald, C. V. (2019). Contributions of the family resemblance approach to nature of science in science education. Science & Education, 28(3-5), 311-328.
Feyerabend, P. K. (2010). Against method. London: Verso.
Foucault, M. (1972). Archaeology of knowledge (A. M. S. Smith, Trans.). New York: Harper & Row.
Foucault, M. (1977). Language, counter-memory, practice: selected essays and interviews (D. F. Bouchard, & S. Simon, Trans.). Ithaca: Cornell University Press.
Giere, R. N. (1997). Understanding scientific reasoning. Fort Worth, TX: Harcourt, Brace, Jovanovich.
Hodson, D. (2008). Towards scientific literacy : A teachers' guide to the history, philosophy and sociology of science. Rotterdam: Sense Publishers.
Hodson, D., & Wong, S. L. (2014). From the Horse's Mouth: Why scientists' views are crucial to nature of science understanding. International Journal of Science Education, 36(16), 2639-2665.
Huh, K. (2012). On Michel Foucault's concept of discours. Concept and communication, 9, 5-32.
Hunter, M., & Schaffer, S. (1989). Robert Hooke: New studies. Wolfeboro, NH: Boydell Press.
Irwin, A., & Wynne, B. (1996). Misunderstanding science? The public reconstruction of science and technology. New York: Cambridge University Press.
Irzik, G., & Nola, R. (2014). New directions for nature of science research. In M. R. Matthews (Ed.), International handbook of research in history, philosophy and science teaching (Vol. 2, pp. 999-1021). New York: Springer.
Jammer, M. (1989). The conceptual development of quantum mechanics. Los Angeles, CA: Tomash Publishers.
Jenner, B., & Titscher, S. (2000). Methods of text and discourse analysis. Thousand Oaks, CA: SAGE.
Jho, H. (2014). Implications of science education as interdisciplinary education through the cases of scientists and artists in the modern era: Focus on the relationship between science and the arts. Journal of the Korean Association for Science Education, 34(8), 755-765.
Jho, H. (2018). Trends in research on the nature of science: A bibliometric analysis with R-mapping tool. Journal of Learner-Centered Curriculum and Instruction, 18(18), 937-956.
Khine, M. S. (2012). Advances in nature of science research: concepts and methodologies. Dordrecht: Springer.
Kimball, M. E. (1968). Understanding the nature of science: A comparison of scientists and science teachers. Journal of Research in Science Teaching, 5(2), 110-120.
Klopfer, L. E., & Cooley, W. W. (1963). The history of science cases for high schools in the development of student understanding of science and scientists: A report on the HOSG instruction project. Journal of Research in Science Teaching, 1(1), 33-47.
Kuhn, T. S. (2012). The structure of scientific revolutions. Chicago: University of Chicago Press.
Kukla, A. (2000). Social constructivism and the philosophy of science. New York: Routledge.
Ladyman, J. (2002). Understanding philosophy of science. New York: Routledge.
Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. Journal of Research in Science Teaching, 29(4), 331-359.
Lederman, N. G. (1998). Assessing the nature of science: What is the nature of our assessment? Science & Education, 7(6), 595-615.
Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. Journal of Research in Science Teaching, 39(6), 497-521.
Lederman, N. G., Wade, P., & Bell, R. L. (1998). Assessing understanding of the nature of science: a historical perspective. In W. F. McComas (Ed.), The nature of science in science education: rationales and strategies (pp. 331-350). Dordrecht: Kluwer Academic Publishers.
Lee, S. W.-Y., & Tsai, C.-C. (2012). Students' domain-specific epistemological beliefs: A comparison between biology and physics. The Asia-Pacific Education Researcher, 21(2), 215-229.
Levere, T. H., & Shea, W. R. (1990). Nature, experiment, and the sciences : essays on Galileo and the history of science. Dordrecht: Kluwer Academic Publishers.
Liou, P.-Y. (2015). Developing an instrument for assessing students' concepts of the nature of technology. Research in Science & Technological Education, 33(2), 162-181.
Liu, S.-Y., & Tsai, C.-C. (2008). Differences in the scientific epistemological views of undergraduate students. International Journal of Science Education, 30(8), 1055-1073.
Matthews, M. R. (1994). Science teaching: the role of history and philosophy of science. New York: Routledge.
Matthews, M. R. (1998). In defense of modest goals when teaching about the nature of science. Journal of Research in Science Teaching, 35(2), 161-174.
Matthews, M. R. (2012). Changing the focus: From nature of science to features of science. In M. S. Khine (Ed.), Advances in nature of science research (pp. 3-26). Dordrecht: Springer.
Maudlin, T. (2010). The metaphysics within physics. New York: Oxford University Press.
Maudlin, T. (2012). Philosophy of physics: Space and time. Princeton, NJ: Princeton University Press.
McComas, W. F. (1998). The nature of science in science education: rationales and strategies. Boston: Kluwer Academic Publishers.
Millar, R., & Osborne, J. (1998). Beyond 2000: Science education for the future. London: King's College.
Ministry of Education (2015). National science curriculum. (Vol. 2015-74). Sejong: Ministry of Education.
Mullis, I. V. S., & Martin, M. O. (2013). TIMSS 2015 assessment

frameworks. http://timssandpirls.bc.edu/timss2015/frameworks.html.
National Research Council (1996). National science education standards. Washington, D.C.: National Academic Press.
National Research Council (2012). Framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Washington, D.C.: National Academy Press.
Newman, H. B., & Ypsilantis, T. (1996). History of original ideas and basic discoveries in particle physics. New York: Plenum Press.
Newton, I. (1952). Optics: Or a treatise of the reflections, refractions, inflexions & colours of light. New York: Dover.
Organisation for Economic Co-operation and Development (2016). PISA 2015 assessment and analytical framework: science, reading, mathematic and financial literacy. Paris: OECD Publishing.
Peters-Burton, E., & Baynard, L. R. (2013). Network analysis of beliefs about the scientific enterprise: A comparison of scientists, middle school science teachers and eighth-grade science students. International Journal of Science Education, 35(16), 2801-2837.
Pomeroy, D. (1993). Implications of teachers beliefs about the nature of science: Comparison of the beliefs of scientists, secondary science teachers, and elementary teachers. Science Education, 77(3), 261-278.
Popper, K. R. (1963). Conjectures and refutations: The growth of scientific knowledge. London: Routledge.
Popper, K. R. (2002). The logic of scientific discovery. London: Routledge.
Porter, A. C. (2006). Curriculum assessment. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), Handbook of complementary methods in education research (pp. 141-159). Mahwah, NJ: Lawrence Erlbaum Associates.
Ratcliffe, M., & Grace, M. (2003). Science education for citizenship: Teaching socio-scientific issues. Philadelphia: Open University Press.
Rubba, P. A., & Anderson, H. O. (1978). Development of an instrument to assess secondary school students understanding of the nature of scientific knowledge. Science Education, 62(4), 449-458.
Sankey, H. (2008). Scientific realism and the rationality of science. Burlington, VT: Ashgate.
Schwartz, R. S., & Lederman, N. G. (2008). What Scientists Say: Scientists' views of nature of science and relation to science context. International Journal of Science Education, 30(6), 727-771.
Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. Science Education, 88, 610-645.
Shapin, S. (1996). The scientific revolution. Chicago, IL: University of Chicago Press.
Shim, K.-C., Park, J.-S., Lee, G.-Y., Son, J.-W., Moon, H.-J., Park, J.-Y., *et al*. (2017). Science Laboratory Experiments. Seoul: Visang Education.
Sismondo, S. (2010). An introduction to science and technology studies. Malden, MA: Wiley-Blackwell.
Smith, M. U., & Scharmann, L. C. (1999). Defining versus describing the nature of science: A pragmatic analysis for classroom teachers and science educators. Science Education, 83(4), 493-509.
Tsai, C.-C., & Liu, S.-Y. (2005). Developing a multidimensional instrument for assessing students' epistemological views toward science. International Journal of Science Education, 27(13), 1621-1638.
Waight, N. (2014). Technology knowledge: high school science teachers' conceptions of the nature of technology. International Journal of Science and Mathematics Education, 12, 1143-1168.
Waight, N., & Abd-El-Khalick, F. (2012). Nature of technology: Implications for design, development, and enactment of technological tools in school science classrooms. International Journal of Science Education, 34(18), 2875-2905.
Weedon, C. (1996). Feminist practice and poststructuralist theory. Malden, MA: Blackwell.
Wittgenstein, L. (1978). Philosophical investigations. London: Basil Blackwell & Mott.
Wittgenstein, L. (2001). Tractatus logico-philosophicus. London: Routledge.

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