REAL: Research in Education Assessment and Learning ISSN: 1947-5497 www.realjournal.org

Research Article in Comparative Study

Cross-culture comparison of nature of science representations in five junior high school science textbooks

Nan Wang[1,2], Xiaojian Ma[3], and Wangyi Xu[1,2*]

[1] Chinese Education Modernization Research Institute, Hangzhou Normal University, Zhejiang, China

[2] Jing Hengyi School of Education, Hangzhou Normal University, Zhejiang, China

[3] School of physics, Hangzhou Normal University, Zhejiang, China

[*] Corresponding Author: xwy@hznu.edu.cn

(Received: 04/15/2026; Accepted: 06/03/2026; Published: 07/17/2026)

DOI: https://doi.org/10.37906/real.2026.4

Abstract: Understanding the nature of science (NOS) is crucial for cultivating students' scientific literacy. This study examined the extent, representation (explicit or implicit), accuracy, and completeness of NOS in junior high school science textbooks from China, Korea, Japan, and the United States. Five textbook editions across these four countries were analyzed to identify overall consistency and variations in their treatment of NOS. The findings revealed that NOS representations across selected textbook sections were generally inadequate, with only textbooks from three countries satisfactorily addressing certain NOS aspects. Among these, textbooks from three countries covered all selected content sections, while only one textbook effectively represented all aspects of NOS. Furthermore, NOS representations were unevenly distributed within each textbook, and over half of the NOS content was only partially informed. It is recommended that future textbook revisions adopt more comprehensive and evenly distributed coverage of NOS and explicitly emphasize NOS components to enhance students' scientific literacy.

Keywords: nature of science; textbook analysis; multicultural; representation

1. Introduction

For decades, fostering scientific literacy has remained a foundational goal of science education, as outlined in international frameworks (AAAS, 1993; NGSS Lead States, 2013) and national curricula (Ministry of Education, 2022). A scientifically literate individual is defined as one who can apply robust scientific knowledge - encompassing concepts, theories, and inquiry processes - to navigate decision-making in scientific, technological, and social contexts (Abd-El-Khalick et al., 1998). At the heart of this literacy is the Nature of Science (NOS), which has emerged as a unifying theme in global science curricula, shifting educational focus from factual memorization to epistemological understanding of scientific inquiry (Dogan & Abd-El-Khalick, 2008; Chaiklin, 2022). This paradigm shift is reinforced by the integration of NOS in science education reforms worldwide. As Zhuang et al. (2021) emphasize in their analysis of Chinese high school physics textbooks, understanding NOS is critical for students to "grasp the dynamic, tentative, and socially embedded nature of scientific knowledge." Similarly, Xie et al. (2025) highlight that NOS representations in curriculum standards shape students' perceptions of science as both a cognitive-epistemic system (e.g., scientific practices, methods) and a social-institutional system (e.g., professional activities, cultural embeddedness).

Cross-cultural variations in NOS articulation are evident in national science education standards. The Next Generation Science Standards (U.S.) designate NOS as a core curricular component, emphasizing its integration with scientific inquiry (NGSS Lead States, 2013). Japan's curriculum standards emphasize "scientific exploration through observation, hypothesis, and experimentation," reflecting a cultural focus on empirical rigor to promote NOS awareness (Ministry of Education, 2017). In South Korea, the curriculum explicitly links NOS to the tentativeness of scientific knowledge and the myth of the scientific method, aligning with societal values of critical thinking (Ministry of Education, 2022). China's science standards, as analyzed by Xie et al. (2025), prioritize the cognitive-epistemic dimensions of NOS - such as scientific theories and empirical methods - while demonstrating a gradual increase in social-institutional representations (e.g., science-society interactions). This aligns with Zhuang et al.'s (2021) finding that Chinese textbooks often embed NOS implicitly in historical narratives (e.g., Galileo's free-fall experiments), yet lack explicit discussions of the social contexts of science. Such cultural disparities highlight the need for comparative analyses of NOS representations in instructional materials.

Despite advancements in NOS research, two critical gaps persist. First, existing studies disproportionately focus on high school textbooks. Zhuang et al. (2021) found that in five Chinese high school physics textbooks, NOS representations were concentrated in prefaces and afterwards, with over 50% of aspects presented implicitly. However, junior high school science textbooks - where foundational scientific literacy emerges - remain underexplored in cross-national comparisons. Second, while Abd-El-Khalick's framework (2008, 2017) has been applied to analyze U.S., Turkish, and South African textbooks, studies comparing NOS across East Asian and Western curricula are scarce (Ramnarain & Chanetsa, 2016).This gap is particularly significant given cultural influences on science education. For example, Xie et al. (2025) demonstrate that Chinese curriculum standards emphasize collective scientific inquiry, while U.S. standards prioritize individualistic scientific reasoning. Such cultural nuances may shape NOS representations in textbooks - yet whether these differences translate to junior high school instructional materials across four nations remains unexamined.

1.1. Literature review

The approaches to teaching the Nature of Science (NOS) and existing research on NOS representations in textbooks have been extensively explored in science education literature. Science educators and researchers widely recognize textbooks as essential instructional resources that support teachers in planning and delivering science instruction aligned with local and national curricular standards (Abd-El-Khalick et al., 2008). At all levels of school education, science textbooks serve as primary organizers of curricular topics, structuring the knowledge students are expected to master and providing detailed explanations of instructional content (Chiappetta & Fillman, 2007). For middle school science educators, these textbooks play a particularly vital role in shaping students' foundational scientific understanding. As thematic frameworks for courses, they condense the essential information to be taught in the classroom (Chiappetta, Sethna, & Fillman, 1993).

Consequently, the extent and manner of NOS representation in science textbooks directly influence both teaching approaches and students' comprehension of NOS. A robust understanding of NOS is universally recognized as a critical component of scientific literacy and a long-established objective for science education practitioners. This literature review will examine three interrelated domains: theoretical frameworks of NOS, instructional approaches for teaching NOS, and empirical studies on NOS representations in textbooks.

1.2. Literature Review

Different scholars hold divergent views on the nature of science, leading to varied criteria for the nature of science. Over the years, researchers have proposed a range of instruments to measure the nature of science. Wilson developed the first tool to assess students' conceptions of the nature of science in the world (Kampourakis, K., & McComas, W. F., 2010). One of the most influential perspectives on the definition of NOS in the science education context was proposed by Abd-El-Khalick and Lederman (2000). In literature, sociologists, philosophers, scientists and science educators have distinct interpretations of NOS. By the 1960s, NOS was gradually distinguished from other scientific concepts such as scientific inquiry (Lederman, 1992). For instance, Lederman (1992) defined NOS as the epistemology of science, the process of science knowing, or the values and beliefs inherent to the development and validation of scientific knowledge. McComas et al. (1998) believed that NOS is a description of science and the way it works, stemming from the intersection of the history, philosophy, sociology, and psychology of science and cognitive science. Building on this, Moss (2001) proposed a NOS model, which is composed of eight tenets related to the scientific enterprise and the scientific knowledge. According to Abd-El-Khalick et al. (1998), seven aspects underlay NOS in the early definition. Lederman and Abd-El-Khalick et al. (2002) also proposed this view. These were: empirical nature of scientific knowledge, development of scientific knowledge through observation and inference, nature of scientific theories, scientific theories and laws, imagination and creativity, the theory-laden nature, social and cultural embedding of scientific knowledge. More Specifically, the empirical aspect claims that science is derived from observations of natural phenomena. The inferential aspect means that statements about phenomena that are not directly accessible to the senses. The nature of scientific theories is well-established, highly substantiated, internally consistent systems of descriptions. The nature of scientific laws is the description of relationships among observable phenomena. Laws and theories are different types of knowledge and one does not become the other. The creative aspect highlights that science is intertwined with human creativity and imagination. The theory-laden aspect indicates that scientific knowledge is subjective and is influenced by scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training and expectations. Finally, social and cultural embedding of science aspects suggest that the influence among science, society and culture.

Among existing conceptions of NOS, a particular characteristic of NOS, commonly referred to as the "consensus view", has obtained acceptance in many countries and is also central in the research on teachers' and students' understanding of NOS. However, despite the widespread adoption of the consensus view of NOS, it has also faced criticism in the field of science education (Dagher & Erduran, 2016). By emphasizing the common characteristics of scientific knowledge and inquiry, the consensus view may inadvertently promote the homogenized image of science, overlooking the diverse and context-dependent ways in which science operates. Lederman argued that although philosophers of science, historians of science, sociologists of science, and educators of science have not yet reached a consensus on the nature of science, there exists sufficient consensus for K-12 education (Lederman, N.G. 1992). In recent years, Lederman's definition of NOS has been widely regarded as comprehensive in capturing its essential features, so this study will adopt Lederman's NOS theoretical framework (Abd-El-Khalick et al., 1998; Lederman et al., 2002). Furthermore, among researchers on the representations in textbooks, Abd-El-Khalick et al. (2008) introduced a more systematic framework for analyzing NOS representations based on national reform documents of the time, which will also be employed in this study.

1.3. Approaches of teaching NOS

Science textbooks occupy a pivotal position in science education, serving as both instructional resources and mediators of NOS teaching approaches. As emphasized by Zarei et al. (2023), their influence on teaching and learning is profound and cannot be overstated; similarly, Zhu et al. (2023) highlight that textbooks are indispensable for shaping students' NOS conceptions, functioning as dual foundations for instruction and learning. This dynamic interplay means that textbook content provides the structural foundation for NOS teaching, while instructional approaches in turn shape students' perceptions of NOS.

Science education research has emphasized the necessity of integrating NOS perspectives into teaching (Lederman, 2007; Matthews, 2012), primarily through two contrasting approaches. The implicit approach assumes that learners will absorb NOS concepts incidentally through inquiry-based activities, without explicit focus on NOS as a learning objective (Deniz & Adibelli, 2015). Early practices, such as teaching science history through storytelling or everyday examples (Henke & Höttecke, 2015), illustrate this approach. However, research by Bakanay et al. (2022) reveals a critical limitation: teachers often fail to connect scientific history principles with NOS, struggling to identify NOS-relevant elements in historical materials. Abd-El-Khalick and Lederman (2000) further argue that implicit methods are ineffective for cultivating students' NOS understanding.

In contrast, explicit-reflective instruction has emerged as a more effective strategy. Deniz and Adibelli (2015) demonstrate its efficacy in enhancing teachers' NOS views, while Samuel Cornelius Nyarko et al. (2022) advocate for using explicit-reflective methods when leveraging science history for NOS teaching. Studies by Jean Bosco Bugingo et al. (2024) show that explicit-reflective activity-based instruction (ERABI) significantly improves students' NOS perceptions. Comparative research by Hrisa and Psillos (2022) starkly illustrates this: explicit instruction groups achieved notable cognitive gains, whereas implicit groups either stagnated or regressed. Khishfe (2022) and Witucki et al. (2024) further confirm that explicit approaches - particularly when paired with scientific argumentation or socio-scientific issues (SSI) contexts - yield deeper NOS understanding. Collectively, these findings converge on a consensus: explicit methods outperform implicit ones across grade levels and educational contexts.

The integration of science history into NOS teaching has gained traction as a complementary strategy. Meichtry (1993) notes shifts in scientific belief systems through historical education, while Ampatzidis et al. (2024) emphasize that historical narratives systematically highlight NOS principles. Erduran (2022) views the inclusion of science history and philosophy in curricula as a pivotal step for NOS advocacy. However, Park et al. (2022) acknowledge challenges for novice teachers: preservice educators recognize the enriching potential of science history but often struggle with content-focused teaching limitations. Khishfe (2024) adds that effective NOS teaching requires contextual alignment with students' prior knowledge and daily experiences, a principle reinforced by the historical approach's emphasis on social and cultural scientific contexts.

Empirical evidence supports the synergistic effect of historical narratives and explicit-reflective strategies. For example, Nur and Fitnat (2015) demonstrate that combining historical stories with explicit reflection enhances NOS learning, while Valencia Narbona et al. (2022) show equivalent NOS gains in groups receiving history-based explicit instruction. Khishfe (2023) further confirms that both explicit NOS and argumentation instruction foster overall improvements in NOS concept understanding.

These studies highlight two critical dimensions of explicit NOS instruction: the clarity of NOS content and the coherence of its presentation. Concrete and explicit historical materials are essential for promoting NOS concept development (Brunner & Abd-El-Khalick, 2020), underscoring the importance of analyzing textbook representation approaches and their cross-textbook consistency when evaluating NOS instructional efficacy.

1.4. NOS represented in science textbooks

The representation of NOS in science textbooks has been studied extensively. Firstly, some researchers have discussed the reliability and validity of textbook coding. For example, Chiappetta and Fillman proposed that in most textbook analysis studies, the high consistency of researchers' coding percentage was used to illustrate the rigor of the research coding process. In this way, the practice of demonstrating research credibility ignored the factors of chance and speculation. Therefore, they introduced the kappa index. It was used to calculate the consistency of coders who classify the same unit in the sample to improve the reliability of the article (Chiappetta, E. L., & Fillman, D. A. 2007). In addition, Chiappetta et al. (1991) analyzed the quantity and distribution of the four aspects of NOS in seven American middle school chemistry textbooks. These four aspects are: (a) science as a body of knowledge, (b) science as a way of investigating, (c) science as a way of thinking, and (d) the interaction among science. The results revealed that the representations of these four dimensions in these textbooks were uneven. Similarly, Lump (1996) also analyzed high school biology textbooks using the same framework. The results showed that the textbooks failed to integrate the four strands well, and science content was separated from the nature of science. Phillips et al. (2015) used the same analytical framework to analyse the presentation of NOS in first to fifth grade elementary science textbooks. The research conducted by Yu et al. (2022) revealed that in the editions of five textbooks, on average, 97% of the analytical texts focused on memory and comprehension, while the other four levels accounted for no more than 3% in total. The textbooks overly emphasized the cognitive levels of memory and comprehension, while representing the levels of application, analysis, evaluation and creation least.

Other researchers have explored various approaches to NOS representation. Niaz and Maza proposed that the preamble chapter of the textbook reflected the author's overall perspective on NOS. Therefore, they organized and summarized the 9 standards reached by science education research through literature analysis as the framework for textbook analysis. They also analyzed the preamble chapters of 75 university-level chemistry textbooks in the United States and used "S" to indicate satisfaction, "M" to indicate mention, "N" to indicate no mention, in this way, the presentation of 9 standards in 75 textbooks was summarized, and the release years were classified to summarize the presentation of NOS in American textbooks of different ages (Niaz M, Maza A, Niaz M, et al., 2011). Based on the background of science curriculum reform in Turkey, Aydin and Tortumlu (2015) analyzed the presentation of NOS categories in chemistry textbooks for grades 9-12 in Turkey, the NOS representation approach (explicit, implicit, and historical) , the embedding of the content and the degree of satisfaction with the textbooks' presentation of NOS. They created a multilevel scoring system to assess NOS representations, with 1 point assigned for a reference and 2 points for a satisfactory representation. The results showed that from the 9th to the 12th grade, the number of NOS mentioned in textbooks decreased, and the The most frequently approaches were implicit manner, finally, NOS is expressed in a content-embedded way in the 9th and 10th grades, while in Grade 12, it is presented more in a content-general way. Upahi et al. (2020) also used the NOS analytical framework to explore how NOS is represented in three Nigerian chemistry textbooks. The results revealed that the NOS was mostly represented in an implicit approach. And the different aspects of NOS were unevenly distributed in textbooks. In addition, three aspects of NOS were missing in two-thirds of the textbooks, such as the interdisciplinary nature of science. Wan et al. (2024) adopted the definition of scientific literacy based on the 2018 PISA science framework, which includes four dimensions: (1) scientific competencies, (2) scientific knowledge, (3) task contexts and (4) science attitudes. In particular, the dimension of scientific attitude was not focused on, as it had little relevance to the tasks in textbooks. They encoded 3888 tasks from four editions of the Chinese junior high school physics textbooks. The results showed that tasks related to 'interpret data and evidence scientifically' and especially 'evaluate and design scientific inquiry' were rare, and they did not effectively promote students' understanding of the nature of scientific inquiry.

Among the relevant studies on the representation of NOS in textbooks, Abd-El-Khalick and his team proposed a more systematic analytical framework to explore how NOS was represented, and applied this framework to the analysis of various textbooks (Abd-El-Khalick et al., 2008, 2017). Abd-El-Khalick et al. analyzed the representations of the nature of science in 14 high school chemistry textbooks widely used in the United States over the past 40 years, selected the sections that best reflected the nature of science for analysis, and proposed ten NOS categories based on the contents emphasized in the reform of science education in the United States. Next, each aspect was given a score ranging from -3 to +3, with the assessment based on the way of representation (explicit vs implicit), along with the degree of accuracy, completeness, and consistency. Based on the analysis result that the representation of scientific essence in chemistry textbooks had declined rather than increased, Abd-EI-Khalick et al. argued that the primary reason is that teachers had not provided guidance on NOS in an accurate, consistent and effective way, and teachers faced difficulties in translating their understanding of NOS into teaching practice. Moreover, the lack of guidance in this aspect has resulted in the lack of significant inadequacy in the representation of NOS in American textbooks (Abd-El-Khalick, F., Waters, M. and Le, A.-P. 2008). Then, Abd-El-Khalick and his colleagues (2017) applied the same analytical framework to assess how NOS was represented in 34 textbooks covering a period of more than 30 years. Less than 2.5% of the pages in these textbooks were found to be specifically dedicated to describing NOS. Furthermore, the representation of NOS in these textbooks has been significantly inadequate and has not shown any notable improvement over the past three decades.

The analytical framework developed by Abd-El-Khalick and his colleagues (2008, 2017) has also been employed to analyse how NOS is represented in other countries or regions. Chaisri and Thathon (2014) applied the original framework developed by Abd-El-Khalick and colleagues in 2008. This framework involved eight aspects of NOS, excluding two aspects: the myth of 'The Scientific Method' and social NOS. The researchers utilized this framework to analyze the representation of NOS in Thai middle school biology textbooks under the topic of evolution. Their findings indicated that these eight NOS aspects are hardly ever presented in an explicit manner in the textbooks. Ramnarain and Chanetsa (2016) adopted Abd-El-Khalick et al.'s (2008) original framework, adding an aspect of NOS—'science versus pseudoscience'—to analyze three 9th-grade science textbooks in South Africa. The analysis showed that the textbooks were insufficient in describing the nature of science, particularly in the three aspects of social dimension of science, science versus pseudoscience, and the 'myth of the scientific method'. Zarei et al. (2023) utilized the analytical framework proposed by Abd-El-Khalick et al. to conduct a characterization analysis of the three chemistry textbooks used in Iranian high schools regarding the nature of science (NOS). The results indicated that contents such as the tentative nature of science, the myth of scientific methods, and scientific theories were rarely mentioned, and none of these were covered in all three textbooks. Overall, the textbooks performed poorly in characterizing the nature of science (NOS). Okan et al. (2023) analyzed the presentation of the nature of science in Turkish science textbooks and found that the overall representation of the essence of science was insufficient. Yeh et al. (2023) analyzed the presentation of NOS in three chapters of South African physics textbooks, identified the proposed learning objectives, and assessed the consistency between NOS-related content and these objectives from the perspective of RFN. Atakan et al. (2024) investigated the dimensions of scientific nature in the science textbooks taught from grades 6 to 8 from 1926 to 2018. The research revealed that there was less attention paid to creativity and the theoretical drive of scientific knowledge as well as the social and cultural structure. The textbooks rarely addressed the myths of scientific methods, scientific theories, and laws. Overall, all the courses were generally insufficient.

The framework proposed by Abd-EI-Khalick et al. (2008) was also employed to analyze the representation of NOS in Chinese science textbooks. Wei et al. (2013) examined the representations of NOS in eight histories of science from three versions of science textbooks used in Chinese junior high schools. It was found that the aspects of NOS in the selected histories of science were not well represented. Specifically, the aspects of empirical and inferential were relatively well addressed. Li, X et al. (2020) analyzed the representation of the nature of science (NOS) in five junior high school physics textbooks in China. The studies found that there was no specific textual content dedicated to representing 'scientific laws' and 'scientific theories', and the explicit representation of other aspects of NOS was minimal. Zhuang et al. (2021) evaluated the presentation of NOS in five high school physics textbooks from multiple perspectives, including scope, manner (explicit and implicit), accuracy and completeness (from naïve to informed), and the overall consistency of NOS across different aspects. The results indicated that the presentation of the scientific nature in all five physics textbooks was far from satisfactory. Zhu, Y et al. (2023) analyzed Chinese middle school chemistry textbooks. The results of the analysis of the textbooks indicated that each textbook series had a mixed understanding of NOS, and most of the NOS representations were informed and implicit. Wei et al. (2024) used a self-developed scale based on the analytical framework of Abd-El-Khalick et al. (2008) to divide the nature of science. They analyzed the NOS of textbooks based on content level, presentation position and presentation form. The longitudinal comparison revealed that the correlation of NOS in PEP gradually decreased with increasing grade levels, while that in ESP exhibited an "inverted U" curve. Moreover, differences in the content level, presentation position, and presentation form of NOS were observed across the two versions of textbooks at different grade levels.

1.5. Research questions

The analytical framework proposed by Abd-El-Khalick et al. (2008, 2017) has been widely adopted in international studies to analyze Nature of Science (NOS) representations in science textbooks. However, existing research remains disproportionately focused on high school contexts, with limited cross-national investigations into NOS representations in junior high school science textbooks - particularly in China, Japan, the United States, and South Korea. This study aims to address this gap by examining NOS representations in five editions of junior high school science textbooks from these four countries, guided by two research questions:

RQ1: How are the ten NOS aspects represented in the five selected junior high school science textbooks?

RQ2: How do the distributions of NOS representations vary across different chapters and content domains within each textbook?

2. Methodology

2.1. Materials

This study undertakes a cross-national analysis of five junior high school science textbooks from China, South Korea, Japan, and the United States (designated Textbooks A–E), including five nationally approved curricular materials. Among them, textbooks D and E are both from the United States. In addition, Textbooks A are published by Zhejiang Education Press, while textbook D is translated from the Scientific Explorer series published by Zhejiang Education Press. Textbooks B are published by Korea Mirae (N) Press. Textbooks C are from the designated science textbooks by Japan's Ministry of Education, Culture, Sports, Science and Technology, which are published by Tokyo Shoseki. Textbook E, named *Physical Science*, is published by Glencoe, which is a subsidiary of McGraw-Hill. These five editions of textbooks all represent mainstream curricular resources.

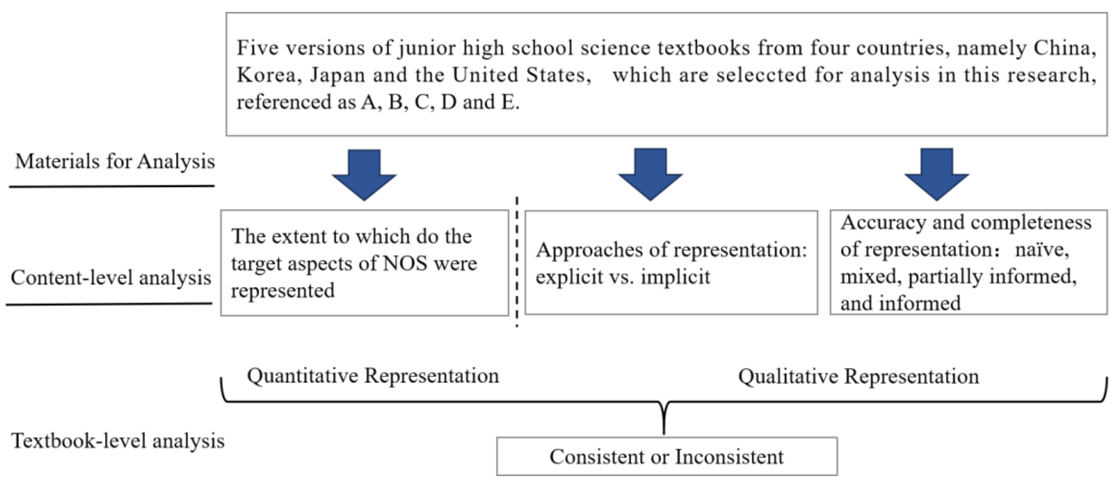
The Force and Motion theme was chosen for its fundamental importance for science education, as it provides a robust context to examine Nature of Science (NOS) representations. Twelve content topics were systematically extracted, covering core concepts such as description of motion, nature of force, Newton's Laws and others. Cross-textbook validation confirmed that these topics are widely covered across all five textbooks, despite variations in curricular sequencing. Missing content was systematically coded as 0 to quantify representational gaps (Fig. 3).

The analysis entailed a comprehensive inspection and comparison of textbook components: preface, textbook text, graphs, tables, historical narratives, experimental activities, and student tasks.

2.2 Analytical framework

The selected material was analyzed at both the content level and the textbook level. Specifically, at the content level, the target aspects of NOS, along with the approaches to representation, accuracy, and completeness, were analyzed individually. Then, the textbook-level analysis, which is based on the initial results from the content-level analysis, will reflect the extent to which the textbook consistently represents the specific aspects of NOS. Finally, Fig. 1 summarizes the analysis framework, which will be described in detail in the next section.

Figure 1. The analysis framework of NOS representation



2.3 Ten aspects of NOS

The ten-aspect framework of NOS proposed by Abd-El-Khalick et al. (2008, 2017) was adopted in this study, as detailed in Table 1. The analysis was based on textbook content level and textbook level. Secondly, the ten aspects of NOS were interrelated yet independent of each other. In the process of material analysis, the NOS aspects reflected in the material were marked, and sometimes a material would reflect two NOS aspects simultaneously. The aspects of NOS stated in Table 1, provided a framework to analyze the textbooks with respect to the extent to which aspects of NOS are represented in the textbooks.

Table 1. Explication of the NOS aspects developed by Abd-El-Khalick et al. (2008)

NOS aspect	Dimensions emphasized in textbook analysis
Empirical	Scientific claims are derived from, and/or consistent with, observations of natural phenomena
Inferential	There is a crucial distinction between observations and inferences. Observations are descriptive statements about natural phenomena that are accessible to the senses (or extensions of the senses) and about which observers can reach consensus with relative ease (e.g. objects released above ground level tend to fall to the ground). Inferences, on the other hand, are statements about phenomena that are not directly accessible to the senses (e.g. objects tend to fall to the ground because of ’gravity’).
Creative	Science is not an entirely rational or systematic activity. Generating scientific knowledge involves human creativity in the sense of scientists inventing explanations and theoretical entities. The creative NOS, coupled with its inferential nature, entails that scientific entities (atoms, force fields, species, etc.) are functional theoretical models rather than faithful copies of ’reality’.
Theory-driven	Scientists’ theoretical and disciplinary commitments, beliefs, prior knowledge, training and expectations influence their work. These background factors affect scientists’ choice of problems to investigate and methods of investigations, observations (both in terms of what is and is not observed) and interpretation of these observations.
Tentative	Scientific knowledge is reliable and durable, but never absolute or certain. All categories of knowledge (’facts,’ theories, laws, etc.) are subject to change.
Myth of the scientific method	Scientific claims change as new evidence, made possible through conceptual and technological advances, is brought to bear; as extant evidence is reinterpreted in light of new or revised theoretical ideas; or due to changes in the cultural and social spheres or shifts in the directions of established research programs.
Scientific theories	Scientific theories are well-established, highly substantiated, internally consistent systems of descriptions, which (a) account for large sets of seemingly unrelated observations in several fields of research, (b) generate research problems and questions and (c) guide future researches. Theories are often based on suppositions or axioms and posit the existence of non-observable entities. Thus, direct examination is untenable. Only indirect evidence supports the theories: scientists extract specific testable predictions from theories and study them against observations.
Scientific laws	Laws are the description of relationships among observable phenomena. Theories, by contrast, provide explanations for observable phenomena or regularities in those phenomena. Theories and laws are not hierarchically related (the naïve view that theories become laws when sufficient supporting evidence is obtained, or that laws have a higher status than theories). Laws and Theories are different types of knowledge and one does not become the other.

NOS aspect	Dimensions emphasized in textbook analysis
Social dimension of science	Scientific knowledge is socially negotiated. This should not be confused with relativistic concepts of science. This dimension specifically refers to the constitutive values related with established venues for connection and criticism within the scientific enterprise, which serve to increase the objectivity of collectively scrutinized scientific knowledge through decreasing the impact of individual scientists' idiosyncrasies and subjectivities.
Social and cultural embeddedness of science	Science is a human enterprise that is embedded and practiced in the context of a larger cultural environment. So, science affects and is affected by different cultural elements and domains, including social context, philosophy, religion, worldview, power structures, political and economic factors.

2.4 NOS representation approach

The implicit approach to instruction allows students to infer the features of scientific knowledge and practice by engaging in the scientific process without explicit instruction. In contrast, explicit teaching approaches address NOS concepts directly through structured discussion, reflective prompts, and explicit instruction and features. Abd-El-Khalick et al. (2008, 2017) argued that two NOS representations should be explored when analyzing NOS representations in science textbooks. Detailed descriptions and examples of these two methods are listed in Table 2.

Table 2. The difference between explicit and implicit approaches for NOS representations (Table was adapted from Abd-El-Khalick et al., 2008)

Approach	Description	Example
Explicit	Provide a sufficiently clear discussion or reflective opportunity to help students form the meta-understanding of the characteristics, development, and validation of scientific knowledge	"A large number of experiments have shown that when one object slides over the surface of another, the magnitude of the frictional force is related to the pressure exerted on the surface of the object and also to the roughness of the contact surface." ("NOS.1 Empirical", Textbook A)
Implicit	Contain the NOS in the text material, which requires self-directed or teacher-guided reflections to comprehend the NOS aspect.	"At one time, people thought that forces caused motion. In other words, a object would move only if there were unbalanced forces acting on it.......According to the first law of motion, instead of causing motion, unbalanced forces cause changes in motion." ("NOS.5 Tentative", Textbook E)

2.5. The degree of accuracy and completeness NOS representation

Among the ten aspects of NOS, the accuracy and completeness of NOS expressed in different textbooks vary. A scoring rubric was developed for evaluating the representations of NOS at the textbook-level. This study follows the framework of Abd-El-Khalick et al.'s (2008, 2017), using a four-level scoring method for assessment. The accuracy and completeness of the representation were categorized into four levels: naïve, mixed, partially informed and informed (see Table 3).

Table 3. The extent of accuracy and completeness of NOS representations (Table was adapted from Abd-El-Khalick et al., 2008)

Level	Description
Informed	Statements targeted the same or directly related NOS aspects that convey an accurate and complete representation.
Partially Informed	Statements targeted the same or directly related NOS aspects that convey an accurate, but incomplete representation.
Mixed	Statements targeted the same or directly related NOS aspects convey an informed and naïve representation in different and/or same parts of textbooks.
Naïve	Statements targeted the same or directly related NOS aspects that convey a naïve representation of target NOS aspect.

2.6. Scoring rubric for evaluating the representations of NOS at textbook-level

Following the framework proposed by Abd-El-Khalick et al. (2008, 2017) at the textbook level, the scoring standard has been modified based on the basis of the original framework. The modification is necessary because the situation differs in junior high school science textbooks in the actual scoring process. For example, the NOS aspect in some materials is recessive and incomplete, so the score of -1 is adjusted. In this study, the analysis was carried out for each aspect of NOS separately. The materials representing the same aspect of NOS were first sorted together. Then, according to a comparison of these materials, a score ranging from -3 to +3 was given. In this scoring system, a score of +3 indicates that the corresponding NOS aspect in the selected material is explicitly, well-informed and consistent. A score of +2 is awarded when the aspect of NOS is explicitly mentioned but only partially informed. A score of +1 is given if the NOS aspect is implicit but well-informed and consistent. A score of 0 means that it is unclear whether the NOS aspect is expressed explicitly or implicitly. -1 points are assigned when the NOS aspect is implicit, partially informed, but consistent. -2 points are given for mixed expressions of explicit or implicit NOS aspects. Finally, -3 points indicate that the NOS aspect is explicitly stated but naive. The adjustment is more in line with the conduct of this study (see Table 4).

Table 4. Scoring rubric for NOS representations modified from Abd-El-Khalick et al. (2008, 2017)

Score	Representations of NOS	Criteria
+3	Explicit, informed, and consistent	• Explicit statements that convey an informed representation, • Consistency across selected textbook materials in addressing target NOS aspect, and • Consistency in addressing other directly related NOS aspects.
+2	Explicit, partially informed	• Explicit statements that convey an informed, but incomplete representation, and • Consistency across selected textbook materials in addressing target NOS aspect.
+1	Implicit, informed, and consistent	• An informed representation of target NOS aspect could be inferred from textbook materials, and • Absence of other explicit or implicit messages that are inconsistent with the inferred implicit representation.
0	Aspect not addressed	• No explicit or implicit treatment of target NOS aspect, or • Not enough materials to make an informed judgment or convey a sense about target NOS aspect.
-1	Implicit,Partially informed,and consistent	• Implicit statements that could be inferred an informed, but incomplete representation, and • Consistency representation of target NOS aspect could be inferred from textbook materials.
-2	Mixed explicit and/or implicit	• Implicit, informed representations that could be inferred from some textbook materials are countered by explicit, naïve statements in other parts, or • Explicit statements that convey conflicting messages about the same or directly related NOS aspects.
-3	Explicit, naïve	• Explicit statements that clearly communicate a naïve representation of target NOS aspect

2.7. Analysis procedure

To establish inter-rater reliability, two researchers conducted data analysis independently. The other researchers contributed to discussions regarding analytical frameworks and scoring models. All researchers were familiar with the concept of NOS.

The actual process consisted of four steps. First, two researchers encoded the ten NOS aspects involved in each textbook. After reaching a consensus on the inconsistent coding, the researchers performed further analysis on the remaining two dimensions represented by NOS: the approaches to representation in the textual materials (i.e. explicit vs implicit) and the accuracy and completeness of the NOS representation (i.e. informed, partially informed, mixed, or naive). After that, the consistency of each aspect of NOS in each textbook was checked and scored. Finally, the number of NOS in each textbook involving 12 content topics was counted.

In order to familiarize themselves with the analytical framework, two of the researchers conducted a trial study using force and motion materials from the Chinese Zhejiang Education Edition textbooks. In the trial study, the two researchers read textbooks independently and labeled passages that dealt with force and motion. Then, the selected materials were gathered together to encode the ten aspects of NOS involved in the materials (NOS1-NOS10). Later, the analysis was carried out for each aspect of NOS separately. The two researchers first sorted the materials representing the same aspect of NOS together. Then, based on a comprehensive comparison of these materials, a score ranging from −3 to +3 was assigned for the concerned aspect. Finally, the total score of the national textbooks was calculated by summing all the scores allocated for the ten NOS aspects, which resulted in a score ranging from −30 to +30. For example, in Table 5, regarding the myth of 'the scientific method' (NOS6), textbook D reached a score of 3, indicating that the overall representation of the myth of scientific method in the selected materials of textbook D was explicit, informed, and consistent. On the other hand, textbooks A reached a score of 1, suggesting that the representation of this aspect in its materials was implicit, informed, and consistent. Textbook E had a description of "Implicit, partially informed, and consistent", and textbooks B had a description of "Mixed explicit and/or implicit". The same scoring process was applied to other aspects of NOS. The coding differences between the two researchers were reflectively discussed and recorded. For the ten aspects of NOS, the overall agreement was 70.3% (Cohen's Kappa = 0.647), which is highly consistent (McHugh, 2012). Subsequently, the two researchers revisited again and reached a consensus on the ten aspects of NOS in the selected material. The remaining four national textbooks were then analyzed. The final overall agreement for the ten aspects of NOS was 80.9% (Cohen' Kappa = 0.771).

Next, the two researchers read the selected materials again and coded the materials from two aspects: one on approach and the other on accuracy and completeness. For these two aspects, the two researchers analyzed the materials independently, then discussed and coded the differences reflectively. After revision, the two researchers analyzed the materials from the five textbooks. The overall inter-rater reliability was 94% (Cohen' Kappa = 0.91) for the approach of the materials and 92% (Cohen's Kappa = 0.88) for the accuracy and completeness of the materials, which is highly consistent.

Finally, the two researchers rated the consistency of NOS in each aspect of the five national textbooks, and the scoring differences were resolved through discussion. For the grading of the materials, the overall agreement was 90% (Cohen' Kappa = 0.868), which was also extremely consistent.

3. Results

The results of NOS representations in these five junior high school science textbooks are summarized in Fig. 2 and 3 and in Table 5. Table 5 presents the individual and total scores for each aspect of NOS in the national textbooks. Fig. 2 shows the relative proportions of different NOS aspects in the national textbooks. Fig. 3 illustrates the distribution of NOS across the textbooks for each selected content section.

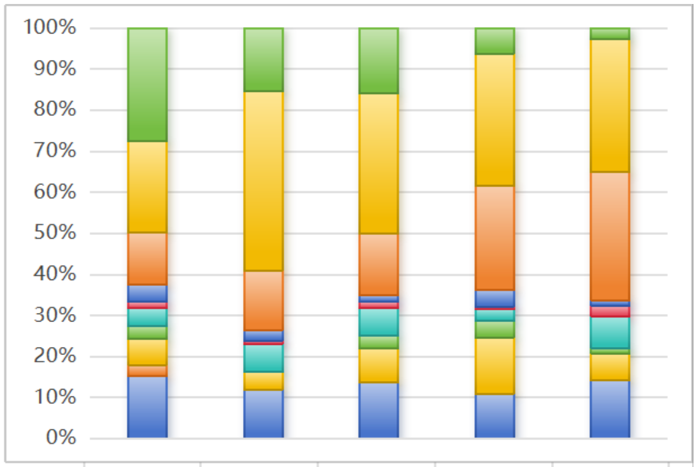
Table 5 provides the consistency of each aspect of NOS in each textbook and the comprehensive scores for each aspect of NOS in the textbooks from each country. In textbooks A, a score of 2 received the highest number, with four, followed by a score of -1. In textbooks B, two aspects including 'scientific theories' and 'social dimensions of science' were assigned a score of 0, indicating that the two aspects in textbooks B were not reflected. In addition, half of the NOS aspects were rated with a score of -1. In textbooks C, except for the aspect of social dimensions of science, the proportions of each score under different aspects of NOS were similar. In textbooks D, the proportions of the score of -1, 2, 3 and 0 were in descending order. In textbooks E, six out of ten aspects reached a score of -1, including the aspects of empirical, theory-laden, tentative, myth of 'the scientific method', scientific theories and scientific laws. A partially informed representation of NOS aspects could be inferred from the selected materials in textbooks E. In textbooks B, C, D and E, the aspect of social dimensions of science were rated a score of 0, which indicated a lack of reflection of the social dimension of science in the selected materials.

Fig. 2 shows the difference in the number of NOS aspects across the five editions of the textbooks. In textbooks A, the aspects of empirical, inferential, social and cultural embeddedness of science and creativity accounted for a large proportion in descending order, and all ten aspects of NOS were reflected. Textbooks B and C were very similar in proportion, both of which had the largest quantity of NOS2, followed by the aspects of empirical, creative and social and cultural embeddedness of science. The difference was that the quantity of textbooks B on the aspect of scientific theories was 0. Textbooks D and E in the United States both had the most quantity on the aspects of inferential and creative. Except for the aspect of social dimensions of science, textbooks D had the least quantity on the aspects of the tentative and myth of 'the scientific method', and textbooks E was the least quantity on the aspects of theory-laden and scientific theories. From a horizontal perspective, the five versions of textbooks had the highest proportion in the aspects of inferential and creative, while the quantities of the aspects of theory-laden and tentative were relatively smaller. Regarding the aspect of social dimensions of science, except for textbooks A, the number of textbooks from the other four countries was 0, which also indicated the lack of the reflection of the social dimensions of science in the selected materials. Furthermore, the social-cultural embeddedness was best reflected in textbooks A, while textbooks D had the largest number of NOS8, with a total of 20.

The diagram in Fig. 3 provides visual distribution of the NOS between each content section selected across five versions of textbooks. It can be seen from the diagram that the quantities of Content 1 and Content 7 were relatively small, while Content 9, 10 and 11 were relatively larger. Textbooks A had the largest number of representations in Content 10. In addition, textbook B did not have content 7, content 8, and content 9, while textbook E did not have content 10 and content 11.

3.1. The quantity and distribution of NOS representation among the five national textbooks

As shown in Fig. 2, the total number of NOS representations varies in different national textbooks. Textbooks in national A contain the largest number of NOS representations, more than twice as many as textbook E (189 vs 77). Only textbooks A represent the ten aspects of NOS, while the remaining four textbooks are missing the aspect of social dimensions of science (NOS9). Additionally, textbooks B are also missing the aspect of scientific theories (NOS7). That is to say, Textbooks B have the most significant deficiencies, including the nature of scientific theories and Social dimensions of science. Although the number of NOS in different aspects of the textbooks varies, the number of aspects of empirical and inferential in textbooks A, B, and C is the largest, while the proportion of the aspects of inferential and creative in the remaining two textbooks (D and E) is the largest. Apart from the aspects of empirical, inferential and creative, each textbook's representation of social and cultural embeddedness of science is slightly more pronounced than the other aspects, while the remaining aspects vary but are generally underrepresented.



	A	B	C	D	E
Total	189	117	132	146	77
NOS1 Empirical	52	18	21	9	2
NOS2 Inferential	42	51	45	47	25
NOS3 Creative	24	17	20	37	24
NOS4 Theory-laden	8	3	2	6	1
NOS5 Tentative	3	1	2	1	2
NOS6 Myth of The Scientific Method’	8	8	9	4	6
NOS7 Scientific Theories	6	0	4	6	1
NOS8 Scientific laws	12	5	11	20	5
NOS9 Social dimensions of sc ience	5	0	0	0	0
NOS10 Social and cultural e mbedness of science	29	14	18	16	11

Figure 2. The graph shows the relative proportions of NOS representations of the ten aspects in the five national textbooks

To further explore the distribution of NOS in the textbooks, the number of NOS representations in the 12 selected content domains was recorded and plotted in Fig. 3. As shown in fig. 3, the number of NOS in the five national textbooks was relatively higher in energy and its forms (content 10), work and power (content 11), and energy conversion and conservation (content 12), but textbooks E lacked these contents. In terms of composition and decomposition of forces (Content 7), the number of NOS in five national textbooks was the least, with textbook B having a score of 0. Additionally, textbooks B had no representations for composition and decomposition of forces (content 7), Newton’s first law (content 8), and pressure (content 9). In the remaining content domains, the representations of NOS were similar and underwhelming.

3.2. The quality of NOS representations among the five national textbooks

The scores for each NOS aspect of five national textbooks are listed in Table 5. The total scores for different textbooks range from 11 to -3 on a possible scale of -30 to +30. Among them, textbook C achieved the highest score of 11, while textbook B scored the lowest score of 3. Except for textbooks C, the other four countries have a high percentage of -1 in their textbooks, which represents implicit representation at the partially informed level. For example, in textbook E, six out of ten aspects achieved a score of -1, including the aspect of empirical, theory-laden, tentative, myth of the scientific method, scientific theories and scientific laws. These results suggest that partially informed inferences were made. In the textbooks of these five countries, none of the aspects in the textbooks A and B achieved a score of 3, indicating that none of the aspects in the two national textbooks were represented explicitly and at the level of being well-informed and consistent across different content areas.

Table 5. Scores on different aspects of NOS representation

Aspect of NOS	NOS Scores of Textbook				
	A	B	C	D	E
NOS1 Empirical	2	-1	-1	-1	-1
NOS2 Inferential	1	-1	1	2	1
NOS3 Creative	2	2	2	3	3
NOS4 Theory-laden	2	2	3	2	-1
NOS5 Tentative	-1	-1	3	-1	-1
NOS6 Myth of 'The Scientific Method'	1	-2	1	3	-1
NOS7 Scientific Theories	-1	0	-1	-1	-1
NOS8 Scientific laws	1	-1	1	-1	-1
NOS9 Social dimensions of science	-1	0	0	0	0
NOS10 Social and cultural embeddedness of science	2	-1	2	2	3
Total	8	-3	11	8	1

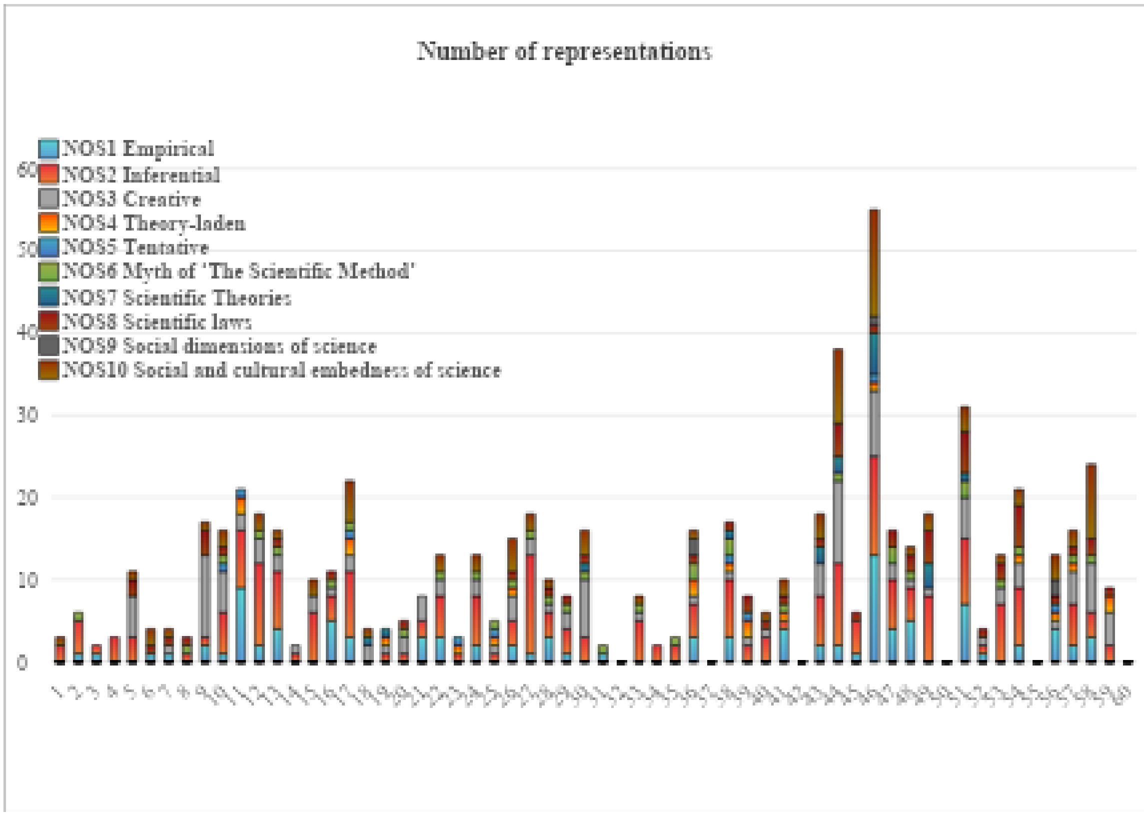


Figure 3. The distribution of Nature of Science (NOS) representations was analyzed across five junior high school science textbooks published by five distinct publishers from four different countries (labeled as A, B, C, D, E). content 1: Description of Motion; content 2: Velocity and acceleration; content 3: Nature of force; content 4: Gravity; content 5: Friction; content6: Buoyancy; content 7: Composition and decomposition of forces; content 8: Newton's first law; content 9: Pressure; content 10: Energy and its forms; content 11: Work and power; content 12: Energy conversion and conservation

However, among the textbooks from the other three countries, there are aspects reaching a score of 3. Among them, textbooks C, D and E all have two aspects reaching a score of 3, which are reflected in aspects such as scientific theories, tentative, creative, the myth of 'The Scientific Method' and social and cultural embeddedness of science. For example, the following excerpt from textbook E demonstrates how the aspect of 'social and cultural embeddedness of science' was represented:

In October 1947, Chuck Yeager - at Muroc Army Air Field (now Edwards Air Force Base, California) - is first to fly plane faster than speed of sound. In August 2005, Commander Eileen Collins and pilot James Kelly guide Space Shuttle Discovery in its 27,357.58 km/h glide from space to landing strip at Edwards Air Force Base.

The excerpt from textbook E explicitly positions science as a human endeavor intrinsically situated within cultural contexts. By presenting scientifically accurate statements that acknowledge the sociocultural dimensions of scientific practice, the text demonstrates a coherent understanding of science's social and cultural embeddedness. As a result, textbook E received the highest rating score of 3 ("Explicit, informed, and consistent") for its representation of this Nature of Science (NOS) aspect.

Furthermore, most of the 10 aspects received a score of -1 (Implicit, partially informed, and consistent) in the five national textbooks. At least two aspects achieved a score of -1 in each country's textbooks. For instance, in the aspect of ‘empirical’, four countries’ textbooks achieved a score of -1, and all of them had implicit expressions. For example, the following excerpt from textbooks B regarding the ’empirical’ aspect reads as follows:

Just like rain, snow, waterfalls, and firecrackers launched into the sky, any object on Earth will fall towards the Earth’s center. This is because gravity points towards the center of the Earth and this direction is perpendicular to the horizontal plane.

Although the examples of the NOS aspect of ‘empirical’are taken from students’ daily life, its expression was considered implicit and requires teacher guidance for students to understand the NOS aspect of ‘empirical’. Other statements about the ’empirical’ aspect in textbooks B were expressed in a similar way, so textbook B was given a score of -1 for the representation of the NOS aspect of ‘empirical’.

In contrast, the NOS aspect of ‘empirical’ in textbooks A was regarded as an explicit expression. For instance, a quotation from textbooks A regarding ‘empirical’ is as follows:

A large number of experiments have shown that when the area of the force-bearing surface is the same, the greater the pressure, the more obvious the effect of the pressure; when the pressure is the same, the smaller the area of the force-bearing surface, the more obvious the effect of the pressure.

In the excerpt from the above textbooks A, one can observe that the textbooks makes an explicit statement such as “A large number of experiments have shown”, clearly describing that scientific knowledge is based on or derived from observations of the natural world and was based on verification. However, because the other statements regarding ‘empirical’ aspect were not sufficiently informed, the textbooks A received a score of 2 for the representation of ‘empirical’ aspects.

4. Discussion and Conclusion

This study conducted a comparative analysis of Nature of Science (NOS) representations across 12 force-and-motion content domains in five secondary science textbooks from China, Japan, South Korea, and the United States. The results reveal three critical patterns: First, the majority of NOS representations in these textbooks are insufficient. There are significant differences in the quantity of NOS among the five national textbooks. Only textbooks A represented all ten aspects of NOS, while the other four national textbooks did not address the aspect of social dimensions of science. Among these, textbooks B did not express either the aspect of social dimensions of science or the aspect of scientific theories. However, in several aspects such as Theory-laden, Tentative, Creative, Myth of ‘The Scientific Method’, and Social and cultural embeddedness of science, the representations in textbooks C, D and E were accurate and informed, receiving a score of 3. Overall, the majority of NOS representations in the textbooks from the five countries were implicit and partially informed. The five national textbooks had implicit and incomplete representations or no representations at all for the aspect of scientific theories.

Although the nature of science (NOS) is argued to be a fundamental element in science curriculum and teaching, empirical studies continue to report that the representation of NOS in science textbooks is inadequate, especially in physics textbooks worldwide (Han et al., 2024). In the textbooks of these five countries, textbooks A has the largest number of NOS representations, but there are cases of uneven distribution across each content domain. Some contents are not covered in the textbooks, such as the lack of content 10, content11, and content 12 in textbooks E, which prevents the NOS from being reflected. Therefore, although many curriculum standards documents included the concept of the Nature of Science (NOS) as early as the 1980s, and it was emphasized in the curriculum standards of various countries, there remains considerable room in the curriculum to clarify and enrich the content related to NOS (Caramaschi et al., 2021).

The study has shown that the representation of NOS is unevenly distributed in the textbooks from the five countries. Given the selection of 12 content domains related to force and motion, NOS is most prominently represented in the areas of energy and its forms, work and power, and energy conversion and conservation. Other content areas are less likely to represent NOS.

It is also evident that not all topics are equally suitable for representing NOS. For example, in the section on the composition and decomposition of forces, the number of NOS representations in the textbooks from the five countries was the least. Additionally, relevant content is lacking in some textbooks, such as textbooks B and E. To gain an in-depth understanding of NOS, it also requires long-term exposure to scientific practice methods. Therefore, the lack of specific NOS teaching resources in the textbooks may lead to insufficient attention from science teachers in the actual teaching process, resulting in a less satisfactory level of students' mastery of NOS.

4.1. Limitations

Due to the limited scope of this study, two limitations need to be considered when interpreting the results. First of all, this study only analyzed 12 contents of force and movement in selected junior high school textbooks, so the analysis results can not be generalized to other content areas in these textbooks. Second, this study focuses solely on textbook content, which does not represent how junior high school teachers present NOS when using textbooks. The teaching methods employed by teachers in actual teaching will affect students' understanding of NOS.

4.2. Implications

Based on this research, it is evident that there is still much room for improvement in the representation of NOS in junior high school science textbooks across various countries. First, textbooks should be revised to align with the educational goals established by the curriculum standards of each country. Second, the developers of these textbooks, including authors and publishers, should have a deep understanding of NOS and ensure that it is represented comprehensively and accurately. It is clear that textbook authors have a significant influence on the representation of NOS. The content covered in the textbooks should be more comprehensive,with no critical areas omitted. Furthermore, not all topics are suitable for representing NOS (e.g. the synthesis and decomposition of forces). Third, the representation of NOS should be evenly distributed across different subject areas, rather than being concentrated in only a few sections. Fourth, pre-service teachers generally hold a naive understanding of the nature of science, and their ability to reflect on NOS in social science reasoning is limited (Şen et al., 2025). They should work to enhance their understanding of the nature of science. Studies have shown that the analysis of textbooks can serve as a professional development tool for teachers, enhancing the understanding of the nature of science among in-service science teachers (Chanetsa et al., 2025).

Finally, since it is challenging for students to form a sufficient understanding of NOS through their own comprehension, the teaching methods for NOS should primarily rely on explicit teaching methods. As previously mentioned, teachers can adopt explicit and reflective activity-based instruction (ERABI) to promote students' understanding of the nature of science. They can also incorporate the teaching of scientific history into the curriculum to help students understand how scientific knowledge has evolved over time.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References:

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers’ conceptions of nature of science: a critical review of the literature. International Journal of Science Education, 22(7), 665–701. https://doi.org/10.1080/09500690050044044

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. https://doi.org/10.1002/(SICI)1098-237X(199807)82:4<417::AID-SCE1>3.0.CO;2-E

Abd-El-Khalick, F., Myers, J. Y., Summers, R., Brunner, J., Waight, N., Wahbeh, N., Zeineddin, A. A., & Belarmino, J. (2017). A longitudinal analysis of the extent and manner of representations of nature of science in U.S. high school biology and physics textbooks. Journal of Research in Science Teaching, 54: 82–120. https://doi.org/10.1002/tea.21339

Abd-El-Khalick, F., Waters, M. and Le, A.-P. (2008), Representations of nature of science in high school chemistry textbooks over the past four decades. Journal of Research in Science Teaching, 45: 835-855. https://doi.org/10.1002/tea.20226

American Association for the Advancement of Science (AAAS). (1993). Benchmarks for science literacy: Project 2061. Oxford University Press.

Ampatzidis, G., & Ergazaki, M. (2024). Using the History of the Super-Organismic-Plant-Community Concept To help students understand the nature of science. Science & Education 33, 1097–1116. https://doi.org/10.1007/s11191-023-00433-8

Atakan, M., & Akçay, B. (2024). Representation of changes about nature of science in Turkish middle school science textbooks. Science & Education, 33, 551–580. https://doi.org/10.1007/s11191-022-00403-6

Aydin, S., & Tortumlu, S. (2015). The analysis of the changes in integration of nature of science into Turkish high school chemistry textbooks: Is there any development? Chemistry Education Research and Practice, 16(4), 786–796. https://doi.org/10.1039/c5rp00073d

Bakanay, Ç. D., & Çakır, M. (2022). In-service science teachers’ purposes for integrating the history of science: the role of their science teaching orientation. International Journal of Science Education, 44(6), 939–961. https://doi.org/10.1080/09500693.2022.2059120

Brunner JL, Abd-El-Khalick F. (2020). Improving nature of science instruction in elementary classes with modified science trade books and educative curriculum materials. Journal of Research in Science Teaching, 57: 154–183. https://doi.org/10.1002/tea.21588

Caramaschi, M., Cullinane, A., Levrini, O., & Erduran, S. (2021). Mapping the nature of science in the Italian physics curriculum: from missing links to opportunities for reform. International Journal of Science Education, 44(1), 115–135. https://doi.org/10.1080/09500693.2021.2017061

Chaiklin, S. (2022). Science education policy introduction. In M. M. Atwater (Ed.), International handbook of research on multicultural science education. Springer. https://doi.org/10.1007/978-3-030-37743-4_67-1

Chaisri, A., & Thathong, K. (2014). The nature of science represented in Thai biology textbooks under the topic of evolution. Procedia-Social and Behavioral Sciences, 116, 621–626. https://doi.org/10.1016/j.sbspro.2014.01.268

Chanetsa, T., & Ramnarain, U. (2025). The effect of textbook analysis as a teacher professional development tool on teacher understanding of nature of science. Science & Education, 34, 73–93. https://doi.org/10.1007/s11191-023-00442-7

Chiappetta, E. L., & Fillman, D. A. (2007). Analysis of Five High School Biology Textbooks Used in the United States for Inclusion of the Nature of Science. International Journal of Science Education, 29(15), 1847–1868. https://doi.org/10.1080/09500690601159407

Chiappetta, E.L., Fillman, D.A. and Sethna, G.H. (1991), A method to quantify major themes of scientific literacy in science textbooks. Journal of Research in Science Teaching, 28: 713-725. https://doi.org/10.1002/tea.3660280808

Chiappetta, E. L., Sethna, G. H., & Fillman, D. A. (1993). Do middle school life science textbooks provide a balance of scientific literacy themes? Journal of Research in Science Teaching, 30: 787–797. https://doi.org/10.1002/tea.3660300714

Dagher, Z. R., & Erduran, S. (2016). Reconceptualizing the nature of science for science education: Why does it matter? Science & Education, 25, 147–164. https://doi.org/10.1007/s11191-015-9800-8

Deniz, H., & Adibelli, E. (2015). Exploring How Second Grade Elementary Teachers Translate Their Nature of Science Views into Classroom Practice After a Graduate Level Nature of Science Course. Research in Science Education 45, 867–888. https://doi.org/10.1007/s11165-014-9447-5

Dogan, N., & Abd-El-Khalick, F. (2008). Turkish grade 10 students' and science teachers' conceptions of nature of science: A national study. Journal of Research in Science Teaching, 45(10), 1083–1112. https://doi.org/10.1002/tea.20243

Erduran, S. (2022). Too philosophical, therefore useless for science education? Science &Education, 31, 563–567. https://doi.org/10.1007/s11191-022-00340-4

Han, Z., & Wei, B. (2024). When nature of science meets quantum physics: Insights from NOS representation in Chinese physics textbooks. Science & Education. https://doi.org/10.1007/s11191-024-00550-y

Henke, A., & Höttecke, D. (2015). Physics Teachers' Challenges in Using History and Philosophy of Science in Teaching. Science Education 24, 349–385. https://doi.org/10.1007/s11191-014-9737-3

Hrisa, K., & Psillos, D. (2022). Investigating the effectiveness of explicit and implicit inquiry-oriented instruction on primary students' views about the non-linear nature of inquiry. International Journal of Science Education, 44(4), 604–626. https://doi.org/10.1080/09500693.2022.2050486

Jean Bosco Bugingo, Lakhan Lal Yadav & K. K. Mashood. (2024). Effect of explicit and reflective activity-based instruction on senior secondary physics students' views towards Nature of Science, International Journal of Science Education, DOI:10.1080/09500693.2024.2346621

Kampourakis, K., & McComas, W. F. (2010). Charles darwin and evolution: Illustrating human aspects of science. Science & Education, 19(6-8), 637–654. https://doi.org/10.1007/s11191-009-9201-y

Khishfe, R. (2022). Nature of Science and Argumentation Instruction in socioscientific and scientific contexts. International Journal of Science Education, 44(4), 647–673. https://doi.org/10.1080/09500693.2022.2050488

Khishfe, R. (2023). Connected learning: An approach for teaching nature of science aspects and argumentation components. Journal of Research in Science Teaching, 60(10), 2180–2215. https://doi.org/10.1002/tea.21855

Khishfe, R. (2024). Nature of science conceptions and argumentation skills in different socioscientific contexts. International Journal of Science Education, 1–26. https://doi.org/10.1080/09500693.2024.2368690

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. https://doi.org/10.1002/tea.3660290404

Lederman, N. G. (2007). Nature of science: past, present, and future. In S. K. Abell & N. G. Lederman (Eds.), Handbook of research on science education (pp. 831–879). Mahwah: Lawrence Erlbaum Associates. https://doi.org/10.4324/9780203824696-35

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: 497–521. https://doi.org/10.1002/tea.10034

Li, X., Tan, Z., Shen, J., et al. (2020). Analysis of five junior high school physics textbooks used in China for representations of nature of science. Research in Science Education, 50, 833–844. https://doi.org/10.1007/s11165-018-9713-z

Lumpe, A. T., & Beck, J. (1996). A profile of high school biology textbooks using scientific literacy recommendations. The American Biology Teacher,58(3),147–153. https://doi.org/10.2307/4450103

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). Springer. https://doi.org/10.1007/978-94-007-2457-0_1

McComas, W. F., & Olson, J. K. (1998). The nature of science in international science education standards documents. In W. F. McComas (Ed.), The nature of science in science education: Rationales and strategies (pp. 41–52). Springer. https://doi.org/10.1007/0-306-47215-5_2

McHugh, M. L. (2012). Interrater reliability: The kappa statistic. Biochemia Medica, 22(3), 276–282.PMID: 23092060; PMCID: PMC3900052. DOI: 10.11613/BM.2012.031

Meichtry, Y.J. (1993), The impact of science curricula on student views about the nature of science. Journal of Research in Science Teaching,30: 429-443. https://doi.org/10.1002/tea.3660300503

Ministry of Education, Culture, Sports, Science and Technology Japan. (2017). Junior high school curriculum guidelines. Retrieved March 8, 2025, from https://www.mext.go.jp/component/a_menu/education/micro_detail/__icsFiles/afieldfile/2019/03/18/1387018_010.pdf

Ministry of Education, P. R. China. (2022). Science curriculum standards for compulsory education [义务教育科学课程标准]. Beijing Normal University Press.

Ministry of Education, Republic of Korea. (2022). General and substantive discussion on primary and secondary school education curriculum [Ministry of Education Announcement No. 2022-33].

Curriculum. Retrieved March 8, 2025, from https://www.moe.go.kr/boardCnts/viewRenew.do?boardID=141&lev=0&statusYN=W&s=moe&m=0404&opType=N&boardSeq=93458

NGSS Lead State. (2013). Next generation science standards: For state, by state. National Academies Press. https://doi.org/10.17226/18290

Niaz, M., & Maza, A. (2011). Nature of Science in General Chemistry Textbooks. In SpringerBriefs in Education (pp. 1–37). Springer Netherlands. https://doi.org/10.1007/978-94-007-1920-0_1

Nur, E.M., & Fitnat, K. (2015). Explicit-Reflective Teaching Nature of Science as Embedded within the Science Topic: Interactive Historical Vignettes Technique. Journal of education and training studies, 3, 40-49. https://doi.org/10.11114/jets.v3i6.965

Okan, B., & Kaya, E. (2023). A content analysis of the representation of the nature of science in a Turkish science textbook. In G. S. Carvalho, A. S. Afonso, & Z. Anastácio (Eds.), Fostering scientific citizenship in an uncertain world (Vol. 13). Springer. https://doi.org/10.1007/978-3-031-32225-9_5

Park, W., Erduran, S., Song, J., & Kim, M. (2022). "It's a lesson with no correct answer": Design issues in preservice teachers' use of history of science for lesson planning. International Journal of Science Education, 45(3), 181–203. https://doi.org/10.1080/09500693.2022.2154132

Phillips, M. C., Vowell, J. E., Lee, Y. H., & Plankis, B. J. (2015). How Do Elementary Science Textbooks Present the Nature of Science? The Educational Forum, 79(2), 148–162. https://doi.org/10.1080/00131725.2015.1004210

Ramnarain, U. D., & Chanetsa, T. (2016). An analysis of South African Grade 9 natural sciences textbooks for their representation of nature of science. International Journal of Science Education, 38(6), 922–933. https://doi.org/10.1080/09500693.2016.1167985

Samuel Cornelius Nyarko & David Wyss Rudge. (2022). Using the history of plate tectonics to teach the nature of science, International Journal of Science Education, 44:12,1958-1977, DOI: 10.1080/09500693.2022.2105977

Şen, A., & Öztuna Kaplan, A. (2025). Reflections of pre-service science teachers' understanding of the nature of science on a socioscientific issue. Science & Education, 34, 4405–4431. https://doi.org/10.1007/s11191-025-00619-2

Upahi, J. E., Ramnarain, U., & Ishola, I. S. (2020). The nature of science as represented in chemistry textbooks used in Nigeria. Research in Science Education, 50, 1321–1339. https://doi.org/10.1007/s11165-018-9734-7

Valencia Narbona, M., Núñez Nieto, P., & Cofré Mardones, H. (2022). Understanding of Nature of Science (NOS) in pre-service teachers with different science content knowledge, before and after an intervention. International Journal of Science Education, 45(2), 125–143. https://doi.org/10.1080/09500693.2022.2152294

Wan, D., Lee, Y. J., Chen, S., & Yu, Q. (2024). How scientific literacy is conceptualized in tasks from junior secondary physics textbooks. International Journal of Science Education, 1–24. https://doi.org/10.1080/09500693.2024.2429045

Wei, B., Li, Y. and Chen, B. (2013), Representations of NOS in Histories of Science. School Science and Mathematics, 113: 170-179. https://doi.org/10.1111/ssm.12013

Wei, L., Gao, B., Wang, J., et al. (2024). Research on the nature of science in China's current high school physics textbooks. Science & Education, 33, 1467–1483. https://doi.org/10.1007/s11191-023-00443-6

Witucki, A., Beane, W., Pleasants, B., et al. (2024). An Explicit and Reflective Approach to Teaching Nature of Science in a Course-Based Undergraduate Research Experience. Science & Education 33, 1371–1399. https://doi.org/10.1007/s11191-023-00441-8

Xie, L., Wang, L. M., Li, Z. et al. (2025) Representations of Nature of Science in Chinese Physics Curriculum Standards over the Past Two Decades. Science & Education. https://doi.org/10.1007/s11191-024-00611-2

Yeh, Y. F., Dhurumraj, T., & Ramnarain, U. (2023). Representations of the nature of science in South African physical sciences textbooks on electricity and magnetism. Science & Education, 32, 1537–1559. https://doi.org/10.1007/s11191-022-00370-y

Yu, J., Li, C., & Li, G. (2022). Alignment between biology curriculum standards and five textbook editions: a content analysis. International Journal of Science Education, 44(14), 1–20. https://doi.org/10.1080/09500693.2022.2119621

Zarei, E., Hossein Nia, R. (2023). Analysis of High School Chemistry Textbooks Used in Iran for representations of Nature of Science. Interchange 54, 253–270. https://doi.org/10.1007/s10780-023-09490-y

Zhu, Y., & Tang, A. (2023). An analysis of the nature of science represented in Chinese middle school chemistry textbooks. International Journal of Science Education, 45(4), 314–331. https://doi.org/10.1080/09500693.2022.2160939

Zhuang, H., Xiao, Y., Liu, Q., Yu, B., Xiong, J., & Bao, L. (2021). Comparison of nature of science representations in five Chinese high school physics textbooks. International Journal of Science Education, 43(11), 1779–1798. https://doi.org/10.1080/09500693.2021.1933647