



Impact of Teaching Materials Based on the Family Resemblance Approach on Pre-service Chemistry Teachers' Views of Nature of Science

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Abstract

This study investigated the impact of teaching materials developed using the reconceptualized family resemblance approach to the nature of science (RFN) on pre-service chemistry teachers views about the nature of science (NOS). The materials were based on the book *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* by Shapin and Schaffer (1985), which covers various aspects of NOS emphasized by the RFN. The pre-service teachers underwent 15 weeks of constructivist learning, including lectures, discussions, and essay writing, and their understanding of NOS was evaluated using a pre- and post-test. The results revealed changes in their understanding of NOS, particularly in the social aspects of science. This study is significant in shedding light on the specific challenges that participants encountered when grappling with the idea of science as a social and institutional system.

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Keywords

Boyle-Hobbes debate - nature of science (NOS) - pre-service chemistry teachers - reconceptualized family resemblance approach to the nature of science (RFN) - teaching materials

1 Introduction

This study investigates the 17th-century debate between Boyle and Hobbes in England regarding the existence of a vacuum in an air pump and aims to develop teaching materials based on the history of science. The debate between Boyle and Hobbes highlights fundamental issues such as Boyle's belief in empirical experimentalism, induction, and objectivity of scientists versus Hobbes's conviction of logical causality, deduction, and social aspects of scientists, which are relevant not only as a historical anecdote but also as a critical component of science concepts. This research aims to reconstruct the debate explored in Shapin and Schaffer's (1985) book, Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life, to create materials for teaching chemistry pre-service teachers (PSTs) about the reconceptualized family resemblance approach to the nature of science (RFN) and to evaluate how these materials can alter pre-service teachers' understanding of the categories and items of the RFN. The study aims to investigate the impact of teaching science history on the understanding of the nature of science (NOS) among chemistry PSTS using the RFN approach and to consider the implications of these teaching materials for RFN education.

Scientific literacy is the primary goal of science education, which necessitates a correct understanding of NOS (NRC, 1996). Understanding NOS is crucial for developing the knowledge, skills, and attitudes necessary to make rational decisions about social issues (Meichtry, 1992). Students should comprehend the reciprocal impact of science and technology on society and be aware that scientific knowledge is tentative and subject to change, not simply a list of experimental results (Matthews, 1994).

Although previous studies have examined the general understanding of NOS, few studies have specifically investigated the impact of science history on this understanding. Science history can provide context to help learners comprehend the work and identity of scientists and deepen their understanding of NOS (Abd-El-Khalick & Lederman, 2000; Gandolfi, 2021; Schwartz et al., 2004). However, historical contexts that reflect NOS in science textbooks have been

limited to specific examples. In South Korea's chemistry education textbooks, for example, historical contexts have only provided background information on the development of the concept of the atom and the periodic table of elements. The 2015 Korean science curriculum included an achievement standard for 12th-grade chemistry, which requires students to investigate and present the process that led to the creation of the current periodic table (Ministry of Education, 2015).

2 Reconceptualized Family Resemblance Framework

This study employs the RFN framework developed by Kaya and Erduran (2016) to investigate how PSTS' understandings of NOS change as they interact with teaching materials related to the historical debate between Boyle and Hobbes. Before the RFN framework, the family resemblance approach to NOS (FRA-to-NOS) was introduced by Irzik and Nola (2014) as an extension of the concept of NOS. Irzik and Nola identified two categories of science, science as a cognitive-epistemic system and science as a social system, with the latter further divided into four categories: professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values. Erduran and Dagher (2014a, b, 2016, 2017) later expanded upon these categories, adding new ones such as social organizations and interactions, political power structures, and financial systems within institutional and social norms. Kaya and Erduran (2016) further refined and expanded the framework, providing a more detailed description and keywords for RFN categories.

This study aims to investigate changes in PSTS' understanding of NOS using RFN. NOS has a multifaceted definition, with a consensus perspective suggesting several components that are commonly employed in NOS teaching, learning, and curricula across many countries (McComas et al., 2000; Osborne et al., 2003). Examples of such components include the potentiality, subjectivity, and creativity of scientific knowledge, which are in line with the consensus perspective (Lederman, 2007; Lederman & Lederman, 2014). However, it is debatable whether NOS can be defined by a few agreed-upon components, leading to alternative perspectives of NOS, such as critical NOS (Clough, 2006), critical thinking NOS (Yacoubian, 2012, 2015), teaching about NOS (Kötter & Hammann, 2017), whole science (Allchin, 2011), features of science (Matthews, 2012), and RFN (Erduran & Dagher, 2014; Kaya & Erduran, 2016). These alternative positions emphasize the dynamic nature of science, focusing closely on the interaction between science and its contexts, such as sociocultural, political, and economic factors. This paper focuses on RFN as it provides a useful

theoretical foundation for an alternative perspective. RFN offers a conceptual framework that accounts for the many contrasts and correlations across multiple scientific areas, promoting a more comprehensive understanding of Nos through the categories of institutional and social contexts, as well as cognition and epistemology, in the complex web of science. Kaya et al. (2019) investigated the educational effects of applying RFN to PSTS' education, and previous studies have specifically examined PSTS' learning of NOS in a more tangible context.

For example, Cullinane and Erduran (2023) illustrated how PSTS navigated ideas presented to them during NOS workshops in the Republic of Ireland and found differences in their understanding of what constituted NOS incorporation. Erduran and Kaya (2019) also proposed the development of "epistemic identity" in PSTS' education and in-service continuous professional development of teachers. The RFN framework extends emphasis on the cognitive aspects of the epistemic core to include affective, social, and institutional aspects. Erduran et al. (2020) used a particular framework on NOS with visual representations to guide the development of learning resources and teacher education strategies. However, no efforts have been made thus far to address the teaching of RFN to PSTS through the history of science.

Based on these prior works, the present study develops NOS teaching materials related to the debate between Boyle and Hobbes in the 17th century. Studying the history of science can provide insight into how science is socially organized and managed, as scientists are influenced by various social, economic, and political factors. Therefore, teaching NOS through the history of science can be a valuable tool in enhancing scientific literacy, a central goal of science education. Such an approach can help PSTS develop a deeper understanding of the workings of science and its role in society, ultimately strengthening their ability to critically analyze and interpret scientific information.

This study applies the RFN framework to the 2015 revised Korean National Science Curriculum (Ministry of Education, 2015), using Boyle and Hobbes's debate as an example. It investigates how PSTS' perceptions of RFN change when they collaborate to construct new knowledge through discussion and demonstrate their understanding by writing essays on the debate. The study attempts to implement the constructivist learning process in science classes (Taber, 2016) through discussion-based learning and essay writing to provide open-ended questions and encourage active participation of PSTs. Discussion sessions on Boyle and Hobbes's historical debate are facilitated, guiding the PSTs to explore their ideas and connect them with scientific concepts and knowledge. Additionally, feedback is provided on the PSTs' essay writing

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processes to help them develop their scientific communication skills and encourage reflection on their learning.

This study focuses on two research questions:

- 1. To what degree can the developed teaching materials effectuate a quantitative transformation in PSTS' comprehension of RFN?
- 2. How can the developed teaching materials facilitate a qualitative examination of PSTS' understanding of RFN through the analysis of their essays or discussion transcripts?

3 Method

3.1 Research Process

This research team consisted of three researchers: a professor in the department of chemistry education at a college of education, a secondary-school chemistry teacher who had written a master's thesis in chemistry education, and a humanities major.

This study was conducted in a chemistry education course at a college of education in Korea. The course, titled Essay Writing in Chemistry, was designed for 4th-year college students. The objective of the course was to teach PSTS the importance of science education and effective methods of teaching it. The course also aimed to enhance PSTS' understanding of NOS, which is essential for effectively comprehending and utilizing scientific knowledge. To achieve these goals, the course emphasized the concepts and understanding of the history of science and scientific methodology, scientific reasoning and verification, data analysis and interpretation, and scientific logic. Additionally, the course aimed to develop PSTS' ability to plan and conduct their own research, thereby enhancing their problem-solving and creative thinking skills. Therefore, the historical debate between Boyle and Hobbes surrounding the air pump was utilized as useful material for this course. Essay writing in chemistry education is particularly useful in the reflexive model of learning because it involves PSTS reflecting on their learning processes and experiences. To write a successful essay, PSTS must not only have a deep understanding of the subject matter but also be able to critically reflect on their learning processes and experiences. This kind of reflection can help PSTS develop a more comprehensive understanding of the material of Boyle and Hobbes's debate and also assist them in identifying areas where they need to focus more attention or seek further clarification. Thus, essay writing can be a valuable tool for promoting a reflexive model of learning science history where PSTs are encouraged to be active participants in their learning process. The class was conducted through real-time remote lectures and assignments due to COVID-19.

In Week 1 of the class, the authors provided an orientation lecture to the PSTS to introduce them to the purpose of the study and its expected impact. After obtaining permission from the pre-service teachers, the 29 participants in the class agreed to participate in the research process. Before conducting the survey and transcribing discussions or conversations, the authors obtained consent from the participants.

In Week 2, the authors administered a questionnaire to the participants to assess their understanding of RFN as a pre-test online assignment. The 29 PSTs then divided themselves into seven groups. In the 3rd week, participants engaged in group discussions to share their thoughts and perspectives on RFN questionnaire.

From Week 4 to Week 14, except for the week of the midterm exam, lectures were given every 2 weeks on various contexts related to the categories of aims and values, scientific practices, scientific methods, scientific knowledge, and social-institutional aspects. The lecture content was developed by the authors and was provided to the PSTs as reading material. The specific lecture topics for each week are shown in Table 1.

Week	Category	Content
4-5	Aims and	According to the book Leviathan and the Air Pump (Shapin
	values	& Shaffer, 1985), which examines the historical debate
		between Boyle and Hobbes surrounding the air pump,
		Boyle employed three techniques to convince the public
		that his experimental results were factual: material, social,
		and literary. By using these techniques, Boyle argued that
		his experiments could be established as factual. However,
		Hobbes rejected Boyle's argument through traditional
		deductive thinking and geometrical reasoning (p. 25).
6-7	Scientific	According to the curriculum guidebook in Korea, Boyle's
	practices	Law is typically learned in the 1st year of middle school
		science textbooks. In this class, PSTs conduct two experi-
		ments to investigate the relationship between pressure and
		volume of gas and to promote understanding of science
		as a practice in relation to the debate between Boyle and
		Hobbes. There are two lesson plans to achieve this goal.

TABLE 1 The concrete content of le	lectures from t	the 4th we	ek to t	he 14th	ı week
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TABLE 1 The concrete content of lectures from the 4th week to the 14th week (cont.)

Week	Category	Content
		The first plan involves presenting the experimental results on the relationship between pressure and volume of gas, followed by introducing a particle model to explain Boyle's Law. The second plan involves explaining how the volume of a gas changes as pressure changes by introducing a par- ticle model after learners experiment to explore Boyle's Law.
9-10	Scientific methods	In Weeks 3 and 4, PSTS discuss Boyle's three techniques and Hobbes' criticism of them. Unlike Boyle's literary approach, Hobbes attempted to systematize his scientific writing by utilizing the Socratic-style logical question-and- answer method and geometry. Hobbes argued that simple and logical reasoning, along with geometric abstract shapes, was more suitable for conveying solid scientific knowledge. According to Hobbes, a scientist who was con- tent with merely observing, experimenting with, and col- lecting and analyzing data with an experimental machine was nothing more than a mechanic. A true scientist had to be a philosopher who could contemplate how the phenomenon of a vacuum could be defined, rather than
11–12	Scientific knowledge	simply demonstrating what a vacuum was. Boyle sought probable knowledge, which is defined as being likely but not certain. This type of knowledge was pursued by experimentalists, including Boyle, and could be corrected through experimentation. Hobbes, on the other hand, viewed Boyle as an agnostic, who did not know why the vacuum occurs. Hobbes believed that this attitude of agnosticism was not scientific and that a true scientist must determine the cause of the vacuum. As such, Hobbes can be considered a rationalist who sought
13–14	Social- institutional aspects	The Royal Society, in which there was a competition between Boyle and Hobbes, namely between experimen- talists and deductive philosophers, played a crucial role in the formation of the modern concept of science as a social institution. Hobbes criticized the Society for being

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Week	Category	Content
		dominated by a faction of experimentalists, including Lord
		Chancellor Bacon and Boyle. Consequently, Hobbes was
		expelled from the Society. Additionally, Boyle employed
		a social technique to attract people to the experimental
		site by allowing them to witness the experiment. Boyle
		claimed that the majority of noblemen who witnessed his
		experiment could guarantee its reliability. Air pump trials
		were often conducted in the Royal Society assembly room
		(Shapin & Shaffer, 1985). According to Boyle (1660), they
		were conducted "in the presence of ingenious men" (p. 1)
		or "in the presence of an illustrious assembly of virtuosi
		(who were spectators of the experiment)" (p. 400). Hobbes
		(1661) criticized Boyle's experiment for inviting only a
		select few to observe and support his experimental results.

TABLE 1 The concrete content of lectures from the 4th week to the 14th week (*cont.*)

After reading the relevant literature on RFN, the authors administered a questionnaire consisting of a total of 25 in all categories of RFN (five in each), to the participants. These questions were discussed in groups, and participants shared their changed thoughts related to the questionnaire on social media. They also gave presentations of their discussions to the other participants, and the authors provided feedback on these presentations. The online debate sessions were followed by reports submitted by the respective group representatives.

To help participants become familiar with the materials learned in the lecture, the authors helped them to imagine how they would teach this content to their students. In Weeks 5 and 6, in addition to group discussions on the reading materials, the group representatives conducted an experiment on Boyle's Law as shown in the textbook for the 1st year of middle school. This experiment catalyzed the PSTS to reflect on the nature of the scientific practice.

In Week 15, the authors conducted a post-test survey to assess participants' understanding of RFN using the questionnaire. Participants wrote essays on their final thoughts related to the RFN questionnaire. Due to time constraints, the authors excluded the category of educational application of the RFN questionnaire from the scope of the study.

3.2 Participants

The participants in this study consisted of 29 Korean PSTS (13 male and 16 female). They were all 4th-year college students majoring in chemistry education in Korea and had completed most of the regular courses covering major subjects and pedagogical studies in chemistry education, including general chemistry, organic chemistry, inorganic chemistry, physical chemistry, analytical chemistry, science education studies, a study of chemistry teaching materials, and relational experiments.

The course in which they were enrolled, Essay Writing in Chemistry, was designed as a core subject for the first semester of the 4th year of college to improve the PSTS' ability to write creatively and critically by connecting chemistry and pedagogy. The authors encouraged the participants to organize their groups autonomously to promote active group discussion, so the participants formed seven groups, six of which had four members and one of which had five.

As mentioned earlier, the authors obtained informed consent from the PSTS for their participation in the study and informed them that they could withdraw from the study at any time. To ensure anonymity in collecting and analyzing their data, pseudonyms were assigned to the participants in this paper. Excerpts from their discussions, along with data sources and dates, are cited.

3.3 Development of Questionnaire and Materials of the Contextualized RFN

The research process took place from December 2019 to April 2020. In December 2019, the authors conducted a review of existing research and various perspectives on NOS. Based on this review, the authors selected the most comprehensive and extensive scope of NOS, which is referred to as RFN. From January to February 2020, the authors created decontextualized and contextualized materials for investigating the understanding of RFN.

The decontextualized approach to NOS involves teaching about NOS as a set of abstract and general concepts that are detached from any specific scientific context. This approach emphasizes the philosophical and epistemological aspects of science, such as the role of scientific evidence, the scientific method, and the criteria for scientific knowledge, but does not link these concepts to the actual practices and historical development of science (Abd-El-Khalick & Lederman, 2000; Lederman & Lederman, 2014).

In contrast, the contextualized approach to NOS aims to provide students with a more situated and authentic understanding of science as a human and social activity that is embedded in specific cultural, historical, and institutional contexts. This approach emphasizes the importance of examining real-world examples of scientific inquiry, such as historical case studies and contemporary scientific controversies, to help students see how scientific knowledge is shaped by social, cultural, and political factors. By exploring the social and cultural dimensions of science, the contextualized approach seeks to promote a more critical and reflexive understanding of science and its role in society (Bell et al., 2011; Clough, 2006).

To investigate the understanding of the decontextualized RFN, the authors utilized the RFN questionnaire developed by Kaya et al. (2019) after restructuring it. The original questionnaire contained 70 items related to RFN for PST education. However, the authors only used 25 items (see Table 2) for this study, excluding items that were not relevant to Boyle and Hobbes's debate, which was the focus of this study. For example, items such as "The gender of scientists influences how they do science" were excluded as they were not related to the debate. Consistent with the methodology used by Kaya et al. (2019), this study employed a set of positively and negatively worded items to assess the PSTS' understanding of RFN. Specifically, the letter "N" was used to indicate that an item was false, while the letter "P" was used to indicate that an item was true. The selected items were translated into Korean, and the translated Korean questionnaire was given to the participants for examination. These 25 items were used as discussion topics and questions during class at different frequencies per week, as indicated in Table 3.

Category	Iter	ns (P: Positive, N: Negative)
I. Aims and values	1.	Scientific aims and values affect scientists' choice of methods in their investigations. (P)
	2.	The diversity of scientists solving a problem together means less-biased results. (P)
	3.	Scientific facts are not affected by bias and the indi- vidual subjective prejudices of scientists (N)
	4.	Scientists should change their minds when they real- ize that their ideas are not supported by evidence. (P)
	5.	Cognitive and cultural values of science cannot be distinctly distinguished from each other. (P)

TABLE 2	Categories	of RFN	used	in	this	study	ÿ
	a						

Category	Items (P: Positive, N: Negative)					
11. Scientific	1.	All branches of science use observations. (P)				
practices	2.	The power of experimentation comes from scientists				
		testing a scientific hypothesis many times (P).				
	3.	Scientists build and use models to understand com-				
		plex scientific phenomena. (P)				
	4.	Scientists from all branches of science validate				
		scientific knowledge by evaluating each other's				
		ideas. (P)				
	5.	There are standards for evaluating the quality of				
		scientific work. (P)				
111. Scientific	1.	Diversity of methods contributes to scientific under-				
methods		standing. (P)				
	2.	There is no step-by-step order to doing science. (P)				
	3.	Scientists must use different methods to produce				
		enough evidence so that they can solve problems. (\mbox{P})				
	4.	Each branch of science has a different nature. (P)				
	5.	All hypothesis testing is manipulative. (N)				
IV. Scientific	1.	Scientific progress occurs when ideas are evaluated				
knowledge		and revised. (P)				
	2.	Scientific knowledge does not change. (N)				
	3.	There are different kinds of theories. Some are				
		accepted, others are still debated. (P)				
	4.	Scientific knowledge consists of a coherent set of				
		ideas. (P)				
	5.	Laws are more verifiable scientific knowledge than				
		theories. (N)				
v. Social-institutional	1.	Race and ethnicity of scientists have nothing to do				
aspects		with science. (P)				
	2.	Science takes place in institutions such as universities				
		and research centers. (P)				
	3.	Scientists do not have to share their research with				
		society. (N)				
	4.	There are social hierarchies among science teams,				
		and these can change. (P)				
	5.	Some scientists earn more money than others, caus-				
		ing tension between scientists. (P)				

	Weeks 4 and 5	Weeks 6 and 7	Weeks 9 and 10	Weeks 11 and 12	Weeks 13 and 14	Total
I-1	1					1
I-2	1					1
I-3	1					1
I-4	1					1
I-5	1					1
II-1		1				1
II-2		1				1
11-3		1				1
II-4		1				1
11-5		1				1
III-1			1			1
III-2			1			1
111-3			1			1
III-4			1			1
111-5			1			1
IV-1				1		1
IV-2				1		1
IV-3				1		1
IV-4				1		1
IV-5				1		1
V-1					1	1
V-2					1	1
V-3					1	1
V-4					1	1
V-5					1	1
Total	5	5	5	5	5	25

Frequency of items used in class TABLE 3

Kaya et al. (2019) employed a 5-point Likert scale to measure participants' opinions on the items. In contrast, this study opted for a 3-point Likert scale (I agree, I do not know, and I disagree) to elicit participants' views. Placing the neutral position (I do not know) between the two extremes of agreement and disagreement offers participants the independence to select any response clearly (Joshi et al., 2015). This study preferred a 3-point scale over a 5-point scale for several reasons. First, a 3-point scale may simplify response options for

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participants, enabling them to choose a response that best reflects their views and resulting in fewer incomplete or ambiguous responses. Second, a 3-point scale may minimize the likelihood of participants choosing a neutral or middle option simply because it is available, rather than expressing a clear opinion, which can enhance the quality of the data collected. Finally, a 3-point scale may be more appropriate for a smaller sample size, which may be a concern in this study, as it permits more meaningful statistical analysis. Furthermore, since participants could provide descriptive answers after responding to the Likert scales, it was possible to assess the extent of their agreement or disagreement. This type of response encouraged participants to expound on their perspectives and provide supporting evidence (Driver et al., 1996).

3.4 Data Analysis

The participants in this study responded to a questionnaire, and their responses were categorized as "naïve" or "informed" based on whether or not the intended educational outcome was achieved, as described by Eymur (2019). The naïve category included responses such as "I disagree with this positive item" and "I agree with this negative item," no response, and out-of-place answers. In contrast, the informed category included responses such as "I agree with the positive item" and "I disagree with this negative item." Descriptive answers were also taken into consideration when determining the selection of views. Participants' vague responses, such as both "disagree partly" and "agree partly," were classified as naïve. In other words, naïve or informed were associated with the achievement of the intended educational outcome, while negative (N) or positive (P) were related to the truthfulness of the items.

The McNemar test was used for quantitative analysis, while a method combining individual and joint analysis was used for qualitative analysis. The McNemar test is useful for dealing with a low number of cases (McNemar, 1947), as in this study. The pre- and post-scores were labeled using categorical variables (naïve and informed), and each response to the 25 items was assigned a separate sign for analysis. SPSS was used as a statistical tool for analysis, and pre- and post-test results were compared for categories and individual items.

The qualitative analysis aimed to identify and describe trends in participant responses related to each of the five RFN categories. The analysis process consisted of six stages, with the first three being training stages for the authors. The remaining three stages involved a full-scale analysis of the data, which was conducted in the paragraph unit for both essays and discussion transcripts. Denzin's (1978) triangulation was used to improve the reliability of data analysis in qualitative research. Each author analyze the transcript of online discussions and essays separately to ensure the content of each discussion and

Downloaded from Brill.com 10/14/2024 02:37:01AM ASIA-PACIFIC SCIENCE EDUCATION 9 (2023) 1945 ASIA-PACIFIC SCIENCE EDUCATION 9 (2023) 1945 ASIA-PACIFIC SCIENCE EDUCATION 9 (2023) 1945 https://creativecommons.org/licenses/bv/4.0/ essay appeared the same for the same participant. Overall, this study aimed to understand the PSTS' knowledge from their perspective, with a focus on RFN categories. In the section that follows, the responses shared from participants were originally in Korean and were independently translated in English and confirmed by each of the authors.

Results and Discussion 4

Quantitative Results 4.1

Tables 4 and 5 present the results of McNemar's test conducted on the responses of 29 subjects to 25 items administered as a pre-test and a post-test. The test was implemented in two ways: first, analysis by category, which involved grouping items, and second, the calculation for separate items. The results for the analysis by category are presented in Table 4.

The significance probability of Categories 1 to 4 was higher than the significance level. Thus, we did not know if there was a change between the pre- and post-test, which means there was no significant change as a result of instruction for Categories 1 to 4. Category 5, social-institutional aspects of NOS, on the contrary, was lower than the significance level. As a result, the instruction

	Category	Pre		Post		Exact Sig (2-tailed)
		Informed	Naive	Informed	Naive	`
		Number / percentage (%)				
Aims and	1	27	2	29	0	.500
values		(93%)	(7%)	(100%)		
Scientific practice	2	25	4	28	1	.250
		(86%)	(14%)	(97%)	(3%)	
Scientific methods	3	27	2	29	0	.500
		(93%)	(7%)	(100%)		
Scientific	4	28	1	29	0	1.000
knowledge		(97%)	(3%)	(100%)		
Social-institutional	5	12	17	28	1	.000
aspects		(41%)	(59%)	(97%)	(3%)	

Statistical analysis results by category (group of items) TABLE 4

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in Category 5 had an educational effect. The calculation for separate items is shown in Table 5.

	Category	Pre		Post	Post					
		Informed	Naive	Informed	Naive	· · ·				
		Number / percentage (%)								
Aims and values	1.1	27 (93%)	$^{2}(7\%)$	29 (100%)	0	.500				
	1.2	24 (83%)	5 (17%)	26 (90%)	3 (10%)	.500				
	1.3	18 (62%)	11 (38%)	26 (90%)	3 (10%)	.008				
	1.4	18 (62%)	11 (38%)	23 (79%)	6 (21%)	.063				
	1.5	21 (72%)	8 (28%)	25 (86%)	4 (14%)	.219				
Scientific practice	2.1	17 (59%)	12 (41%)	22 (76%)	7 (24%)	.581				
-	2.2	21 (72%)	8 (28%)	20 (69%)	9 (31%)	1.000				
	2.3	29 (100%)	0	29 (100%)	0	N/A				
	2.4	23 (79%)	6 (21%)	27 (93%)	$^{2}(7\%)$.125				
	2.5	15(52%)	14 (48%)	25 (86%)	4 (14%)	.002				
Scientific methods	3.1	27 (93%)	2 (7%)	29 (100%)	0	.500				
	3.2	15(52%)	14 (48%)	27 (93%)	$^{2}(7\%)$.000				
	3.3	26 (90%)	3 (10%)	29 (100%)	0	.250				
	3.4	29 (100%)	0	29 (100%)	0	N/A				
	3.5	3 (10%)	26 (90%)	16 (55%)	13 (45%)	.001				

TABLE 5 Statistical analysis results for separate items

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	Category	Pre		Post	Post		
		Informed	Naive	Informed	Naive	(2 unital)	
		Number /]	percentage	e (%)			
Scientific knowledge	4.1	28 (97%)	1 (3%)	29 (100%)	0	1.000	
	4.2	27 (93%)	2 (7%)	29 (100%)	0	.500	
	4.3	29 (100%)	0	29 (100%)	0	N/A	
	4.4	17 (59%)	12 (41%)	24 (83%)	5 (17%)	.039	
	4.5	0	29 (100%)	16 (55%)	13 (45%)	.000	
Social- institutional	5.1	2 (7%)	27 (93%)	16 (55%)	13 (45%)	.001	
aspects	5.2	3 (10%)	26 (90%)	20 (69%)	9 (31%)	.000	
	5.3	23 (79%)	6 (21%)	27(93%)	2 (7%)	.125	
	5.4	21 (72%)	8 (28%)	28 (97%)	1 (3%)	.016	
	5.5	14 (48%)	15 (52%)	28 (97%)	1 (3%)	.000	

 TABLE 5
 Statistical analysis results for separate items (cont.)

The results of the pre-test showed that for most items, over 75% of participants' perceptions of NOS were already informed. Out of the 25 items, 12 had a high percentage of informed responses: 1.1, 1.2, 1.5, 2.3, 2.4, 3.1, 3.3, 3.4, 4.1, 4.2, 4.3, and 5.3. The lack of educational effect observed concerning these items can be attributed to the participants' existing informed views before the classes. Notably, statistical processing could not be performed for Items 2.3, 3.4, and 4.3, as all pre-service teachers were already informed about them during the pre-test.

The second group of items, 1.4, 2.1, and 2.2, did not show an educational effect in the post-test despite having a low percentage of informed responses

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ASIA-PACIFIC SCIENCE EDUCATION 9 (2023) 194–225 Access. This is an open access article distributed under the terms of the CC BY 4.0 license. https://creativecommons.org/licenses/bv/4.0/ in the pre-test. Item 1.4 related to the aims and values category, while 2.1 and 2.2 were associated with the practices category. It appears that the teaching materials developed in this study failed to change the participants' understanding of these three items. The material targeting Item 1.4, "Scientists should change their minds when they realize that their ideas are not supported by evidence (P)," focused on Boyle's attitude of not discarding ideas without evidence, despite Hobbes's attack. The material for 2.1, "All branches of science use observations (P)," was about Boyle's observation of air-pump experimentation, and the material for 2.2, "The power of experimentation comes from scientists testing a scientific hypothesis many times (P)," relates to Boyle's repeated testing of his scientific hypothesis on the existence of air, supported by experimental evidence, social witness, and the use of literary devices. Therefore, it is essential to create new teaching materials relevant to these items and evaluate their educational effectiveness.

The third group consists of 10 items that were found to have educational effects due to the significant difference in responses between the preand post-test. These items were 1.3, 2.5, 3.2, 3.5, 4.4, 4.5, 5.1, 5.2, 5.4, and 5.5. Notably, a substantial educational effect was observed for items associated with social-institutional aspects. While an educational effect was statistically observed for Items 3.5, 4.5, and 5.1, only 55% of the participants demonstrated an informed view according to the post-test. Item 3.5, "All hypothesis testing is manipulative (N)," was related to the scientific method aspect; Item 4.5, "Laws are more verifiable scientific knowledge than theories (N)," with the scientific knowledge aspect; and Item 5.1, "Race and ethnicity of scientists have nothing to do with science (P)," with social-institutional aspects. In the pre-test, only three (10%) participants had an informed view regarding Item 3.5, none had an informed view regarding Item 4.5, and two (7%) participants had informed views regarding Item 5.1. Despite the significant percentage of participants holding naive views before the class, developing more teaching materials related to these items is necessary. Ultimately, these teaching materials may enhance PSTS' understanding of RFN.

4.2 Qualitative Discussions

The purpose of this study was to evaluate the educational impact of teaching materials on the PSTS' understanding of NOS by analyzing categories and individual items. The findings indicated that Category 5, which pertains to the social-institutional aspects of science, had a positive educational effect. While the responses to some items exhibited informed perspectives before the class and remain unchanged, others demonstrated substantial improvement after the class, particularly those related to social-institutional aspects. Nonetheless, even though there was statistical evidence of educational progress for specific items such as 3.5, 4.5, and 5.1, only 55% of participants exhibited informed perspectives on these items in the post-test. Therefore, a qualitative investigation of these items, along with those associated with social-institutional aspects, may reveal areas for improvement in NOS education.

4.2.1 Determining the Manipulativeness of Hypothesis Testing: Implications for Science Education

Regarding Item 3.5, "All hypothesis testing is manipulative (N)," 90% of the participants could not understand it in the pre-test. They thought a hypothesis was based on inference about some problems and should be manipulatively tested by designing desirable conditions. They were stuck on the view that experimental manipulations are the scientific method.

Molly: Hypotheses are tested by a hypothetical deductive method. In hypothetical deductive thinking, when designing an experiment to test a hypothesis, variable manipulation is essential.

Data from discussion, April 28, 2020

Thus, in class, the authors established clear learning objectives for understanding Item 3.5. The authors then designed the relational instructional materials and gave the lecture to the PSTS, encouraging PSTS' active learning. The lecture included the following points: Hobbes argued that it would be wrong to claim that Boyle discovered a vacuum by experimentation without defining it. In other words, he argued that in the step-by-step sequence of doing science, hypothesis setting came first and experimentation should follow. However, Boyle rejected this step-by-step sequence and argued that the concept of vacuum could be derived purely through experimentation without a hypothesis. From Boyle's point of view, there is no step-by-step sequence of doing science, as Hobbes had insisted. Hobbes did not test manipulative experiments to prove his hypothesis that air is an infinitely microscopic object. He tried to prove his hypothesis using mathematical geometry. Hobbes viewed that anything related to the "simple circular motion" of the infinite fluid subtleties of air is mathematical. Therefore, he described the motion of the air with the actual causal knowledge gained when we make geometrical constructions related to motion, as a part of mathematics. After the lecture, PSTS engaged in discussion as a means of addressing the issue at hand.

After the instruction and discussion, regarding Item 3.5, the informed view increased significantly from 10% (pre-test) to 55% (post-test). This cognitive change was possible because they viewed the scientific method of modeling

suggested by Hobbes as important. Some participants with an informed view of Item 3.5 admitted the importance of structuring the scientific model by reminding themselves of Hobbes:

Laura: Hobbes thought that logical inference and geometrical abstraction are suitable tools to test scientific knowledge. Therefore, his thought can be called deductive thinking, and his hypothesis could not be tested with variable manipulation.

Data from an essay, June 9, 2020

Jane: One might posit that Hobbs underscored the importance of logical causality as a fundamental component of a scientist's proficiency, that is, geometry and modeling rather than the exploration of natural phenomena and the observation of experiments. Thus, we can explain that testing a hypothesis should not be limited to just showing that observation. Hobbes believed that when it comes to hypothesis testing, variable manipulation, theory formulation, and modeling should work complementarily. Scientists need to carry out their experimental processes and communicate them accurately. However, I think that the role of the scientist is not to simply communicate the experimental situation and describe the process in a lengthy manner, but to perform modeling that clearly and simply presents the core concepts that the scientist obtained through the experimental process.

Data from an essay, June 9, 2020

From a science education perspective, both views have their merits. Laura's view highlights the importance of logical inference and geometrical abstraction in testing scientific knowledge, which can be particularly useful in areas where variable manipulation is difficult or impossible. Jane's view also emphasizes the need for the complementary use of various tools in hypothesis testing, which can promote a more comprehensive and robust understanding of scientific phenomena. Additionally, her emphasis on clear and simple modeling can be beneficial in promoting effective communication and understanding of scientific concepts.

From this data, we can infer the thinking of the PSTS: they respect the role of hypotheses in the scientific process and the dialectic interaction between deductive modeling and manipulative experimental demonstration. In addition to these responses, they acknowledge that variable manipulation is necessary if hypothesis testing is carried out through experiments, but that variable manipulation is not necessary if the hypothesis is one requiring full observation and investigation. In other words, the diversity of scientific methods has finally been acknowledged.

These results recall the discussion of Erduran and Dagher (2014a), who noted that it is useful to distinguish between the two senses of the scientific method. The first sense refers to a method of disciplined inquiry, while the second sense of method refers to a standard method involving a specific procedure. While the first sense is broad in scope and endorses a diversity of methods, the second sense is more restrictive. From Erduran and Dagher's perspective, the PST s only adhered to the second sense of the scientific method, regarding it as being often communicated in school science. This sense of the scientific method can narrow the nature of scientific inquiry and introduce students to a simplistic version of the scientific method. Thus, instead of simplifying a complex scientific process, science teachers need to encourage learners to recognize the wide variation in the content of scientific methods, such as Hobbes's modeling.

In Kaya et al. (2019), PSTS mentioned observations, hypotheses, experiments, and control variables as scientific methods in pre-interviews. However, in post-interviews, they noted the diversity of scientific methods via hypothesis and non-hypothesis testing, manipulation and non-operation, and other areas of science. Therefore, our study supports the findings of Kaya et al. In our study, by deconstructing their existing beliefs about the scientific method through the concrete examples of Boyle and Hobbes, participants came to understand its diversity. The findings of this study center on the elements of scientific procedures, but they also touch on the scope and coverage of scientific methods in school science. Specifically, this study could shed light on the various components that constitute scientific methods, and how these can be effectively taught and learned in the context of science education.

The term "manipulative" in Item 3.5 means experiments involving variables and manipulations. Participants' naïve viewpoint can be attributed to science textbooks and science classes (Reiff, 2004). South Korean PSTs have learned a series of inductive and deductive inquiry methods from textbooks in middle and high school. In this experience, the idea that the manipulation of variables is performed in the process of hypotheses being proved may be solidified. In light of this phenomenon, the teaching materials developed in this study are not sufficient to lead PSTs to accept the informed views of RFN. Therefore, far more RFN teaching materials are necessary across various contexts in the history of chemistry for PSTs' education.

4.2.2 The Epistemological Value of Distinguishing between Scientific Laws and Theories in PST Education

Item 4.5, "Laws are more verifiable scientific knowledge than theories (N)" was not understandable by 100% of the PSTs.

Before the class, the PSTs all felt that there was a difference between scientific laws and theories. However, discerning the difference between scientific theories and laws is not an objective process with exact criteria of categorization; rather it is a subjective one (Wong & Hodson, 2010).

Jane: Scientific laws are more rigorously verifiable than scientific theories because they are based on direct observations and measurements, while theories rely on assumptions and models. We could use the example of the law of gravity, which can be tested and measured with high precision using experiments and observations, while the theory of gravity relies on more abstract concepts that are more difficult to directly verify, such as space-time curvature and the existence of gravitons. As a result, people tend to view laws as more reliable and certain than theories, giving them a higher status in scientific knowledge.

Data from discussion, April 28, 2020

To promote PSTS' engagement and participation, the authors encouraged active learning through instruction and discussion sessions. After the lecture and discussion sessions, the PSTS' understanding of Item 4.5 changed. Brown was a representative of this view:

Brown: The distinction between scientific laws and theories lies in the nature of their explanations. Scientific laws are mathematical descriptions that predict the behavior of natural phenomena but do not necessarily explain the underlying causes of that behavior. In contrast, scientific theories seek to explain natural phenomena by building on a foundation of proven hypotheses or facts. As such, laws and theories belong to different categories and cannot be compared hierarchically. While laws are more concerned with describing and predicting phenomena, theories aim to provide a deeper understanding of the underlying causes and mechanisms. Therefore, both laws and theories are essential components of scientific knowledge and play important roles in advancing our understanding of the natural world.

Data from an essay, June 9, 2020

Brown argued that scientific laws and theories are distinct categories, as laws are mathematical systems that describe natural phenomena, whereas theories are explanations of the natural world based on established hypotheses or facts. Brown believed that there is no hierarchical relationship between laws and theories. From a science education perspective, while it is important to understand the differences between laws and theories, it is also important to recognize that they are both critical components of scientific knowledge and understanding. Laws provide a framework for understanding and predicting natural phenomena, while theories provide explanations for why these phenomena occur. Therefore, both laws and theories are important for developing scientific literacy and should be taught in science classrooms.

In other words, both laws and theories are explanatory systems arbitrarily constructed to explain natural phenomena, and they have been recognized for their social validity and have become scientific knowledge through consensus. The results showed that the PSTS came to understand that it is difficult to say which is more verifiable. Both laws and theories are explanatory systems arbitrarily constructed to explain natural phenomena, and they have been recognized for their social validity and have become scientific knowledge through consensus.

Cognitive controversy over differences of these scientific laws and theories has already been discussed in previous studies. According to Erduran and Dagher (2014a), there are classifications of theories and laws (e.g., levels of theories and types of laws), which need to be differentiated and covered in science teaching and learning, and the various classes of theories and laws can contribute to students' understanding of scientific knowledge as a coherent system of knowledge forms. On the other hand, Cheong (2014) pointed out that there has been confusion in the use of the terms "theory" and "law" even in the scientific community conducting actual research. Wong and Hodson (2010) also noted that, although knowing the relationship between theory and law is not a very important issue for actual scientists, knowing the difference between the categorical terms "law" and "theory" tends to be dealt with in a significant way in modern scientific literacy education. To summarize, this study highlights the importance of theory, law, and consistency in scientific knowledge, but the debate around the difference between theory and law reflects the broader question of what falls under the scope of scientific knowledge.

Distinguishing between laws and theories is not an easy task even for experts, so more sophisticated lessons about the epistemological value of the distinguishing are needed in PST education. 4.2.3 Exploring PSTS' Conceptions of Science through a Socio-Institutional Lens: Implications for Science Education

As Table 4 shows, the social and institutional aspects of Category 5 show the greatest educational effect. The PSTS had an informed view in the pre-test for Item 5.3 only, for other items, many PSTS had a naive view in the pre-test, as shown in the examples below.

Mary: Natural phenomena exist with or without science, but theories and laws created by efforts to interpret and explain these natural phenomena are related to the interpretation of scientists. Therefore, I think that the effects of race and ethnicity on the identities of scientists influence their perspectives.

Data from the pre-test of 5.1, March 14, 2020

Cook: There is no scientific method that guarantees absolute scientific knowledge, and scientific knowledge is not absolute truth. Therefore, high academic background or equipment of a research center can be helpful for high-level research in studying and conducting science, but fundamental scientific activities can be done by anyone who is in contact with natural phenomena.

Data from the pre-test of 5.2, March 14, 2020

Sally: I do not know exactly what the social hierarchy of science means. I just believe that the hierarchy of science can be divided into entities that are less fundamental and entities that are more fundamental.

Data from the pre-test of 5.4, March 14, 2020

John: Depending on income, tension may be created, but it is likely that the tension is created more by the results of the study, not by money. This is because scientists seem to be more interested in establishing new facts or theories because they are interested in their own field rather than doing research based on only money.

Data from the pre-test of 5.5, March 14, 2020

The authors presented the following teaching materials as group discussion topics to the PSTS:

5.1. Race and ethnicity of scientists have nothing to do with science (P): Boyle
and Hobbes were both British, yet Boyle represented the new experimentalism and Hobbes supported the continental traditional natural philosophy.

Although they were of the same race and ethnicity, they had different scientific views.

- 5.2. Science takes place in institutions such as universities and research centers (P): After modern science, which began with Boyle, scientists have been recognized as scientists through activities performed in academic settings such as the Royal Society, universities, and research centers with institutional authority.
- 5.4. There are social hierarchies among science teams, and these can change (P): Boyle contributed to the disqualification of Hobbes from the Royal Society. Through this, Hobbes's status as a scientist was undermined. As a result, Hobbes became known only as a political theorist (he wrote *Leviathan*) and was not mentioned in science textbooks. Among the experimentalists, Hobbes's critique became known as an attack by an ignorant sociologist who knew nothing of experimentation.
- 5.5. Some scientists earn more money than others, causing tension between scientists (P): King Charles II awarded Hobbes a pension and nominated him for the Royal Society. The king's financial support for Hobbes was a threat to the experimentalists.

During the discussion session, the authors conducted facilitating learnercentered learning by encouraging the PSTs to construct their understanding and knowledge through collaborative activities using the items and relational points of Boyle and Hobbes's debate. After the class, a PST responded to Item 5.1 as follows:

Sally: What kind of race a scientist is or what genetics they have has nothing to do with science. I agree with this item because the characteristics of a scientist affect science in terms of the individual scientist's beliefs or the cultural characteristics of the society to which the scientist belongs, but fundamentally this effect does not occur because of race or ethnicity. Data from an essay, June 9, 2020

After the class, a participant responded to Item 5.2 as follows:

Tom: In order for scientific knowledge to be recognized by society, an accredited body whose recognition has value is needed. Institutions such as universities, research centers, and academies play that role. As a special case, there are exemplars where the start of scientific discovery is not in an institution, but as a result, in the process of acknowledging its value, it will have to go through institutions' certifications, so I agree with this item.

Data from an essay, June 9, 2020

A response to Item 5.4 was as follows:

Samuel: I agree with this item. The team of scientists was also a social community, and it was believed that there was an implicit hierarchy in meetings where achievements and recognition of members were required. Before class, I thought that this hierarchy could be changed through research results. But, like Hobbes's example, I knew that scientists' status could be forcibly demoted simply because of a social relationship, regardless of their research performance. The paradigm accepted as normal science is that the majority of its members agree on it because it means having a high position. Furthermore, I think that the recognition of science from the social hierarchy can be one cause of provisionality.

Data from an essay, June 9, 2020

A participant responded to Item 5.5 as follows:

Cook: I think of it as money for research rather than money for the scientist's private life. One of the most important things to keep scientific research going is money. Research can be conducted smoothly when financial support for research grants or budgets is stable. Also, when the research of a certain scientist is greatly approved in society, money and fame are obtained accordingly. Therefore, some scientists jump into research in fields of social interest and compete to obtain faster and more accurate research results.

Data from an essay, June 9, 2020

The responses from Sally, Tom, Samuel, and Cook highlighted different aspects of science and its practice. Sally emphasized that a scientist's race or ethnicity does not affect science, while Tom pointed out the role of accredited institutions in recognizing scientific knowledge. Samuel acknowledged the existence of a social hierarchy in the scientific community and its impact on scientific recognition. Cook stressed the importance of funding for scientific research and how it can incentivize researchers. These perspectives are valuable for science education as they provide insights into the social and cultural factors that influence scientific practice and recognition.

Such results reflect previous discussions that have advocated the incorporation of a societal dimension in science teaching, such as science-technologysociety (STS, e.g., Aikenhead, 1994), socioscientific issues (e.g., Zeidler et al., 2005), and recontextualization of science learning to promote civic engagement and citizenship (e.g., Bencze et al., 2012). Kaya et al. (2019) also reported that after RFN education, the PSTS' understanding was enhanced concerning social and institutional systems, including political power structures, scientific minds, social discourse and dissemination, financial systems, professional activities, and scientific institutions.

However, since the PSTs who participated in Kaya et al. (2019) were educated only with the RFN items without specific contexts, their perception of the social and institutional aspects of science may be evaluated as abstract. Therefore, this study is meaningful in that it reveals at what point participants face difficulties concretely when grappling with the conception of science as a social-institutional system.

The pre-test showed that most of the participants had naïve views concerning the items in the category of the social-institutional aspects, while the post-test demonstrated that their views changed considerably after the class. This result indicates that the participants had had little exposure to an RFN educational domain of social-institutional aspects, thereby suggesting the need for education in such aspects.

It should be noted that despite the educational effect of the class, 45% of the participants retained their naïve views in relation to Item 5.1, "The race and ethnicity of scientists have nothing to do with science (P)." Such views could be generated from the thought that inborn abilities or qualities, such as IQ and physical appearance, determine academic achievement. This attitude of PSTs could be linked to unbalanced expectations of learners and a preference for high-achieving students. If PSTs think that students' ability to learn can be determined by intrinsic characteristics such as genetic and biological features, efforts are needed to remove such prejudices, which may have been prevalent in the educational environment for a long time.

In addition, only three (10%) of the participants in the pre-test had an informed view regarding Item 5.2, "Science takes place in institutions such as universities and research centers (P)." The participants' thoughts about science activities could be related to their lack of awareness about the social-institutional aspects of RFN. The naïve view of the participants on this item comes from the thought that science activities in schools are no different from those of scientists. They do not distinguish between the activities of students in science classes and those of actual scientists. This thought does not take into account the institutional landscape where scientists do their work. This prejudice can be attributed to the lack of experience of the participants in their activities as scientists. It is necessary to provide an environment where PSTs can practice the activities of scientists that are distinct from school science.

5 Conclusion

This article explored the multifaceted definition of NOS and the different perspectives surrounding its various components. While consensus has been reached on some aspects of NOS, alternative viewpoints have emphasized the dynamic nature of science and its interaction with different contexts. This study focused on the RFN framework, which advocates for a comprehensive understanding of NOS its institutional and social contexts and its cognitive and epistemic aspects.

Therefore, this research created NOS teaching materials based on the 17th-century historical debate between Boyle and Hobbes to provide insights into how science is socially organized and managed and to improve scientific literacy. These teaching materials were designed to help PSTs to develop a deeper understanding of how science works and its function in society, thus enhancing their ability to analyze and interpret scientific information critically. Erduran and Kaya (2019) have also suggested developing the "epistemic identity" of PSTs' education and continuous professional development, emphasizing the affective, social, and institutional aspects of the epistemic core. However, previous research on RFN education has revealed a lack of focus and attention on the learning processes of PSTs with a focus on the history of science. This study has the potential to fill the gaps in prior research and address the missing pieces concerning PSTs' learning processes involving science history in RFN education.

The results of this study indicated that Item 1.4, which falls under the aims and values category of the RFN framework, as well as Items 2.1 and 2.2, which are associated with the scientific practice category, did not exhibit a statistically significant educational effect. It can be inferred that the teaching materials utilized in this study are insufficient in demonstrating the educational effect of these items, thus highlighting the need for future research on the development of related materials and their impact on education.

To deepen PSTS' understanding of the social and institutional aspects of science, RFN education should provide comprehensive teaching materials that focus on the diversity of scientific methods and their applications in various contexts. These materials can highlight the significance of rhetorical strategies and the historical and philosophical aspects of science in shaping scientific knowledge. RFN education should also address broader questions, such as what falls under the scope of scientific knowledge and the importance of consistency in scientific knowledge. By doing so, PSTS can develop a more nuanced and critical perspective on scientific practice and its aims and values. The 17th-century debate between Boyle and Hobbes regarding the nature of matter and the legitimacy of experimentation is a valuable topic for historical analysis in science education, particularly in the context of RFN education for PSTS. This historical example can emphasize the importance of critical thinking and skepticism in scientific practice and the influence of social and political factors in shaping scientific debates and discourse. Integrating such historical cases into RFN education can help pre-service chemistry teachers develop a more sophisticated understanding of the scientific enterprise and its relationship with society.

Regarding practical approaches, one potential strategy for incorporating examples from scientific history such as the Boyle-Hobbes debate into RFN education is to utilize inquiry-based learning methods. By encouraging PSTs to examine primary sources and engage in critical analysis and debate, they can acquire a more interactive and engaging learning experience that can assist students in developing a deeper comprehension of the complex social and cultural factors that shape scientific knowledge. Additionally, PSTs can use multimedia resources, such as videos or podcasts, to provide students with a diverse range of perspectives on historical cases and their relevance to contemporary issues in science and society. By adopting innovative and student-centered approaches to RFN education, PSTs can enhance their competence to help students become more knowledgeable and engaged citizens who can contribute to the ongoing dialogue and advancement of scientific knowledge.

This study examined RFN categories in the context of the historical debates between Boyle and Hobbes, providing deeper insights into the challenges that PSTS face in recognizing NOS. Future research is needed to identify strategies for overcoming these obstacles. Furthermore, given the potential of RFN to enhance teacher education on NOS recognition, a follow-up study should be conducted to explore the application of RFN to the professional development of in-service chemistry teachers.

Abbreviations

- PST's Pre-service teachers
- RFN Reconceptualized family resemblance approach to the nature of science

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Ethical Consideration

Approval to conduct this study was granted by the Korea National University of Education Ethics Review Board. The data collected from this project were obtained with the necessary clearance from the partner institutions, guardians, and the students involved in the study. The names of the school and participants used in this study are all pseudonyms.

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