

**Eliciting students' understanding of nature of science with text-based tasks:
Insights from new Korean high school textbooks**

Wonyong Park

University of Oxford

Seungran Yang and Jinwoong Song

Seoul National University

This is a post-peer-review, pre-copyedit version of an article published in
International Journal of Science Education. The final authenticated version is available
online at <https://doi.org/10.1080/09500693.2020.1714094>

Abstract

Research on nature of science (NOS) have confirmed that students' understanding of NOS is best achieved by explicitly considering NOS a cognitive learning expectation and providing opportunities to reflect on it. However, little has been discussed on how to design and use tasks enhancing students' NOS understanding. In an attempt to fill this gap, we analysed the way NOS tasks are used in seven textbooks for a new subject 'scientific inquiry and experimentation' in Korea. Our analysis of 84 tasks led to three categories being identified: guiding to NOS ideas, expanding NOS understanding and thinking critically about NOS. Whereas the majority of the textbook tasks were used as guides to declarative NOS ideas, few tasks invited students to think critically about controversial aspects of NOS. Most tasks were pointed at the epistemic aspects related to scientific methods or knowledge, while the social aspects of science were seldom addressed. Besides, the number and diversity of NOS tasks varied significantly across different publishers. Based on these findings, we call for more strategic and systemic use of NOS tasks in science textbooks, including the use of diverse tasks in proper manners and sequences, as a crucial step to successful NOS instruction in schools.

1 Introduction

Currently there is a shared belief that school science should move beyond teaching scientific content knowledge and pursue scientific literacy as its key objective (AAAS, 1989; NGSS Lead States, 2013). On the one side, such recognition has led to a major change in pedagogical approaches, calling for more inquiry-oriented and student-led science learning in schools (Abd-

El-Khalick et al., 2004; Anderson, 2002; Schwab, 1958). On the curricular side, the past century saw a significant shift of emphasis from a traditional science content knowledge to methods of science (Armstrong, 1910; Dewey, 1938), followed by a more recent shift to broader epistemic and social contexts under the slogan of nature of science (NOS) (Hodson, 2014; Lederman, 2007; NGSS Lead States, 2013). Those who argue for the inclusion of NOS in science curricula believe that understanding NOS is essential for enhancing science subject matter knowledge, making sense of scientific knowledge and making informed decision, thus constituting an essential part of scientific literacy (Driver, Leach, & Millar, 1996; Hodson, 2014; Lederman, 2007). Science educators' recognition of the significance of NOS has led to it being widely introduced to state-level curricula and standards documents around the world (AAAS, 1989; MOE, 2015; NRC, 1996; NGSS Lead States, 2013).

Bringing together these two major strands of change, there is one naturally occurring question: Is the pedagogical claim also valid for the new curricular content? That is, should we also approach NOS teaching in a student-centred and inquiry-oriented manner instead of in a teacher-led way? Most science educators would agree to this idea in principle, but in practice, the pedagogy of NOS is more complicated than it seems. For one reason, NOS as a new curricular content differs in many aspects from the traditional subject matter in science curricula. Teaching that 'science is socially and culturally embedded' is, in many important ways, different from teaching that 'things continue their motion when under no external forces'. It follows that the teaching strategies, developmental considerations and the organisation of teaching materials for NOS knowledge should be different from those that school science has used for teaching content knowledge. These crucial differences at least partially explain why there still remains much unresolved debate about NOS instruction, despite decades of research efforts in the domain. Instructional approaches to NOS, or how we can elicit students' deeper understanding of NOS, are consistently being asked about and discussed by many science education researchers (Bell, Lederman, & Abd-El-Khalick, 1998; Hodson, 2014).

This article seeks to contribute to the knowledge on how to effectively prompt students' understanding of NOS, particularly when NOS is contextualised with historical episodes. This is done by analysing the instructional tasks used by the textbooks for a Korean subject called 'scientific inquiry and experimentation' (SIE), since this newly introduced subject is an amalgam of scientific inquiry and NOS—each of which represents pedagogical and curricular innovations in contemporary science education. The main aim is to describe the types of NOS tasks in SIE textbooks and how various task types are being used in SIE textbooks. Implications of the typology and textbook analysis results for textbook development and instructional design are discussed.

2 Nature of Science in Science Education

2.1 History of Science and NOS

As science educators and historians have appreciated the value of history of science in various areas such as enhancing conceptual comprehension, humanising science concepts and making science more engaging (e.g. Matthews, 2014; Monk & Osborne, 1997; Shapin, 1992), an increasing number of reform documents and research studies have attended to its potential roles in illuminating NOS aspects (Allchin, 2013; Monk & Osborne, 1997; NRC, 1996; NGSS Lead States, 2013; Rudge & Howe, 2009). During the past two decades, more specific suggestions have been made for using famous historical experiments for educational purposes, and its usefulness in prompting novel questions, ideas and important issues in science disciplines has been discussed (Allchin et al., 1999; Cavicchi, 2006, 2008a, 2008b; Crawford, 1993; da Silva, Pinto, & Ferreira, 2018; Heering, 2000, 2007, 2012). For example, Chang (2011) recently proposed that historical experiments can make significant contributions to NOS understanding, using the example of complexities in the boiling point of water, and also that students can develop sophisticated NOS understandings through replicating experiments from the past.

The key idea shared by these authors is that the history of science, including historical experiments, is a powerful tool that enables a contextualisation of NOS by revealing the epistemic, methodological and social aspects of science (Allchin, Andersen, & Nielsen, 2014; Irwin, 2000; Matthews, 1994). Meanwhile, empirical studies have shown that the use of history alone does not promise significant gains in terms of students' NOS understanding (Abd-El-Khalick & Lederman, 2000; Meichtry, 1992; Tao, 2003). Instead, it has been argued that historical illustrations must be accompanied by some forms of student activity that are informed by constructivism (Allchin et al., 2014), which brings us to the question of how to design and implement an effective NOS instruction using historical episodes.

2.2 Explicit-Reflective Approach to NOS Instruction

Research on the teaching and learning of NOS has identified two essential conditions in which NOS is best learned (Abd-El-Khalick, Bell, & Lederman, 1998; Akerson, Abd-El-Khalick, & Lederman, 2000). First, it suggests that NOS should be taught as an explicit curricular objective, rather than a by-product of engaging in scientific inquiry activities (Khishfe & Abd-El-Khalick, 2002). In terms of teachers' instructional practice, this means that science teachers must have an explicit intention to teach the target NOS ideas to students through each lesson and that these learning opportunities should be carefully planned and implemented just as for other cognitive subjective matter in science. The use of the history of science has been suggested to be one key approach to contextualising NOS in achieving this aim (Abd-El-Khalick & Lederman, 2000; Lederman, 2007; Rudge & Howe, 2009). Second, NOS is best learned through students' reflection opportunities about what they have learned (Khishfe & Abd-El-Khalick, 2002). This pedagogical

condition concerns the importance of organising and presenting meticulously planned questions, tasks and activities throughout the instruction that help students connect these to the target NOS ideas (Abd-El-Khalick, 2012; Clough, 2011). Such connection has often been enacted in the previous studies by using designed questions while students perform the science inquiry activities (Williams & Rudge, 2016; Yacoubian & BouJaoude, 2010), class discussions (Akerson & Donnelly, 2010; Aragón, José, Acevedo, 2019; Quingley, Ponganon, & Akerson, 2011), or writing reflection papers (Abd-El-Khalick, 2005).

2.3 Family Resemblance Approach to NOS

The family resemblance approach (FRA) as a way of conceptualising science was first introduced by Irzik and Nola (2011). This approach departs from the traditional 'consensus view' of NOS, where a list of important and educationally relevant aspects of science is made and used as a basis of NOS instruction. Instead, proponents of FRA suggest that science could be best understood using 'family resemblances' (originally coined by Wittgenstein) among the diverse disciplines that comprise it. FRA as an approach to NOS has been used for the analysis of science education standards and curriculum documents in the United States (Erduran & Dagher, 2014a; Authors, in press), Ireland (Erduran & Dagher, 2014b), Turkey (Kaya & Erduran, 2016) and Taiwan (Yeh, Erduran, & Hsu, 2019). For the purpose of investigating the relationship between the content of NOS and the types of tasks used to highlight it, we used Erduran and Dagher's (2014a) version of FRA, which consists of four cognitive-epistemic and seven social-institutional NOS categories (Table 1). The FRA wheel is a visual representation of the eleven FRA categories (Figure 1). It consists of three wheels as seen in the figure, with cognitive-epistemic NOS aspects in the centre and social-institutional aspects surrounding them. One distinctive feature of Erduran and Dagher's FRA model is its emphasis on the interdependence of diverse NOS aspects, represented by the 'dotted' lines between categories in Figure 1. In particular, since the model encourages the contextualisation of diverse NOS aspects that encompass the wider social and cultural dynamics (Erduran & Dagher 2014a), it was considered a suitable analytical framework that can reveal the potential strengths and weaknesses of the NOS tasks in the textbooks.

FRA is widely used as a lens for examining the NOS aspects of science textbooks in diverse regional contexts. BouJaoude, Dagher and Refai's (2017) analysis of ninth-grade Lebanese science textbooks revealed that the chemistry and life and earth science textbooks had more NOS aspects addressed compared to the physics textbook, and most instances treated NOS in brief and limited manners. Several studies focused on the NOS aspects in specific content area in a scientific discipline. For example, McDonald (2017) used FRA to analyse the Australian junior secondary school textbooks, particularly their genetics chapters. She found that only three explicit references to NOS were made in the four examined textbooks, all of which pointed to the scientific

knowledge category in FRA. Turning to physics, Authors (2019b) examined how Korean physics textbooks portray the nature of modern physics topics such as general relativity and gravitational waves. They found that, contrary to many previous studies, there were diverse cognitive-epistemic and social-institutional aspects of general relativity addressed in the textbooks, indicating the potential of modern science topics in illuminating NOS. These studies have exemplified the affordances of FRA in analysing textbooks in a coherent and holistic manner and also providing suggestions for textbook authors and teachers.

Table 1

Descriptions of the 11 FRA categories (Erduran & Dagher, 2014)

FRA category		Description
<i>Cognitive-epistemic aspects</i>	<i>Aims and values</i>	The key cognitive and epistemic objectives of science, such as accuracy and objectivity
	<i>Methods</i>	The manipulative as well as non-manipulative techniques that underpin scientific investigations
	<i>Scientific practices</i>	The set of epistemic and cognitive practices that lead to scientific knowledge through social certification
	<i>Scientific knowledge</i>	Theories, laws, and explanations that underpin the outcomes of scientific inquiry
<i>Social-institutional aspects</i>	<i>Social certification and dissemination</i>	The social mechanisms through which scientists review, evaluate, and validate scientific knowledge, for instance, through the peer-review systems of journals
	<i>Scientific ethos</i>	The norms that scientists employ in their work as well as in interaction with colleagues
	<i>Social values</i>	Values such as freedom, respect for the environment, and social utility
	<i>Professional activities</i>	How scientists engage in professional settings such as attending conferences and doing publication reviews
	<i>Social organizations and interactions</i>	How science is arranged in institutional settings such as universities and research institutes
	<i>Financial systems</i>	The underlying financial dimensions of science, including funding mechanisms
	<i>Political power structures</i>	The dynamics of power that exist between scientists and within science cultures

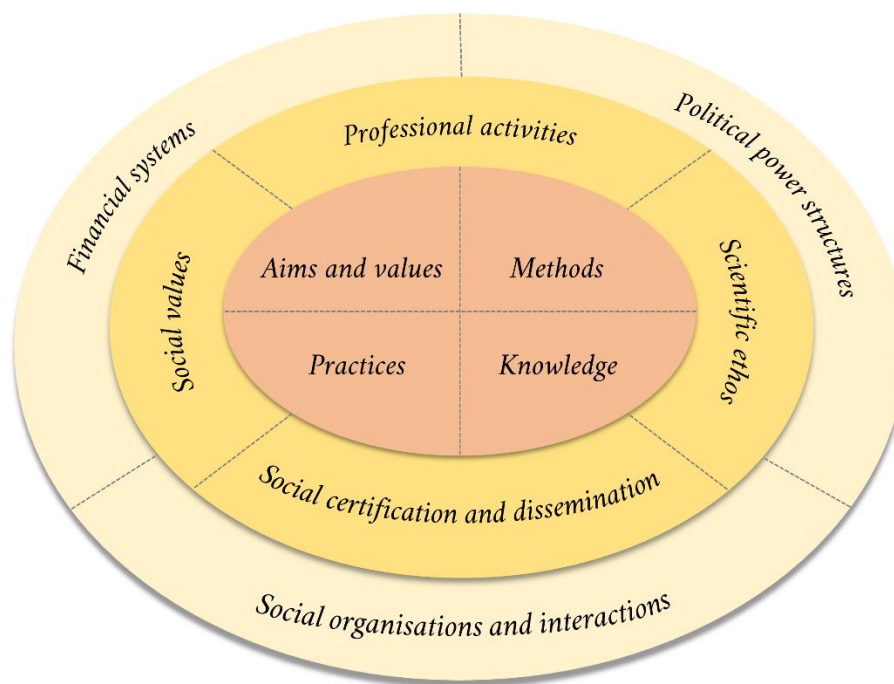


Figure 1. FRA wheel: Science as a cognitive-epistemic and social-institutional system (Redrawn from Erduran & Dagher, 2014a, p. 28)

3 Instructional Tasks for Science and NOS Instruction

Translating the curriculum into appropriate tasks is an essential step in facilitating higher-level understanding of curriculum content and fostering student engagement (Thompson, 2014a). Following Watson and Sullivan (2008), we use the term ‘task’ to refer to the textbook information in the form of questions, situations and instructions intended to prompt student work in the class. It has been claimed by many that instructional tasks are important elements of science teaching and learning that play multiple roles in science learning (Doyle & Carter, 1984; Kang, Windschitl, Stroupe, & Thompson, 2016; Sanford, 1987; Stein, Grover, & Henningsen, 1996) and that different tasks provoke different levels and kinds of student thinking (Stein, Grover, Henningsen, & Silver, 2000). Early systemic studies on the use of instructional tasks began in the field of mathematics education in the 1970s. According to Stein and Lane (1996), instructional tasks affect learning by (i) influencing the way students think as opposed to influencing learning directly, (ii) configuring the kind and level of classroom discourse that is possible and (iii) configuring the possibilities for the occurrence of other forms of recommended instructional practices (p. 55). In addition, Edwards (2014) proposed that an ideal sequence of tasks to promote learning should include (i) introduction of key concepts and modelling of ways of engaging with key concepts, (ii) tightly structured tasks that demand engagement with key concepts and ways of inquiring, (iii) more open tasks that enable learners to apply key concepts and ways of inquiring and (iv) demonstration of

grasp of key concepts and ways of inquiring. Turning to research on tasks in science education, a recent study by Kang and her colleagues (2016) has extended key ideas from mathematics education to science pedagogy and proposed a 'science task framework' that comprises four steps towards learning through tasks (p. 5).

Text-based tasks can play a crucial role in instructional practices, since most teachers cannot always initiate the tasks from their own pedagogical creativity (Watson & Thompson, 2015). Not all tasks in textbooks are addressed by teachers in teaching practice, but in a majority of classrooms across the world, it is still true that the content of textbooks becomes an important source of teachers' selection and design of their plans for NOS instruction (Kahveci, 2010; Roseman, Stern, & Koppal, 2010). This is especially so in East Asian countries such as Korea, where many teachers tend to base their instructional practice on written curricula and authorised textbooks to effectively prepare students for national exams in the culture of accountability and competition (Lew, 2016).

Tasks are important not only in mathematics and science education in general, but also in the instruction of NOS particularly. Adibelli-Sahin and Deniz (2017) found that science teachers feel that NOS understanding can be fostered when reading is followed by organised activities, structured worksheets and discussions. Despite the decades-long emphasis on the explicit and reflective approach to NOS (Abd-El-Khalick, 2005), there have been few studies that attended to the tasks in and for NOS instruction. One possible reason for this scarcity of research on NOS-related textbook tasks is that there have been very few textbooks that are designed to teach NOS. This implies that NOS is still treated as secondary to content knowledge and is not granted its own value in textbooks (Abd-El-Khalick et al., 2017; Campanile, Lederman, & Kampourakis, 2015).

Meanwhile, it is important to note that there are both similarities and dissimilarities between the use of tasks in teaching science and teaching NOS. On the one hand, there is strong resonance in that NOS understanding is considered a cognitive process rather than an affective process (Hodson, 2014; Lederman, 2007). In this cognitive theory of NOS learning, NOS is considered a form of knowledge just as scientific content knowledge is, which implies that similar instructional approaches could be used for both. On the other hand, however, there are reasons that call into question the use of existing task frameworks in analysing and designing NOS tasks, since there are significant differences in terms of subject matter. The sort of knowledge to be learned about NOS has a humanistic, social and epistemological character. NOS deals with how scientific enterprise operates in a larger social and cultural context and how these dynamic processes relate to scientific knowledge, which is quite a contrast with the traditional science content knowledge. In addition, unlike the traditional 'textbook' science knowledge, understanding NOS often entails awareness of uncertainty, ambiguity and controversy (see Kötter & Hammann, 2017 for further discussion).

4 Rationale and Research Questions

The foregoing discussion clearly indicates the need for a set of organised and well-planned instructional tasks that prompt students' reflection during a science lesson that deals with NOS ideas. However, the lack of systemic investigation of NOS tasks in the literature calls for theoretical and practical elaboration upon this topic. In this paper, our key aim is to explore the diverse manners in which the understanding of NOS can be elicited by tasks, particularly when history of science is used to contextualise NOS. There are several characteristics that make the analysis of SIE textbooks a reasonable method of approaching this issue. First, as an amalgam of NOS and inquiry-oriented approaches to science that came with a 'workbook format' (MOE, 2015, p. 111), SIE textbooks provide a large number of tasks that can potentially elicit students' reflection about NOS. This makes SIE textbooks the best option currently available for our purpose, since in most other secondary curricula and textbooks, NOS is treated as secondary to disciplinary contents in its scope and depth. Second, because of the multiplicity of historical episodes that SIE covers, diverse approaches in addressing and prompting reflections about NOS aspects are likely to be found. The study was guided by the two research questions:

1. What types of tasks do the textbooks use to support students' understanding of NOS in the history of science?
2. How do the textbooks use the NOS tasks?
 - (a) How do the number and diversity of NOS tasks vary by publisher?
 - (b) How do the number and diversity of NOS tasks vary in different historical episodes?
 - (c) How do the number and diversity of NOS tasks vary by the NOS content that the task is intended to highlight?

5 Methods

5.1 Textbook and Chapter Selection

As of April 2019, seven SIE textbooks have been published by commercial companies and authorised by the Ministry of Education of Korea, all of which were included in the analysis. These textbooks were developed for use in grade 10 science classrooms in Korea. We analysed the NOS tasks included in the first chapter entitled 'scientific inquiry in history' because this chapter has a greater focus on NOS while the other chapters emphasise the inquiry aspects of science. In other words, 'scientific inquiry in history' is where the 2015 National Curriculum of Korea takes an explicit instructional approach to NOS. In this sense, it can be said that this chapter adopts a

combination of historical and inquiry-oriented strategies for contextualising NOS (Allchin et al., 2014). The analysed textbook materials amounted to a total of 214 pages in the seven textbooks.

As per the curriculum, each textbook includes four episodes in the history of science: Galileo's thought experiment, Mendeleev's periodic table, Mesozoic mass extinction and Pasteur's biogenesis theory (Table 2). In each episode, the textbook begins with a description of the historical and scientific background to the topic followed by a series of student-led inquiry activities that help students follow what happened in the history. Since the main learning objectives of the textbook involve NOS (see Table 2), part of these activities include tasks specifically aimed at addressing NOS. In Galileo's thought experiment, for example, textbooks usually begin by introducing students to Aristotle's account of falling objects, according to which heavier objects fall faster. Next, a multi-step inquiry activity is provided to help students realise the scientific fallacies of Aristotle's idea as they follow the process of Galileo's thought experiment with an inclined plane. Besides this, several textbooks provide some hands-on practical activities through which students can design a simple experiment to test the two theories on free fall.

Table 2

Historical episodes and achievement standards in the national curriculum

Topic	Synopsis of the historical episode	Achievement standard (MOE 2015, p. 114, emphasis added)
Galileo's thought experiment	Galileo used several thought experiments to refute Aristotle's theory of motion widely accepted in his time. In one thought experiment, Galileo considered a ball rolling down on an inclined plane in the absence of any resistance. He noted that when the ball then climbs up another plane, it would reach the same height as it started rolling down from. He then inferred that this should also hold true when the second plane becomes parallel to the ground, meaning that the ball would keep moving forever. Galileo used another thought experiment to prove the universality of gravitational acceleration. These ideas were later exploited by Newton to develop his mathematical theory of motion.	Students can understand the crucial experiments in the history of science that led to <i>paradigm shifts</i> and can explain the progress of science.
Mendeleev's periodic table	In the 1860s, Mendeleev attempted to classify all known chemical elements based on their periodicity, which is considered a significant breakthrough in the history of chemistry. He claimed that he envisioned the complete arrangement in his dream. However, what appeared to be a serendipity was in fact a consequence of other scientists' prior achievements combined with Mendeleev's relentless effort to improve them.	Students can conduct a historical experiment performed by <i>serendipitous discoveries</i> and explain the NOS found in the process.
Mesozoic mass extinction	The Cretaceous–Tertiary (K-T) extinction was an abrupt mass extinction that marked the Mesozoic Era approximately 66 million years ago. To understand what caused the K-T extinction, scientists noted that several K-T layers across Europe contain high levels of iridium, which is rare in the Earth's surface but abundant in asteroids. From this and several other observations, now it is generally thought that the extinction was caused by the impact of a massive asteroid.	Students can conduct inquiry through direct observation and explain the <i>inductive inquiry method</i> .
Pasteur's biogenesis theory	A French biologist Louis Pasteur wanted to prove his hypothesis that living matter only arises from other living matter. To test this hypothesis, Pasteur carried out a two-part experiment with a flask containing broth which was boiled and sterilised. In the first part, he used a 'swan-neck' flask to prevent outside air from entering, and in the second part, the neck was broken off, allowing the air to contact the broth. Several days after, microorganism growth was observed only in the latter, which provided conclusive evidence supporting his hypothesis about the generation of life.	Students can perform historical experiments that employ hypothesizing and explain the features of the <i>deductive inquiry method</i> .

5.2 Defining and Selecting NOS Tasks

Drawing on the literature on instructional tasks and explicit-reflective NOS instruction, we used several criteria for inclusion/exclusion to identify NOS tasks from the seven textbooks. First, in accordance with the definition of ‘task’ (Watson & Sullivan, 2008; see Sect. 3 of this article), we selected interrogative or imperative sentences (or a set of them) that instructed the readers to think and answer. Since tasks usually appear at the end of each section, or in sidebars or boxes and often clearly labelled as ‘task’, ‘exercise, or ‘question’, etc., they could be easily identified from textbooks. Second, tasks were selected only in cases where the expected answers or responses were based on cognitive or epistemic understanding of NOS aspects rather than on the typical scientific inquiry skills. Though we were aware that there is often no clear-cut border between NOS and scientific inquiry, it was necessary to distinguish NOS tasks from inquiry tasks because a key tenet of the explicit-reflective approach is that little NOS learning occurs by simply engaging in inquiry tasks (see Sect 2.2). For this reason, we selected only the tasks with a clear NOS intention and excluded inquiry tasks that ask students to replicate what scientists did, interpret data, draw graphs or find evidence that supports a scientific hypothesis, without asking to reflect on the NOS aspect underlying these activities. For example, simply observing the result of Pasteur’s swan-neck flask experiment and drawing the conclusion was not considered to be an NOS task, whereas explaining why this experiment counts as a deductive inquiry was. The exclusion of these tasks was not to discount the importance of scientific inquiry tasks when teaching with historical experiments but to keep our research focus on the NOS tasks. Based on the ‘task’ criteria, 356 tasks were found in the seven textbooks. Applying the ‘NOS’ criteria then left 84 tasks that were relevant to cognitive understanding of NOS aspects, which were subjected to inductive categorisation.

5.3 Content Analysis and Reliability

Considering that the existing frameworks are less than sufficient to capture the diversity of possible NOS tasks, we approached the textbooks in an inductive manner in order to develop descriptive categories from our data (Hsieh & Shannon, 2005). The purposes of this content analysis were, first, to describe SIE textbooks’ strategies to elicit students’ reflection about NOS aspects and, second, from this information, to obtain clues about how diverse NOS reflection tasks can possibly be classified in general. Analysis was done by two authors, who had completed graduate-level coursework on the NOS, history and philosophy of science, and instructional methods in science, and also had prior experiences in analysing the NOS-related contents of science textbooks.

Several different approaches to classifying instructional tasks have been proposed to date. According to Robinson’s summary (2006), tasks can be classified on the basis of what learners actually do when given the task (behaviour descriptive approach) or what kind of human abilities

are required to perform the task (ability requirement approach). In this study we adopted the *information-theoretic* approach, meaning that our classification was done based on ‘the cognitive processes involved in mediating input to the task performer and the output (spoken, written, and/or other behavioural responses) required for successful task completion’ (Robinson, 2006, p. 10). This was primarily because we considered an understanding of NOS as a cognitive learning outcome (see Sect 2.2), and therefore classification based on the cognitive processes would be most useful in developing and organising NOS tasks in the future. To this end, we first read through the textbooks a few times to get a complete sense of the textbook chapters and the context in which each task is presented. While reading through the textbook, each task was given initial codes such as ‘comparison’, ‘find NOS’, ‘find historical cases’ based on the nature of student activity that it elicits. During this process, the researchers bore in mind what kind of cognitive or epistemic processes are required for students to perform the given task, and the teacher’s guide that came with each textbook were consulted to assist understanding the intent of the analysed tasks. Next, all 84 NOS tasks were subjected to constant comparison (Glaser & Strauss, 2017) to develop subcategories from initial codes and explore possible relationships between the categories. For example, there were many tasks that aimed to make a link between a historical episode and NOS aspects, but as the analysis proceeded these tasks were divided into two distinct categories, ‘identify NOS in a historical case’ (G2) and ‘explain a historical case based on NOS’ (G3). Whereas the former only presents the historical episode and ask a student to figure the NOS aspect, the latter gives both information and asks to link between them. This difference was considered important as the two could be used for different purposes in the instruction. Descriptions of the tasks are provided in our results section.

Once this process was completed, the 10 task types were sequenced in the increasing order of sophistication, from the simple tasks that focus on memorisation of NOS-related concepts to the ones that require deeper reflection related to NOS aspects. Such a progression encompasses, in Kötter and Hammann’s (2016) terms, both ‘teaching the NOS’ and ‘teaching about NOS’. While the former focuses on less controversial and widely agreed upon aspects of NOS (e.g., Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Lederman, Lederman, Bartos, Bartels, Antink-Meyer, & Schwartz, 2014), the latter includes critical and meta-level discourses about NOS which tends to be more controversial and open-ended (Kötter & Hamman, 2016; Matthews, 2012; Yacoubian, 2015). In light of such distinction, we grouped the first five task types into one category, as they all focused on understanding a certain NOS aspect based on the information already given earlier in the textbook. Among the rest, the three task types with many possible answers, but not particularly asking to be critical about NOS, were grouped together. The other two task types where students were encouraged to challenge an NOS aspect were considered to form one category. As a result, the 10 task types were grouped into three larger categories (guiding to NOS ideas, expanding NOS understanding, and thinking critically about NOS). To ensure reliability of the analysis, two

authors individually conducted the categorisation and compared the results, and the differences were resolved through multiple discussions among researchers.

To answer research question 2(c), each of the tasks was assigned an additional code for the NOS aspect that it was intended to highlight (see also Table 5). This was also carried out by two authors by matching the tasks to one of the 11 FRA categories. Some tasks invoked a broad range of NOS-related issues that involve more than one FRA category, and the category named ‘etc.’ was used to indicate these tasks. An inter-coder agreement of 90.47% was reached in the initial analysis, and the disagreement was resolved through multiple rounds of discussion.

6 Results

6.1 RQ 1: Classification of NOS Tasks in the Textbooks

The content analysis enabled us to identify 10 distinct task types that are used by the seven textbooks, which were then grouped into three broader categories (Table 3). In the following, we describe each of these categories and types with textbook examples.

6.1.1 *Guiding to NOS Ideas (G)*

Most textbooks frequently used this category of NOS tasks to encourage students to recall the key NOS concepts or make connections between the historical episode and the target NOS idea. This category can serve as a bridge between the context and the content, by shedding light on how the NOS aspects manifest in the scientific practice, and vice versa, which is an important component of the explicit-reflective approach to NOS instruction (Lederman, 2007; Abd-El-Khalick, 2012). Specifically, we identified five types of NOS tasks that belong to this category.

Perform simple tasks from memory (G1) refers to the tasks that can be answered by memorising definitions, concepts, terms or procedures, and are similar to what Stein and Smith (1998) called ‘low-level tasks’ involving memorised facts. In terms of NOS, these simple tasks were used by the textbook authors in the form of, for example, ‘explain what a paradigm is’ or ‘fill in the blank step in the inductive method’.

Identify NOS in a historical case (G2) was another frequently used type of NOS task, which instructed students to discover a NOS aspect in the given historical episode. Since the national curriculum specifies one prominent target NOS aspect for each episode, the textbooks used diverse variants of this task type to encourage students to identify the target NOS from the given story. A majority of instances of this task type were used to address the inductive and deductive methods in the two historical episodes (‘Mesozoic mass extinction’ and ‘Pasteur’s biogenesis

theory'), but it is evident that this one could be widely used to address most other NOS aspects as well. The example below uses a matching task to help students make connections between historical examples related to the periodic table and what they tell about NOS.

The process through which the modern periodic table was developed by Lavoisier, Döbereiner, Newlands, Mendeleev and Moseley is a good example that shows the nature of science. Draw lines to match the making process of the periodic table with the nature of science aspects. (Textbook 2, p. 18) [G2]

Example

Nature of science

(a) Atomic number is determined by the number of protons, not the atomic weight.	•	•	Science is based on evidence.
(b) The elements predicted by Mendeleev were found to exist in later studies.	•	•	Scientific concepts are subject to change.
(c) Mendeleev created the periodic table by creatively discovering the periodicity and using insights as he arranged the 63 elements.	•	•	Science is replaced by more adequate and new theory.
(d) Mendeleev predicted the elements using the periodic law.	•	•	Science explains and predicts.
(e) The error in Mendeleev's periodic table was later revised by Moseley.	•	•	Science is the result of logic and creativity, and sometimes coincidence.

Explain a historical case based on NOS (G3) was often used after the description of historical context and student-led inquiry activities to prompt students to interpret the history or the inquiry activity in terms of a certain NOS aspect. This included, for example, interpreting the history of ideas about motion in terms of the paradigm shift and summarising how scientists found out what caused the Mesozoic extinction based on the process of the inductive method. These tasks require students' concrete understanding of a NOS aspect as well as ability to apply it to explaining a historical case.

Identify details about NOS through a historical case (G4) was frequently used to support the understanding of scientific methods. For example, after describing the two separate experiments conducted by Francesco Redi (1626–1697) and Lazzaro Spallanzani (1729–1799) to refute the idea of spontaneous generation, three textbooks presented tasks prompting students to understand the procedural features of these experiments that comprise the hypothetico-deductive experimental design. Questions such as 'Why did Redi and Spallanzani each make two separate experiments under different conditions and then compare the results?' prompt students to generalise the steps of the experiments in order to understand the concept of control and experimental groups, which

are core aspects of scientific experimentation.

Compare different NOS aspects (G5) was found mostly in the context of deductive and inductive methods in science, as in the example ‘Compare the deductive and the inductive inquiry processes and explain the similarities and differences’. Although not observed in the analysed textbooks, similar comparisons could be made between other important NOS aspects as well. For example, comparing observation and experimentation can give an opportunity to highlight different forms of scientific practice (Erduran & Dagher, 2014a; Irzik & Nola, 2011). Similarly, examples of experiments in physical sciences and biology can be compared to elicit reflections on the similarities and dissimilarities among different scientific domains, which would enable deeper understanding of scientific experimentation (see Authors, 2019a).

6.1.2 Expanding NOS Understanding (E)

In these tasks, students are encouraged to expand their thoughts outside of the given historical context, search for new examples and reasons for the given NOS, and think about the extent to which a NOS aspect could account for the given historical example. The tasks in this category are usually intended to elicit answers that are more open-ended than ones in the previous category, and students’ diverse responses could result in an even more fruitful expansion of NOS ideas. This also means that there can be a range of student answers, some of which may not be expected by the textbook authors or teachers. For this reason, teachers’ pedagogical skills in dealing with the diversity of student responses to create learning opportunities would be critical for these task types.

Search for historical examples that show a NOS aspect (E1) was frequently used in this category. This one is important because in most cases, there is more than one historical context in which a specific NOS aspect could be found. After explaining the process of scientific progress with the example of Galileo’s theory of motion, one textbook presented a task ‘Find the cases of paradigm shifts in other areas of science’ to engage students in connecting the NOS to other examples. Another example was a task ‘Find chemical elements that were discovered serendipitously and how they were discovered’. These tasks can prompt students to expand their understanding of the NOS in various contexts outside of the given case.

Think about reasons for a NOS aspect (E2) was used to help students understand NOS by reflecting on why science has such characteristics. For example, doing tasks such as ‘Discuss why scientists work together’ can deepen students’ understanding of collaborative NOS more than simply learning it as a fact and statement. Given the nature of NOS knowledge, there are usually more than one possible explanation for these ‘why’ questions. Students can think of the specialisation and compartmentalisation as the reasons that mandate scientists to do collaborative

research. They can also think of the ‘big science’ that characterises contemporary scientific practice, as exemplified by the Large Hadron Collider (LHC) and Laser Interferometer Gravitational-Wave Observatory (LIGO). Getting a sense of ‘why’ is an important addition to the cognitive understanding of NOS aspects, prompting students’ higher-order thinking about those aspects.

Evaluate the applicability of NOS (E3) asked learners to think about the circumstances in which a certain method could be used, specifically in connection with method-related NOS aspects. Tasks such as ‘Discuss in which case the deductive inquiry method is more appropriate than the inductive inquiry method’ give an opportunity to foster more sophisticated understanding of inductive and deductive methods. In a similar way, this task type can also be used to ask whether a specific description of science can explain the given historical episode to a satisfactory extent. This is important because NOS, however conceptualised, is inevitably a simplified knowledge about the complex enterprise of science (Kampourakis, 2016; Kötter & Hammann, 2016).

The example below describes two NOS tasks in Textbook 1 which come after a student-led inquiry activity on how scientists have established the theory about the Mesozoic mass extinction. In the student-led activity that consists of 11 smaller tasks, students are given several pieces of evidence including the discontinuous fossil records and the extraordinary concentrations of iridium in the K-T boundary, and are instructed to interpret the observational data related to the evidence. After they complete these activities, Textbook 1 presents two NOS tasks, the first for summarising the lengthy inquiry process according to the inductive inquiry process (G3) and the second for reflecting on what phenomena could be subjected to such an inquiry process (E3). This shows a good example of how NOS learning opportunities can be organised by utilising history-based inquiry activities and NOS tasks, the latter sequenced in the order of increasing cognitive demand. As students follow such a progression of NOS tasks, they can make connections between the scientific content (mass extinction) and process (how the inductive method unfolds in the example), as well as develop a higher-level understanding of NOS (when the inductive method can be used or not).

1. Summarise the inductive inquiry process through which the cause of the Mesozoic mass extinction was discovered. [G3]

- Recognising problem: *(Sample answer)* In Gubbio, Italy, geologists found an abrupt change in the boundary between the Mesozoic and Cenozoic eras. Many other species including dinosaurs became extinct during this period. Why did these happen?
 - Observing and exploring: *(Sample answer)* Scientists observed that there is a high concentration of iridium around the boundary.
 - Additional observing and exploring: *(Sample answer)* Iridium is also found in the same boundary
-

in other regions such as Denmark and New Zealand.

- Additional observing and exploring: *(Sample answer) The boundary also contains shocked quartz grains and glass particles.*
- Additional observing and exploring: *(Sample answer) There is a massive impact crater underneath the Yucatán Peninsula in Mexico, which was formed at the end of the Mesozoic era.*
- Interpreting the result of observation: *(Sample answer) Interpreting all observations, we know that a crater impacted at the end of the Mesozoic era, and this had a wide influence on the Earth.*
- Drawing conclusion: *(Sample answer) An asteroid impacted the Earth at the end of the Mesozoic era, creating dust clouds and toxic aerosols that caused many plants to die. This broke the food chain and consequently led to the mass extinction.*

2. Summarise the features of the inductive inquiry method and discuss what kind of natural phenomena are suitable to be investigated by the inductive inquiry method. [E3] (Textbook 1, p. 35)

(Sample answer) Inductive inquiry draws a generalised conclusion from a number of facts. Hence, it is appropriate when investigating the natural phenomena that has multiple observable examples or are hard to reproduce in the laboratory.

6.1.3 Thinking Critically about NOS (T)

Critical thinking is ‘the process of thinking about ideas or situations in order to understand them fully, identify their implications, make a judgement, and/or guide decision making’ (Ontario Ministry of Education, 2013, p. 46). This is something that can be effectively fostered by engaging in the tasks that involves the uncertain, value-laden and controversial sides of NOS. Philosophers, historians and sociologists of science have long disagreed on such things as whether there are universal scientific methods and to what extent science is socially influenced. Also, there has been an increasing number of voices among NOS researchers that support embracing these controversial sides of NOS in K-12 science curricula and avoiding transmitting declarative ideas about science (Kötter & Hammann 2017; Irzik & Nola, 2011; Matthews, 2012). Yacoubian (2015) made a convincing case that critical thinking is essential to both sophisticated understanding of NOS itself and decision making based on NOS. In our analysis, the tasks in this category invite learners to critically reflect on these NOS aspects by thinking about their limitations or taking sides and defending their views on an issue.

Discuss limitations of a NOS aspect (T1) was an example of such a task. While NOS is a description of how science is practised, there is no guarantee that what scientists do is flawless and omniscient. Not only have there been numerous false theories in the history of science that have ended up giving rise to better ones (e.g. Bhakthavatsalam, 2019), scientific methods and practices also have various limitations that persist until today. In regard to this, several textbooks offered tasks such as ‘What is the limitation of the deductive (or inductive) research method?’ or ‘Can we say that the hypothesis is true when the results are as expected?’ These are important issues to be

addressed in NOS instruction, considering that teaching the weaknesses and limits of science is as important as teaching its strengths and benefits (Sadler & Zeidler, 2003).

Take sides and defend one's own view about an issue based on NOS understanding (T2) was another significant NOS task type in this category. Since NOS knowledge usually has an epistemic, philosophical and social-scientific character, they often do not have 'right-or-wrong' answers. Because of this, thinking about competing interpretations of an aspect of NOS in a context, selecting a side that is more appealing to oneself and defending one's view are crucial in linking NOS understanding to scientific literacy. These tasks are usually very open-ended and can be answered based on solid understanding of NOS aspects. One such task was 'Various types of periodic tables have been proposed up to the present. Think about whether the modern periodic table based on atomic numbers will continue to be used without change'. This task invites students to consider both the robustness and tentativeness of scientific knowledge and think about the future of our knowledge about the periodic table. Possible answers include the minor changes to the periodic table following the discovery of heavier elements or a new classificatory system that involves a paradigm shift in chemistry.

Table 3
Tasks to elicit students' understanding of NOS

Task type		Textbook example	Frequency
Guiding to NOS ideas	Perform simple tasks from memory (G1)	Explain what a paradigm is. (Textbook 3, p. 20)	9
	Identify NOS in a historical case (G2)	Describe what aspect of nature of science is found in Goodyear's actions. (Textbook 3, p. 21)	12
	Explain a historical case based on NOS (G3)	Describe the changes in thought while explaining natural phenomena throughout Aristotle's, Galileo's and Newton's accounts. (Textbook 2, p. 21)	21
	Identify details about NOS through a historical case (G4)	Why did Redi and Spallanzani each make two separate experiments under different conditions and then compare the results? (Textbook 3, p. 39)	8
	Compare different NOS aspects (G5)	Compare the deductive and inductive inquiry processes and explain the similarities and differences. (Textbook 2, p. 20)	5
Expanding NOS ideas	Search for historical examples that shows a certain NOS aspect (E1)	Find the cases of paradigm shifts in other areas of science. (Textbook 1, p. 21)	9
	Think about reasons for a NOS aspect (E2)	Discuss why scientists work together. (Textbook 2, p. 23)	4
	Evaluate the applicability of NOS (E3)	Discuss in which case the deductive inquiry method is more appropriate than the inductive inquiry method. (Textbook 1, p. 39)	4
Thinking critically about NOS	Discuss limitations of a NOS aspect (T1)	The result of inductive inquiry cannot be called an unconditional truth. Explain why we should think critically about the consequences of inductive inquiry. (Textbook 6, p.31)	7
	Take sides and defend one's own view about an issue based on NOS understanding (T2)	Various types of periodic tables have been proposed up to the present. Think about whether the modern periodic table based on the atomic number will continue to be used without change. (Textbook 4, p. 25)	5

6.2 RQ 2: Textbooks' Uses of NOS Tasks

6.2.1 Task Types by Publishers

Figure 2 presents the distribution of 10 NOS task types across the seven textbooks made by different publishers. An overarching observation is that the types of NOS tasks differed considerably depending on the textbook publisher. Textbook 3 presented the largest number of NOS tasks (32 tasks), while Textbook 5 had the fewest (4 tasks). It is noteworthy that the frequency of NOS tasks was as much as eight times higher depending on the publisher, indicating a significant difference in opportunities for students to deepen their understanding of NOS. While the abundance of NOS tasks does not automatically lead to students' NOS learning, frequent and diverse textbook tasks are still likely to motivate teachers to address these in their lessons by providing useful instructional resources. Meanwhile, our result also revealed that most textbooks did not cover various types of tasks. All textbooks except Textbook 3, which addressed 9 of the 10 task types, addressed less than six task types.

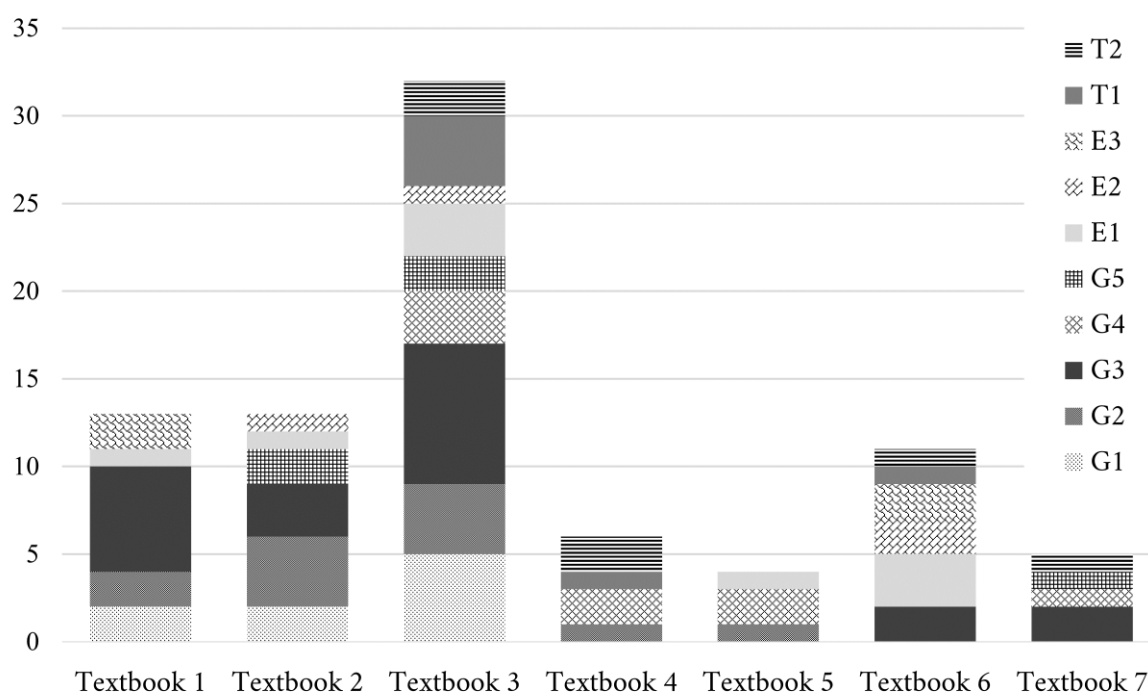


Figure 2. Distribution of NOS task types across textbook publishers

6.2.2 Task Types by Historical Episode

Figure 3 presents the frequency and diversity of tasks by the historical context in which the NOS tasks were given. Both the frequency and diversity varied significantly by the episode, meaning that the instructional methods for NOS were significantly influenced by the way NOS was

contextualised. Among the four episodes, the ‘Mendeleev’s periodic table’ episode had the largest number of tasks (29 tasks), whereas the ‘Galileo’s thought experiment’ episode presented the fewest tasks (13 tasks). Although there were no significant differences in the diversity in task types across the four historical episodes (6–8 types per each episode), it is interesting to note that the ‘Mesozoic mass extinction’ episode, while having a relatively small number of tasks (17 tasks), addressed the most types of NOS tasks (8 types). This was partly because this episode mainly dealt with the NOS related to the inductive method, which has many methodological and epistemological issues that can be meaningfully discussed in high school classroom settings. The tasks ranged from listing the characteristics of inductive inquiry, passing through finding out the examples of inductive inquiry, to discussing why we should be critical about the results of it. These tasks are important for sophisticated understanding of NOS and prevent a naïve ‘stepwise’ conception of scientific methods that could come from simply memorising the steps of deductive inquiry. In addition, most task types in Category G were observed in each of the four episodes, but only a few task types in Categories E and T were found in each episode.

6.2.3 Task Types by NOS Content

Table 4 presents the distribution of NOS task types by the NOS content that the task is intended to address. Among the 11 FRA categories, the three most significant categories being referred by tasks were methods, scientific practices and scientific knowledge. This seems to be related to the fact that the curricular achievement standards for this chapter deal with these aspects of science (see Table 2). As per the national curriculum, each of the four historical episodes points to a specific aspect of NOS: paradigm shifts (Galileo’s thought experiment), serendipitous discoveries (Mendeleev’s periodic table) and inductive and deductive methods (Mesozoic mass extinction and Pasteur’s biogenesis theory) (MOE, 2015; see Table 2). In terms of NOS, each correspond to the nature of scientific knowledge, scientific practices and scientific methods, respectively. The use of many NOS tasks for these categories could therefore be understood largely as an effect of the national curriculum.

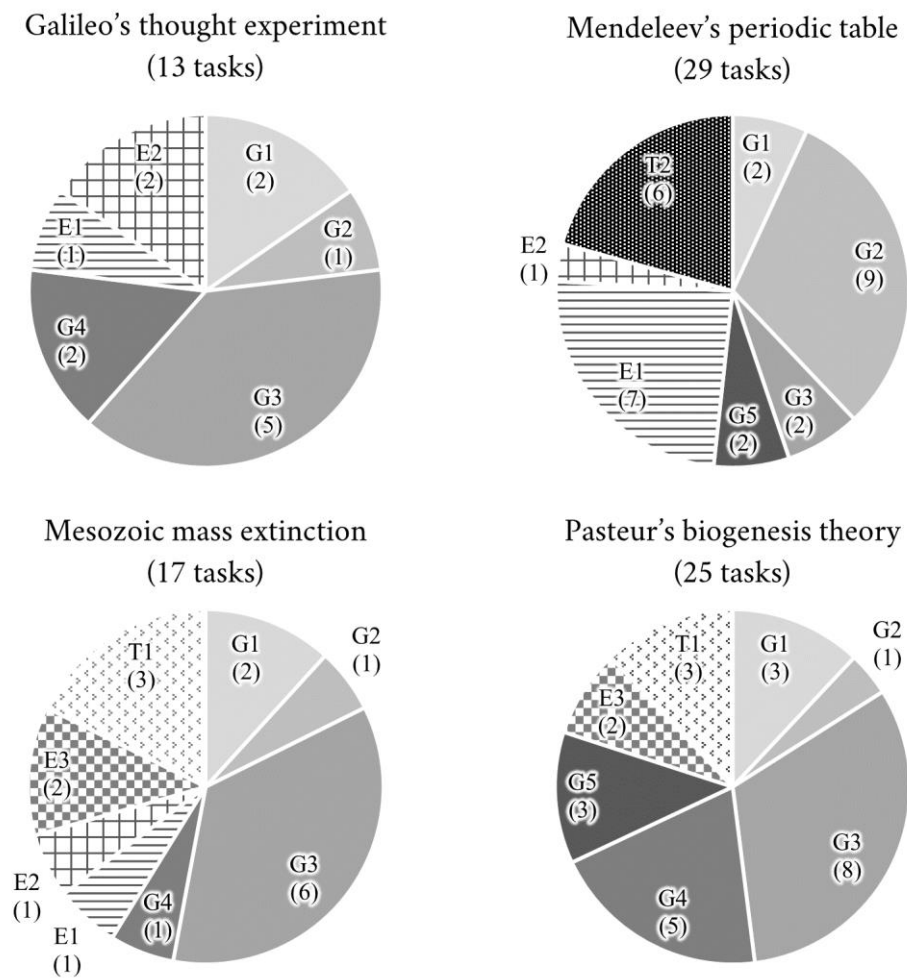


Figure 3. Distribution of NOS task types across historical episodes

Overall, most NOS tasks in the textbooks involved the cognitive-epistemic aspects of science (79 tasks), while only one task touched on the social-institutional aspects of NOS. These included the aspects specified as achievement standards in the curriculum (Table 2), but the textbooks also illustrated many additional NOS aspects relevant to each episode (for a fuller discussion of the NOS aspects represented in SIE textbooks, see Authors, in press). Examples of tasks that belong to each FRA category are presented in Table 5. In particular, while all four cognitive-epistemic categories were addressed more than once, only one social-institutional category (social organisations and interactions) was highlighted by NOS tasks. In particular, the four categories in the middle circle of the FRA wheel were not addressed at all. These refer to the social aspect of science within the scientific community, while the ones in the outermost circle represent the social-cultural interactions between scientific enterprise and the wider society. In this sense, the middle circle can be said to serve as a bridge for understanding the larger social aspects of science.

The absence of tasks in the middle circle therefore implies that students might gain limited understanding of the social aspects of science from the textbooks.

Table 4
Distribution of NOS task types by the NOS content that the task addresses

	G1	G2	G3	G4	G5	E1	E2	E3	T1	T2	Total
AV	–	2	–	–	–	–	–	–	–	–	2
ME	6	2	15	6	5	1	–	4	6	–	45
PR	–	5	1	–	–	6	–	–	–	2	14
KN	2	–	5	2	–	2	3	–	–	4	18
SE	–	–	–	–	–	–	–	–	–	–	0
PA	–	–	–	–	–	–	–	–	–	–	0
SV	–	–	–	–	–	–	–	–	–	–	0
SC	–	–	–	–	–	–	–	–	–	–	0
SO	–	–	–	–	–	–	1	–	–	–	1
PS	–	–	–	–	–	–	–	–	–	–	0
FS	–	–	–	–	–	–	–	–	–	–	0
Etc.	1	3	–	–	–	–	–	–	–	–	4
Total	9	12	21	8	5	9	4	4	6	6	84

Note. AV (aims and values), ME (methods), PR (scientific practices), KN (scientific knowledge), SE (scientific ethos), PA (professional activities), SV (social values), SC (social certification and dissemination), SO (social organisations and interactions), PS (political power structure), FS (financial systems). 'Etc.' denotes tasks that refer to a wider NOS aspect (e.g., discuss the role of society in scientific discovery) that potentially involve multiple FRA categories.

Table 5
Examples of textbook NOS tasks that address each FRA category

FRA category		Textbook Examples	NOS aspect
Cognitive-epistemic aspects	<i>Aims and values</i>	Scientists had tried to clarify the regularity and periodicity between the elements even before Mendeleev's periodic table. What do you think is the reason for this? (Textbook 1,	Finding regularity and pattern as an aim of science

p. 22)			
<i>Methods</i>		Discuss in which case the deductive inquiry method is more appropriate than the inductive inquiry method. (Textbook 3, p. 35)	Inductive method
		Compare inductive inquiry and deductive inquiry processes and write down the commonalities and differences. (Textbook 2, p. 20)	Inductive and deductive method
<i>Scientific practices</i>		Evaluate whether the following statement explains the nature of science well and describe why you thought so: Scientists investigate natural phenomena by careful plans, but they often need creative imagination. (Textbook 4, p. 25)	Scientific activities require both logic and creativity.
<i>Scientific knowledge</i>		What is the relationship between the progress of science and paradigm shifts? (Textbook 3, p. 20)	Progress of scientific knowledge, paradigm shift
		Describe what you think about whether the periodic table would change or not. (Textbook 3, p. 25)	Tentativeness of scientific knowledge
<i>Social-institutional aspects</i>	<i>Social organizations and interactions</i>	Discuss why scientists work together. (Textbook 2, p. 23)	Collaboration and interaction among scientists

7 Discussion

7.1 Implications and Recommendations

Despite its significance in classroom practice and impact on learning, the use of instructional tasks has been a blind spot in the current NOS literature. To promote students' active engagement and accomplishment in NOS, it would be an essential step to understand how higher-level understanding of NOS can be facilitated by tasks presented by textbooks and teachers. In particular, given the central role of school textbooks in teaching NOS (e.g., McDonald & Abd-El-Khalick, 2017; Niaz & Maza, 2011), investigating how textbooks use tasks to illuminate NOS aspects has potential to inform the body of research on the representation of NOS in science textbooks. In this sense, our findings provide initial information about how tasks could be used to teach NOS in an explicit and reflective manner (Abd-El-Khalick et al., 1998; Akerson et al., 2000). It is noteworthy that the number and diversity of NOS tasks in the textbooks significantly varied by publisher. This means that opportunities for NOS learning are likely different across the seven

textbooks, calling for more specific consideration of tasks by textbook authors and publishers.

Also, there were relatively fewer and less diversity of tasks that invited students to examine the complex, uncertain and controversial sides of NOS, which is gaining increasing significance in the era of post-truth and post-normal science where scientific facts are no more deemed to be purely objective and free from values (Funtowicz & Ravetz, 1993; Peters, Rider, Hyvönen, Besley, 2018). In order to exploit the full potential of NOS learning, more tasks that involves critical and reflective thinking about NOS need to be offered by textbooks. For example, in addition to simply guiding students to the declarative NOS idea that ‘scientific knowledge is tentative and is therefore subject to change’, they should be also encouraged to interpret several historical cases in terms of both the tentative and the cumulative aspects of science and appreciate how the dynamics between those two important NOS aspects unfold in each case. Although the analysed textbooks used historical episodes in science to illuminate these NOS aspects, the same claims could be made when NOS is taught through student-led practical activities or socio-scientific cases (Allchin, Anderson, & Nielsen, 2014). A proper selection, combination and sequencing of NOS tasks would make it possible to appreciate both the general aspects of science and the diversity within it, thereby allowing a complete and developmentally appropriate learning of NOS (Erduran & Dagher, 2014a; Hodson, 2014; Kampourakis, 2016).

To effectively support NOS learning, science curriculum and standards documents should provide explicit and detailed guidelines on the use of NOS tasks in science textbooks and lessons. Here it is important to note that a single idea about NOS could be manifested in diverse forms of tasks. Decisions on the design of a NOS task can be influenced by many considerations, such as the historical or inquiry-based context in which the task is presented and the targeted level of sophistication. The design and organisation of tasks should reflect the educational objectives of the curriculum and provide efficacious learning experiences for students. For example, ‘guiding to NOS ideas’ is a useful strategy when students have little background in scientific practice and when the target NOS is less controversial. Doing these relatively simple tasks, students can understand the given historical episode more effectively. After they gain a general picture of the historical episode through these steps, they can be brought to ‘bigger’ questions by higher-level instructional tasks types in the ‘expanding NOS understanding’ and ‘thinking critically about NOS’ categories. These NOS tasks should be carefully planned and implemented throughout and across lessons by teachers, with quality textbooks with well-organised tasks providing a significant basis.

Further research on NOS tasks will be essential in order to provide textbook authors and teachers the information they need to effectively design and implement text-based NOS tasks. Investigations into effective task design for students’ higher-order understanding of NOS are immediately needed. While a number of studies on instructional tasks in science classrooms have been carried out (e.g., Kang, 2017; Kang, Thompson, & Windschitl, 2014), thus far there has been

little interest in the design and implementation of NOS-related tasks in specific. Our findings add to the literature on instructional tasks in science education, which usually addresses tasks related to the conceptual knowledge of science rather than its epistemic and social aspects (e.g., Childs & McNicholl, 2014; Kang, 2017), and call for further research on the qualities of effective instructional tasks specifically to teach NOS. Most empirical reports on science textbooks' NOS representation concentrate on what aspects of NOS are addressed, rather than how NOS learning is supported by related tasks. Effective sequencing and organisation of NOS tasks, the pedagogical content knowledge needed for teachers to design and implement NOS tasks and students' performance in different types of NOS tasks are potential research themes that need the attention of the NOS research community. Besides, further research on NOS tasks will shed a new light on assessment of NOS knowledge, given that tasks can be used not only to support learning but also to formatively and summatively assess student achievement in classrooms (Thompson, 2014b). Given that classroom assessment of NOS learning is an underexplored area in the current NOS literature, the types of NOS tasks reported in this study provide useful information by demonstrating the sorts of the questions that could be asked about NOS in classroom instructions to support and evaluate NOS learning.

7.2 Limitations of the Study

While the three categories and 10 types of NOS tasks identified from seven SIE textbooks give an important clue for a more coherent and complete taxonomy of NOS tasks, there are some limitations to be noted. First, they are not entirely representative of all possible tasks for NOS instruction that could be imagined, given that the analysis is bound by the local curricular context in Korea. The textbooks were written in accordance with the 2015 National Curriculum of Korea, which selected certain NOS aspects as its key learning expectations. Given that different science curricula can prioritise different NOS aspects and different pedagogical approaches to NOS, the results cannot be generalised as a universal trend in textbook-based NOS tasks. Second, it should be noted that the intent of our analyses was not to evaluate how well Korean textbooks deal with NOS in general. The overall quality of textbooks in terms of NOS could not be judged only by how many and how diverse the included NOS tasks were. Additional factors such as the sequencing of the tasks and the accuracy of statements about NOS should also be taken into account, and non-task components of the textbook as well. Third, since this study is strictly based on the inductive categorisation of text-based tasks, how teachers select and use these tasks in classroom practice and what students learn from doing the activities remain unknown. This would also depend on the degree of teachers' reliance on the written curriculum, so the effect of text-based tasks should be supported by research on the implementation of NOS tasks on the classroom level in diverse settings.

References

- Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers' views and instructional planning. *International Journal of Science Education*, 27(1), 15–42.
- Abd-El-Khalick, F. (2012). Nature of science in science education: Toward a coherent framework for synergistic research and development. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 1041–1060). Dordrecht: Springer.
- Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, 37(10), 1057–1095.
- Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, 37(10), 1057–1095.
- Abd-El-Khalick, F., Belarmino, J., Brunner, J., Le, A.-P., Myers, J. Y., Summers, R. G., ... Zeineddin, A. A. (2017). A longitudinal analysis of the extent and manner of representations of nature of science in U.S. high school chemistry, biology, and physics textbooks. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 20–60). London: Routledge.
- 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(4), 417–436.
- Abd-El-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N. G., Mamlok-Naaman, R., Hofstein, A., ... Tuan, H. (2004). Inquiry in science education: International perspectives. *Science Education*, 88(3), 397–419.
- Adibelli-Sahin, E., & Deniz, H. (2017). Elementary teachers' perceptions about the effective features of explicit-reflective nature of science instruction. *International Journal of Science Education*, 39(6), 761–790.
- Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching*, 37(4), 295–317.
- Akerson, V., & Donnelly, L. A. (2010). Teaching nature of science to K-2 students: What understandings can they attain? *International Journal of Science Education*, 32(1), 97–124.
- Allchin, D. (2013). *Teaching the nature of science: Perspectives & resources*. Saint Paul, MN: SHiPS Education Press.
- Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature

- of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education*, 98(3), 461–486.
- Allchin, D., Anthony, E., Bristol, J., Dean, A., Hall, D., & Lieb, C. (1999). History of science—With labs. *Science & Education*, 8(6), 619–632.
- American Association for the Advancement of Science. (AAAS) (1989). *Science for all Americans*. Washington, DC: Author.
- Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1–12.
- Aragón, M., José, M., & Acevedo, A. (2019). Prospective biology teachers' understanding of the nature of science through an analysis of the historical case of Semmelweis and childbed fever. *Cultural Studies of Science Education*, 14(3), 525–555.
- Armstrong, H. E. (1910). *The teaching of scientific method and other papers on education*. London: Macmillan.
- Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (1998). Implicit versus explicit nature of science instruction: An explicit response to Palmquist and Finley. *Journal of Research in Science Teaching*, 35(9), 1057–1061.
- Bhakthavatsalam, S. (2019). The value of false theories in science education. *Science & Education*, 28(1–2), 5–23.
- BouJaoude, S., Dagher, Z. R., & Refai, S. (2017). The portrayal of nature of science in Lebanese ninth grade science textbooks. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 79–97). London: Routledge.
- Campanile, M. F., Lederman, N. G., & Kampourakis, K. (2015). Mendelian genetics as a platform for teaching about nature of science and scientific inquiry: The value of textbooks. *Science & Education*, 24(1–2), 205–225.
- Cavicchi, E. (2006). Faraday and Piaget: Experimenting in relation with the world. *Perspectives on Science*, 14(1), 66–96.
- Cavicchi, E. (2008a). Historical experiments in students' hands: Unfragmenting science through action and history. *Science & Education*, 17(7), 717–749.
- Cavicchi, E. (2008b). Opening possibilities in experimental science and its history: Critical explorations with pendulums and singing tubes. *Interchange*, 39(4), 415–442.
- Chang, H. (2011). How historical experiments can improve scientific knowledge and science

- education: The cases of boiling water and electrochemistry. *Science & Education*, 20(3), 317–341.
- Crawford, E. (1993). A critique of curriculum reform: Using history to develop thinking. *Physics Education*, 28(4), 204.
- da Silva, A. P. B., Pinto, J. A. F., & Ferreira, É. J. B. (2018). Design and implementation of a lesson plan for high school students: A case Study with Oersted's experiment. In *Teaching Science with Context* (pp. 327–339). Dordrecht: Springer.
- Dewey, J. (1938). *Experience and education*. New York, NY: Macmillan.
- Doyle, W., & Carter, K. (1984). Academic tasks in classrooms. *Curriculum Inquiry*, 14(2), 129–149.
- Driver, R., Leach, J., & Millar, R. (1996). *Young people's images of science*. London: Open University Press.
- Edwards, A. (2014). Designing tasks which engage learners with knowledge. In I. Thompson (Ed.), *Designing tasks in secondary education: Enhancing subject understanding and student engagement* (pp. 13–29). London: Routledge.
- Erduran, S., & Dagher, Z. R. (2014a). *Reconceptualizing the nature of science for science education*. Dordrecht: Springer.
- Erduran, S., & Dagher, Z. R. (2014b). Regaining focus in Irish Junior Cycle Science: potential new directions for curriculum and assessment on Nature of Science. *Irish Educational Studies*, 33(4), 335–350.
- Funtowicz, S. O., & Ravetz, J. R. (1993). Science for the post-normal age. *Futures*, September 1993, 739–755.
- Glaser, B. G., & Strauss, A. L. (2017). *Discovery of grounded theory: Strategies for qualitative research*. New York, NY: Routledge.
- Heering, P. (2000). Getting shocks: Teaching secondary school physics through history. *Science & Education*, 9(4), 363–373.
- Heering, P. (2007). Educating and entertaining: Using enlightenment experiments for teacher training. In P. Heering & D. Osewold (Eds.), *Constructing scientific understanding through contextual teaching* (pp. 65–82). Berlin: Frank & Timme.
- Heering, P. (2012). Developing and evaluating visual materials on historical experiments for physics teachers: Considerations, Experiences, and Perspectives. In *Innovative methods for science education: History of science, ICT and inquiry based science teaching* (p. 29). Berlin: Frank & Timme.

- Hodson, D. (2014). Nature of science in the science curriculum: Origin, development, implications and shifting emphases. In M. R. Matthews (Ed.), *International handbook of research in history, philosophy and science teaching*. Dordrecht: Springer.
- Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9), 1277–1288.
- Irwin, A. R. (2000). Historical case studies: Teaching the nature of science in context. *Science Education*, 84(1), 5–26.
- Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, 20(7–8), 591–607.
- Kahveci, A. (2010). Quantitative analysis of science and chemistry textbooks for indicators of reform: A complementary perspective. *International Journal of Science Education*, 32(11), 1495–1519.
- Kampourakis, K. (2016). The ‘general aspects’ conceptualisation as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching*, 53(5), 667–682.
- Kang, H. (2017). Preservice teachers’ learning to plan intellectually challenging tasks. *Journal of Teacher Education*, 68(1), 55–68.
- Kang, H., Thompson, J., & Windschitl, M. (2014). Creating opportunities for students to show what they know: The role of scaffolding in assessment tasks. *Science Education*, 98(4), 674–704.
- Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking. *Journal of Research in Science Teaching*, 53(9), 1316–1340.
- Kaya, E., & Erduran, S. (2016). From FRA to RFN, or how the Family Resemblance Approach can be transformed for science curriculum analysis on nature of science. *Science & Education*, 25(9–10), 1115–1133.
- Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders’ views of nature of science. *Journal of Research in Science Teaching*, 39(7), 551–578.
- Kötter, M., & Hammann, M. (2017). Controversy as a blind spot in teaching nature of science. *Science & Education*, 26(5), 451–482.
- Lederman, J. S., Lederman, N. G., Bartos, S. A., Bartels, S. L., Antink-Meyer, A., & Schwartz, R. S. (2014). Meaningful assessment of learners’ understandings about scientific inquiry—The

- views about scientific inquiry (VASI) questionnaire. *Journal of Research in Science Teaching*, 51(1), 65–83.
- Lederman, N. G. (2007). Nature of science: Past, present, and future. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 831–880). Mahwah, NJ: Erlbaum.
- 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.
- Lew, H. (2016). Developing and implementing 'smart' mathematics textbooks in Korea. In M. Bates & Z. Usiskin (Eds.), *Digital curricula in school mathematics* (pp. 35–51). Charlotte, NC: Information Age Publishing.
- Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science*. London: Routledge.
- Matthews, M. R. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in nature of science research: Concepts and methodologies* (pp. 3–26). Dordrecht: Springer.
- Matthews, M. R. (2014). *Science teaching: The contribution of history and philosophy of science* (2nd ed.). London: Routledge.
- McDonald, C. V. (2017). Exploring representations of nature of science in Australian junior secondary school science textbooks: A case study of Genetics. In C. V. McDonald (Ed.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 98–117). London: Routledge.
- McDonald, C. V., & Abd-El-Khalick, F. (2017). Where to from here? Implications and future directions for research on representations of nature of science in school science textbooks. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 215–231). London: Routledge.
- Meichtry, Y. J. (1992). Influencing student understanding of the nature of science - Data from a case of curriculum-development. *Journal of Research in Science Teaching*, 29(4), 389–407.
- Ministry of Education. (MOE) (2015). *National curriculum: Science*. Sejong: Ministry of Education.
- Monk, M., & Osborne, J. (1997). Placing the history and philosophy of science on the curriculum: A model for the development of pedagogy. *Science Education*, 81(4), 405–424.
- National Research Council. (NRC) (1996). *National science education standards*. Washington, DC: National Academy Press.

- NGSS Lead States. (2013). *Next generation science standards*. Washington DC: National Academy Press.
- Niaz, M., & Maza, A. (2011). *Nature of science in general chemistry textbooks*. Dordrecht: Springer.
- Park, W., & Song, J. (2019). Between realism and constructivism: A sketch of pluralism for science education. In E. Herring, K. Jones, K. Kiprijanov, & L. Sellers (Eds.), *The past, present and future of integrated history and philosophy of science* (pp. 228–247). London: Routledge.
- Park, W., Yang, S., & Song, J. (2019b). When modern physics meets nature of science: The representation of nature of science in general relativity in new Korean physics textbooks. *Science & Education*, 28(9–10), 1055–1083.
- Peteres, M. A., Rider, S., Hyvönen, M., & Besley, T. (2018). (Eds.) *Post-truth, fake news: Viral modernity & higher education*. Dordrecht: Springer.
- Quigley, C., Pongsanon, K., & Akerson, V. L. (2011). If we teach them, they can learn: Young students views of nature of science during an informal science education program. *Journal of Science Teacher Education*, 22(2), 129–149.
- Robinson, P. (2006). Criteria for classifying and sequencing pedagogic tasks. In M. del P. G. Mayo (Ed.), *Investigating tasks in formal language learning* (pp. 1–6). Clevedon: Multilingual Matters Ltd.
- Roseman, J. E., Stern, L., & Koppal, M. (2010). A method for analyzing the coherence of high school biology textbooks. *Journal of Research in Science Teaching*, 47(1), 47–70.
- Rudge, D. W., & Howe, E. M. (2009). An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Science & Education*, 18(5), 561–580.
- Sadler, T. D., & Zeidler, D. L. (2003). Scientific errors, atrocities, and blunders. In D. L. Zeidler (Ed.), *The role of moral reasoning on socioscientific issues and discourse in science education* (pp. 261–287). Dordrecht: Kluwer.
- Sanford, J. P. (1987). Management of science classroom tasks and effects on students' learning opportunities. *Journal of Research in Science Teaching*, 24(3), 249–265.
- Schwab, J. J. (1958). The teaching of science as inquiry. *Bulletin of the Atomic Scientists*, 14(9), 374–379.
- Shapin, S. (1992). Why the public ought to understand science-in-the-making. *Public Understanding of Science*, 1(1), 27–30.
- Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform

- mathematics project. *Educational Research and Evaluation*, 2(1), 50–80.
- Stein, M. K., & Smith, M. S. (1998). Mathematical tasks as a framework for reflection : From research to practice. *Mathematics Teaching in the Middle School*, 3(4), 268–275.
- Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, 33(2), 455–488.
- Stein, M. K., Henningsen, M. A., & Silver, E. A. (2000). *Implementing standards-based mathematics instruction: A casebook for professional development*. New York, NY: Teachers College Press.
- Tao, P. (2003). Eliciting and developing junior secondary students ' understanding of the nature of science through a peer collaboration instruction in science stories. *International Journal of Science Education*.
- Thompson, I. (2014a). (Ed.) *Designing tasks in secondary education: Enhancing subject understanding and student engagement*. London: Routledge.
- Thompson, I. (2014b). *Introduction: Tasks, concepts and subject knowledge*. In I. Thompson (Ed), *Designing tasks in secondary education: Enhancing subject understanding and student engagement* (pp. 3–12). London: Routledge.
- Watson, A., & Sullivan, P. (2008). Teachers learning about tasks and lessons. In D. Tirosh & T. Wood (Eds.), *Tools and resources in mathematics teacher education* (pp. 109–135). Rotterdam: Sense Publishers.
- Watson, A., & Thompson, D. R. (2015). Design issues related to text-based tasks. In A. Watson & M. Ohtani (Eds.), *Task design in mathematics education* (pp. 143–190). Cham: Springer.
- Williams, C. T., & Rudge, D. W. (2016). Emphasizing the history of genetics in an explicit and reflective approach to teaching the nature of science: A pilot study. *Science & Education*, 25(3–4), 407–427.
- Yacoubian, H. A. (2015). A framework for guiding future citizens to think critically about nature of science and socioscientific issues. *Canadian Journal of Science, Mathematics and Technology Education*, 15(3), 248–260.
- Yacoubian, H. A., & BouJaoude, S. (2010). The effect of reflective discussions following inquiry-based laboratory activities on students' views of nature of science. *Journal of Research in Science Teaching*, 47(10), 1229–1252.
- Yang, S., Park, W., & Song, J. (in press). Representations of nature of science in new Korean science textbooks: The case of 'scientific inquiry and experimentation'. In A. L. Tan., T. W. Teo, & Y.

S. Ong (Eds.), *Science education in the 21st century: Re-searching issues that matters from different lenses*. Singapore: Springer.

Yeh, Y. F., Erduran, S., & Hsu, Y. S. (2019). Investigating coherence about nature of science in science curriculum documents: Taiwan as a case study. *Science & Education*, 28(3–5), 291–310.