



INTEGRATING THE 5E MODEL WITH EXPLICIT-REFLECTIVE NOSI TEACHING TO ENHANCE PRE-SERVICE SCIENCE TEACHERS' UNDERSTANDING OF SCIENTIFIC INQUIRY

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Introduction

As global educational reforms increasingly emphasize the development of scientifically literate citizens, scientific literacy has become a central objective in science education that enables individuals to make informed decisions and address real-world problems through the application of scientific knowledge (Akerson & Bartels, 2023; Ministry of Education of the People's Republic of China, 2022; Organization for Economic Co-operation and Development, 2018). Scientific literacy encompasses not only the understanding of scientific concepts and the ability to engage in scientific practices but also an appreciation of the processes through which scientific knowledge evolves (Kartal & Mesci, 2022; Lederman & Lederman, 2020; Schwartz et al., 2023). This appreciation of scientific process is central to the nature of scientific inquiry (NOSI), which concerns the epistemological foundations that inform the development, validation, and dissemination of scientific knowledge (Akerson & Bartels, 2023; Dorji & Tshering, 2024).

Scientific inquiry encompasses the diverse strategies and processes employed by scientists to research phenomena and build scientific explanations (National Research Council [NRC], 1996; Schwartz, et al., 2008). It is also a core approach for learning science. These processes typically involve asking testable questions, designing experimental or observational studies, collecting and analyzing data, drawing evidence-based conclusions, and engaging in scientific communication and argumentation (Constantinou et al., 2018; Crawford, 2014). A comprehensive understanding of NOSI enables students to move beyond a superficial grasp of scientific knowledge, fostering insight into how scientific knowledge is constructed and justified (Berland et al., 2016; Lederman et al., 2019). This epistemological understanding helps students recognize that scientific inquiry is not a rigid, linear procedure, but a dynamic and multifaceted process that requires adaptability and strategic thinking when addressing complex problems. By integrating NOSI understanding and procedural knowledge into inquiry processes, students become more capable of formulating meaningful questions, designing appropriate methods, and using evidence to support their conclusions (Halawa et al., 2024; Lederman

Abstract. *Fostering students' scientific literacy is a key goal of science education, with understanding the nature of scientific inquiry (NOSI) as a central component.*

Achieving this goal requires teachers to possess adequate knowledge in this area. However, assessments indicate that pre-service science teachers (PSTs) have not yet developed comprehensive understandings of NOSI. To address this, this study integrated the 5E model with explicit-reflective NOSI teaching within a science methods course. Quasi-experimental pretest-posttest design was employed. The Views About Scientific Inquiry (VASI) questionnaire was used to assess PSTs' understanding of NOSI. Before the study, most PSTs demonstrated naive or mixed views on various aspects of NOSI. Following the intervention, PSTs' understandings of all aspects improved significantly. Among these, more than half of the PSTs demonstrated informed understandings in four aspects: "begin with questions," "multiple methods," "questions guide procedures," and "conclusions must be consistent with data". These findings highlight the effectiveness of integrating the 5E model with explicit-reflective NOSI teaching in enhancing PSTs' understanding of NOSI. As one of the early attempts, this study lays a foundation for future research on applying the 5E model to NOSI teaching across diverse educational settings and highlights the need for its integration into teacher education curricula and professional development programs.

Keywords: *5E model, nature of scientific inquiry, explicit-reflective teaching, pre-service science teachers*

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et al., 2014; Reith & Nehring, 2020). Empirical studies have shown a strong correlation between NOSI understanding and students' metacognitive skills, critical thinking, and academic achievement (Dogan et al., 2024; Penn et al., 2019). Students with a strong grasp of NOSI are better equipped to regulate their learning process and apply scientific knowledge flexibly across diverse disciplinary and real-world contexts (Dogan et al., 2024).

However, research has indicated that students, as well as pre-service and in-service science teachers, frequently lack a comprehensive understanding of NOSI (Akerson et al., 2024; Dorji & Tshering, 2024; Gai et al., 2022; Güngören & Öztürk, 2021; Lederman et al., 2019). The NOSI conceptions of science teachers influence the implementation of inquiry-based teaching and students' science learning (Lederman et al., 2021). Teachers with an informed understanding of NOSI are better equipped to design inquiry-based learning environments in which students not only engage in scientific practices but also develop an understanding of the principles and values underlying scientific inquiry (Köseoğlu & Cigdemoglu, 2019; Mesci et al., 2020; Özer & Sarıbaş, 2023). Therefore, enhancing preservice science teachers' (PSTs) understanding of NOSI is critical for fostering the scientific literacy of future students, underscoring the importance of incorporating NOSI education into teacher training programs (Dorji & Tshering, 2024; Lederman et al., 2014; Özer & Sarıbaş, 2023).

A growing body of literature has explored diverse methods for enhancing students' understanding of NOSI. Previous studies have emphasized the effectiveness of combining explicit-reflective approaches with inquiry-based methods in promoting NOSI understanding (Erenler et al., 2024; Leblebicioglu et al., 2019; Metin Peten, 2022; Özer & Sarıbaş, 2023). For example, some researchers have integrated explicit-reflective NOSI teaching with science camp or laboratory inquiry activities (Leblebicioglu et al., 2019; Özer & Sarıbaş, 2023), while others have combined it with inquiry-based teaching models such as Argument-Driven Inquiry (ADI) and Problem-Based Learning (PBL) (Cetin, 2021; Dogan, 2017; Erenler et al., 2024; Özer & Doğan, 2024). These studies collectively indicate that embedding NOSI teaching within meaningful inquiry contexts can significantly enhance participants' comprehension of NOSI.

Among various inquiry-based teaching models, the 5E model (Bybee et al., 2006) has been widely applied in science education due to its positive effects on students' academic achievement and scientific attitudes (Cakir, 2017; Daines et al., 2019; Mulyeni et al., 2019; Susilowati & Anam, 2017; Yaman & Karasah, 2018). A recent study has further highlighted the 5E model's potential as a framework for NOSI teaching. In the study by Mesci et al. (2020), the 5E model was used as a foundation for PSTs to develop lesson plans that explicitly incorporated one or more aspects of NOSI. This led to notable improvements in PSTs' understanding of several NOSI aspects. These findings underscore the 5E model's potential as an effective framework for NOSI teaching. The clearly defined phases of the 5E model provide a structured scaffold that systematically guides learners through scientific inquiry, aligning well with the epistemological aims of NOSI teaching.

Theoretical Framework

This study was grounded in the NOSI framework (Lederman et al., 2014) and the 5E model (Bybee et al., 2006). These frameworks provided a coherent theoretical foundation for both the content and structure of the teaching intervention. The NOSI framework guided the epistemological focus of teaching, and the 5E model informed the pedagogical sequencing of learning activities. Together, these frameworks informed the design of the intervention to enhance PSTs' understanding of NOSI.

Nature of Scientific Inquiry

NOSI reflects the nature and principles of the processes and methods used to construct and justify scientific knowledge (Lederman et al., 2014; Schwartz, et al., 2008). This study adopted the NOSI framework, which includes eight aspects of the scientific inquiry process that are relevant across various educational levels, from early childhood to higher education. The aspects and the explanations are as follows.

- All Scientific Inquiry Begins with a Question and Does Not Always Test a Hypothesis
Scientific research commences with questions arising from observed phenomena (Lederman et al., 2014). Researchers employ systematic methodologies to address these questions, integrating findings with established knowledge. While hypothesis-driven models are prevalent, approaches without hypothesis testing, such as descriptive studies, also provide valuable contributions to scientific inquiry.
- There Are No Fixed Steps or Single Methods (i.e., There Are Multiple Methods)
Scientific research does not rely on a single, fixed procedure. Instead, it employs a variety of methodologies, such as experimental, observational, and correlational studies (Penn & Ramnarain, 2022).



Scientists select methods according to the characteristics of the research question, and students should be encouraged to comprehend and participate in a variety of scientific inquiry activities.

- **The Inquiry Procedure Is Guided by Scientific Questions**
Research methodologies and procedure designs are determined by the scientific questions posed (Lederman et al., 2014). Students should recognize the limitations of traditional experimental designs, particularly in impractical or unethical contexts, and learn to select methods that are appropriate for the nature of research questions.
- **Scientists Using the Same Procedures May Get Different Results**
The interpretation of scientific data is not entirely objective. Even when identical procedures are followed, researchers may reach different conclusions due to differences in analytical perspectives (Lederman et al., 2014). Students should understand the influence of human factors in research and recognize that scientific conclusions are shaped by researchers' interpretations.
- **Different Inquiry Procedures May Lead to Different Outcomes for the Same Question**
The choice of research procedures directly influences the results. Factors such as variable manipulation, methods for gathering and interpreting information, and differences in data sets influence the conclusions drawn. Students should understand the logical relationship between procedures, the resulting data sets, and conclusions (NGSS Lead States, 2013).
- **Conclusions Should Be Derived from and Consistent with the Data**
Scientific explanations must be supported by data and cannot be generated without evidence. Students should be able to differentiate between conclusions supported by evidence and assertions lacking verification, recognizing that scientific knowledge is built upon validation and empirical substantiation.
- **Scientific Data and Evidence Are Not the Same**
Data are the raw observations obtained through research, such as numbers or images, while evidence refers to the interpretation of data in relation to a research question (Lederman et al., 2014). Students should understand the differences and learn how to extract meaningful evidence from data (NGSS Lead States, 2013).
- **Explanations Are Constructed Based on Data and Existing Knowledge**

Scientific explanations are grounded not only in data but also in existing theories and prior research (NRC, 1996). New explanations must align with or extend current knowledge. Students should integrate data with background knowledge to understand how scientific explanations are constructed (Lederman et al., 2014).

Lederman et al. (2014) developed the Views About Scientific Inquiry (VASI) questionnaire to evaluate students' comprehension of NOSI. They also established a method for analyzing student responses by classifying them into three levels of understanding. At the naive level, a response of a NOSI aspect conflicts with or deviates from established scientific views. The mixed level reflects partial understanding, where responses include both appropriate and inconsistent elements. At the informed level, the student provides coherent explanations that are consistent with widely accepted scientific perspectives on the given aspect of NOSI.

5E Model

The 5E model is a widely recognized framework for inquiry-based learning (Cakir, 2017; Daines et al., 2019; Mulyeni et al., 2019), designed to engage students actively throughout the learning process. It consists of five key phases: (a) Engage - to stimulate curiosity and connect students' prior knowledge to the new concept being introduced; (b) Explore - to provide opportunities for students to study the topic through hands-on activities and collaboration, enabling them to gather information; (c) Explain - to guide students to construct scientific explanations for their explorations and introduce relevant concepts and terminology; (d) Elaborate - to encourage students to extend their learning by applying new knowledge in different contexts; and (e) Evaluate - to assess students' understanding and skills through multiple methods (Bybee et al., 2006).

In this study, the 5E model serves as a framework for teaching NOSI. Its structured yet flexible approach promotes inquiry-based learning and active student engagement (Bybee et al., 2006), thereby creating a suitable environment for embedding NOSI concepts throughout the learning process. The phases of the 5E model align well with explicit-reflective NOSI teaching. The engagement phase encourages students to pose scientific questions, which aligns with the NOSI principle. The exploration phase immerses students in inquiry activities, providing meaningful context for explicit NOSI teaching, while the explanation and elaboration phases facilitate reflective discussion on NOSI concepts, reinforcing their understanding (Lederman et al., 2014). As PSTs progress



through each phase of the model, they engage with both scientific practice and reflective activities that explicitly link NOSI to scientific practice.

Studies on Nature of Scientific Inquiry

Research has indicated that K-12 students worldwide have a limited understanding of NOSI (Akerson et al., 2024; Gai et al., 2022; Concannon et al., 2020; Lederman et al., 2019, 2021). A large-scale international study involving 7th-grade students from 20 countries and regions revealed a significant lack of understanding of NOSI among students worldwide (Lederman et al., 2019). Similarly, a follow-up international study examining 12th-grade students' understanding of NOSI across 32 countries and regions found that high school students globally hold a predominantly naive understanding of NOSI (Lederman et al., 2021). The lack of a comprehensive understanding of NOSI also exists among PSTs and in-service science teachers. For example, Dorji & Tshering (2024) found that Bhutanese science teachers lacked a clear understanding of the role of scientific questions, often equated scientific research with experiments, did not recognize how researchers' biases and methods could affect results, and had a limited understanding of scientific evidence and raw data. Güngören and Öztürk (2021) similarly reported that Turkish preservice science teachers generally lacked sufficient knowledge of NOSI, with over 50% holding naive views on four key aspects of NOSI. Kan et al. (2024) found that Chinese science teachers have a limited understanding of NOSI, with only 18.6% of teachers holding informed views. Teachers face challenges in identifying scientific questions, transforming data into evidence, and constructing scientific explanations. Similarly, Lee and Park (2019) found that elementary teachers in South Korea had mixed or naive levels of understanding of most aspects of NOSI, with few demonstrating informed understanding. These studies advocate strengthening training in scientific inquiry to improve pre-service and in-service teachers' understanding of NOSI.

The explicit-reflective approach has been established as a widely recognized and effective strategy for enhancing students' comprehension of NOSI (Erenler et al., 2024; Leblebicioglu et al., 2019; Metin Peten, 2022; Özer & Sarıbaşı, 2023). Nevertheless, this approach is not a standalone teaching method and must be integrated into specific teaching methods, such as embedding NOSI in teacher-centered lectures or incorporating it into inquiry-based teaching. Studies indicate that embedding explicit-reflective NOSI teaching within authentic inquiry activities significantly enhances students' understanding of NOSI (Cetin, 2021; Erenler et al., 2024; Metin Peten, 2022). For instance, incorporating explicit-reflective NOSI teaching into a science camp led to moderate improvements in students' NOSI understanding, although some misconceptions persisted (Antink-Meyer et al. 2016).

Beyond science camps, other teaching models that integrate explicit-reflective NOSI education have also been explored, such as argument-driven inquiry (ADI) (Cetin, 2021; Erenler et al., 2024; Metin Peten, 2022), problem-based learning (PBL) (Dogan, 2017; Özer & Doğan, 2024), and learning by teaching (Mesci et al., 2020; Özer & Sarıbaşı, 2023). Erenler et al. (2024) showed that combining the ADI framework with an explicit reflective strategy led to notable improvements in PSTs' grasp of NOSI across six key areas. However, PSTs still faced difficulties in grasping that inquiry procedures are guided by research questions and that conclusions must align with the data. Özer and Doğan (2024) examined the efficacy of creative PBL modules enriched with the history of science to improve middle school students' NOSI understanding. Their results revealed marked gains in understanding how scientific explanations are constructed and the diverse approaches scientists employ in research. Similarly, Özer and Sarıbaşı (2023) implemented inquiry-based laboratory activities, which improved PSTs' understanding of NOSI. However, challenges remained in distinguishing between data and evidence. These studies emphasize the value of hands-on, inquiry-based learning combined with explicit reflection in developing a more sophisticated understanding of NOSI.

While multiple inquiry-based models, such as ADI and PBL, have been explored in various educational contexts, studies indicate that meaningful engagement with NOSI requires structured opportunities for reflection and direct connections to scientific practices. However, a significant gap remains in research examining the effectiveness of specific, well-structured teaching models, particularly the 5E model, for NOSI teaching.

The 5E model has been extensively implemented in science education. Previous studies have emphasized its beneficial effects on learners' mastery of scientific concepts, scientific reasoning, and scientific attitudes (Cakir, 2017; Daines et al., 2019; Mulyeni et al., 2019; Susilowati & Anam, 2017; Yaman & Karasah, 2018). Its five distinct phases provide a coherent framework that facilitates gradual cognitive engagement and reflection throughout the learning process. Compared with less structured models such as PBL or ADI, the 5E model offers more explicit scaffolding, which is particularly advantageous in contexts like China, where traditional rote-learning practice dominates, and PSTs may lack prior experience of inquiry-based approaches.



Research Aim and Research Question

In China, studies have consistently highlighted the challenges students and teachers face in understanding of NOSI (Gai et al., 2022; Kan et al., 2024; Wang & Zhao, 2016). Gai et al. (2022) reported insufficient NOSI understanding among various groups of learners, including primary, secondary and upper-secondary school students, and PSTs. Similarly, Kan et al. (2024) and Wang and Zhao (2016) found that most secondary and upper-secondary science teachers hold naive or mixed conceptions of NOSI. Chai and Gai (2020) reported that over 60% of PSTs held naive views on most aspects of NOSI. Despite these findings, there remains a lack of intervention studies in the Chinese context to enhance PSTs' understanding of NOSI. Some research has explored an explicit-reflective strategy to improve upper-secondary students' views on scientific inquiry (Liu, 2022; Wei, 2022), but these studies lack detailed descriptions of how NOSI was explicitly and reflectively taught and do not follow a structured teaching model. For instance, Wei (2020) integrated explicit-reflective NOSI education into chemistry teaching but did not specify how different NOSI aspects were addressed. The absence of a systematic framework limits the consistency, replicability, and application of NOSI teaching. To address these issues, the present study aims to integrate the 5E model with explicit-reflective NOSI teaching to enhance PSTs' understanding of NOSI. The guiding research question for this study was:

How effective is the 5E model integrated with explicit-reflective NOSI teaching in enhancing PSTs' understanding of NOSI?

Research Methodology*General Background*

A quasi-experimental design with pre- and post-tests was adopted to evaluate the effectiveness of combining the 5E model with explicit-reflective NOSI teaching. The quasi-experimental design was chosen because it allows for the analysis of interventions within authentic educational settings (Creswell, 2014). Specifically, the intervention was implemented within a science methods course at a public university in China specializing in teacher preparation.

Sample Selection

Participants were selected through convenience sampling, based on feasibility and practical considerations, as the researcher had direct access to the university's science education courses. The participants comprised 47 third-year undergraduate students (35 females, 12 males), aged 20–23, majoring in science education and pursuing a primary school science teaching certificate. According to the talent training program of this major, the first two years primarily focus on foundational science courses and basic education and psychology courses (e.g., chemistry, physics, pedagogy, and psychology). During this period, PSTs may engage with inquiry through laboratory experiments or research projects embedded within their coursework. However, these courses do not explicitly emphasize the philosophy of NOS or NOSI. Therefore, prior to this study, the PSTs had not received any courses specifically targeting NOS or NOSI. Prior to the study, informed consent was obtained from each participant to ensure their willingness and understanding of the study's purpose and procedures.

Teaching Intervention

This study was carried out within the context of a science methods course, which is offered for the third year PSTs. The course was redesigned based on the 5E model and explicit-reflective NOSI teaching. The study was conducted during the fall semester of 2023, spanning nine weeks from September to November. The intervention consisted of seven inquiry-based activities. PSTs participated in weekly three-hour sessions, collaborating in pairs to complete each activity. Each activity was structured according to the 5E model and focused on specific aspects of NOSI, as outlined in Table 1. These activities were intentionally designed to promote active engagement in scientific inquiry and to facilitate reflective discussion on the related NOSI aspects.



Table 1*5E Activities and Corresponding Focused Aspects of Nature of Scientific Inquiry*

Week		Topic	Aspects of NOSI
Week 1	Topic 1	Inedibility of Moldy Apples	NOSI 1: All scientific inquiry begins with a question, not always testing a hypothesis NOSI 4: The same procedures may not get the same results
Week 2	Topic 2	Effects of Pheromone on Foraging Behavior in Ants	NOSI 2: There are multiple methods in scientific inquiry NOSI 5: Procedures influence results
Week 3 & Week 4	Topic 3	Effects of Environmental Factors on Seed Germination	NOSI 3: Questions guide inquiry procedures
Week 5 & Week 9	Topic 4	Exploring the Phases of the Moon	NOSI 2: There are multiple methods in scientific inquiry NOSI 8: Explanations are constructed based on data and existing knowledge
Week 6	Topic 5	Factors Influencing Buoyancy	NOSI 6: Conclusions should be derived from and consistent with the data
Week 7	Topic 6	Factors Influencing the Magnetic Force of an Electromagnet	NOSI 7: Scientific data differs from evidence
Week 8	Topic 7	Characteristics of Plane Mirror Imaging	NOSI 1: All scientific inquiry begins with a question, not always testing a hypothesis NOSI 3: Questions guide inquiry procedures NOSI 6: Conclusions should be derived from and consistent with the data

This study followed the 5E model, which consists of five phases: engagement, exploration, explanation, elaboration, and evaluation. In the engagement phase, the lecturer introduced real-life scenarios related to the inquiry topic to capture PSTs' interest. This was achieved through interactive questions, images, videos, or small demonstration experiments, encouraging PSTs to ask questions and formulate hypotheses, with explicit guidance that scientific inquiry begins with a question. During the exploration phase, PSTs selected appropriate methods and designed inquiry procedures to address the scientific questions posed. They then collected data through experiments or observations, accompanied by explicit guidance on the diversity of scientific methods and how inquiry procedures are guided by the research question. In the explanation phase, PSTs presented their data and findings. The lecturer facilitated discussions and reflections on scientific inquiry, guiding PSTs to develop scientific explanations and deepening their understanding of NOSI. In the elaboration phase, the lecturer provided new scenarios, and PSTs applied their newly acquired knowledge and skills to complete additional tasks, reinforcing their learning. Finally, in the evaluation phase, the lecturer summarized the scientific topic and targeted NOSI aspects. Each PST completed an evaluation sheet to assess their learning, and they also submitted a lab report after class for further review and feedback.

The explicit reflective NOSI discussion is embedded in the explanation phase of the 5E model. During this phase, PSTs presented and defended their inquiry results, providing opportunities to critically examine both inquiry processes and outcomes in relation to targeted NOSI aspects. For instance, in the seed germination activity, the reflection focused on how the inquiry procedures were guided by the research questions. After PSTs presented results, the lecturer initiated a structured reflective discussion. This included questions such as, "How did your experimental design address the research question?", "Were there alternative methods you considered, and why were they not chosen?", and "Did your procedure remain consistent with the original question throughout the experiment?". The lecturer explicitly summarized the principle that in scientific inquiry, every procedural choice should logically stem from the research question, ensuring that the inquiry activity remains focused and relevant. In the electromagnetism activity, the focus targeted the distinction between data and evidence. The lecturer began by explicitly introducing the concepts of data and evidence and then facilitated reflection by asking questions such as, "What raw data did you collect?", "What patterns or relationships did you identify?", and "How did you justify your conclusions based on these data?" These discussions provided a reflective environment that emphasized specific aspects of NOSI, helping PSTs to develop a more informed understanding.



Instrument and Procedure

The VASI questionnaire was utilized in this study to assess PSTs’ understanding of NOSI (Lederman et al., 2014). The questionnaire comprises seven open-ended questions, each targeting different aspects of NOSI. Table 2 illustrates the alignment between NOSI aspects and the VASI questionnaire items. A Chinese-translated version of the VASI, previously validated in the Chinese context (Chai & Gai, 2020; Gai et al., 2022), was utilized. The VASI questionnaire was administered in paper-and-pencil format in a quiet classroom to ensure focused and independent completion. Pre- and post-tests were conducted before and after the intervention, respectively, with each session taking approximately 30 minutes.

Table 2
NOSI Aspects and Corresponding VASI Items

Aspects of NOSI		VASI item
NOSI 1	All scientific inquiry begins with a question, not always testing a hypothesis	2
NOSI 2	There are multiple methods in scientific inquiry	1a, 1b, 1c
NOSI 3	Questions guide inquiry procedures	5
NOSI 4	The same procedures may not get the same results	3a
NOSI 5	Procedures influence results	3b
NOSI 6	Conclusions should be derived from and consistent with the data	6
NOSI 7	Scientific data differs from evidence	4
NOSI 8	Explanations constructed based on data and existing knowledge	7a, 7b

Data Analysis

The VASI questionnaire was analyzed using both qualitative and quantitative approaches. Since it is an open-ended questionnaire, PSTs’ answers were first analyzed qualitatively. Pre- and post-test responses were classified into naive, mixed, and informed levels, following the coding framework established by Gaigher et al. (2014). A response was classified as informed if it consistently reflected an understanding fully aligned with the accepted view of a particular aspect of scientific inquiry. A mixed code was assigned when the response demonstrated partial understanding, but was not entirely consistent with the target response or did not provide sufficient explanations. Responses that contradicted the target response were classified as naive views. Subsequently, the coding results were analyzed quantitatively. Recognizing that the coded responses (naive, mixed, informed) represent ordinal variables, this study calculated the frequency and percentage of each NOSI aspect coded as naive, mixed, or informed in both the pre-test and post-test. This approach aligns with those employed in prior NOSI studies (Erenler et al., 2024; Özer & Doğan, 2024; Özer & Sarıbaş, 2023), providing a basis for illustrating changes in PSTs’ responses across these categories. To facilitate analysis, the naive, mixed, and informed categories were assigned values of 1, 2, and 3, respectively, as described by Özer and Sarıbaş (2023). Then, the non-parametric Wilcoxon signed-rank test was employed to compare the pre-test and post-test differences for each NOSI aspect, as recommended for ordinal data (Baumgardner, 1997).

To ensure the reliability of the coding process, 20% of the VASI questionnaires were randomly selected for independent coding by the researcher and two additional science education experts, using the established coding rubric. Inter-rater reliability was assessed using Fleiss’ Kappa, which is suitable for measuring agreement among more than two raters. In this study, inter-coder agreement for all eight VASI items ranged between 90% and 95%, with an overall agreement of 93%, indicating a satisfactory level of consistency (Wever et al., 2006). The remaining questionnaires were coded by the first author.

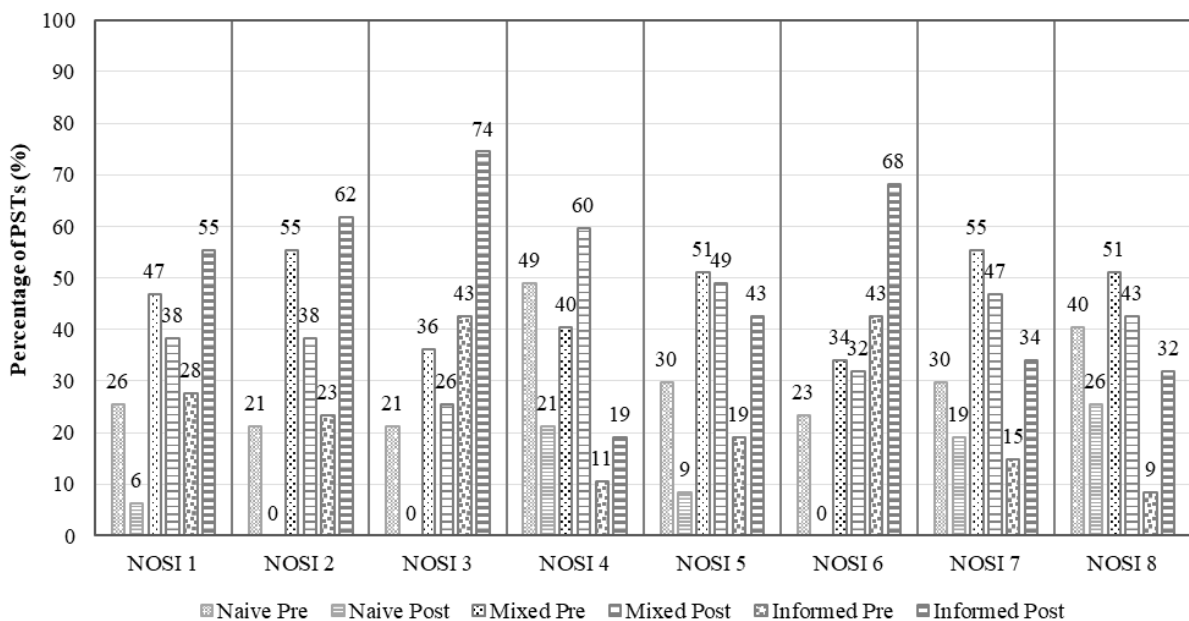


Research Results

Figure 1 and Table 3 present the frequency and percentage distributions of PSTs' responses across the eight aspects of NOSI in both the pre-test and post-test. Figure 1 shows the percentages of PSTs demonstrating naive, mixed, and informed understandings for each NOSI aspect. The results showed variations in PSTs' understanding of different NOSI aspects, and a clear pattern of progression from naive and mixed categories towards the informed category after the intervention. This shift is evident in the increased percentage of participants categorized as informed and the corresponding decrease in those categorized as naive (Figure 1 and Table 3), reflecting a positive effect of the intervention on PSTs' understanding of NOSI. The Wilcoxon test results further supported this progression, revealing significant differences across all aspects of NOSI (Table 3), with effect sizes ranging from 0.26 to 0.42, indicating small to moderate effects. These results suggested substantial improvements in PSTs' understanding of each NOSI aspect from pre-test to post-test.

Figure 1

Changes in PSTs' Understanding of NOSI from Pre-Test to Post-Test



Note. The columns of each NOSI aspect follow the order: naive pre, naive post, mixed pre, mixed post, informed pre, informed post. Dotted patterns indicate pre-test results, and horizontal lines indicate post-test results.

Table 3

Frequency Distributions and Wilcoxon Test Results of VASI Questionnaire

Aspect of NOSI	Category	Pre-test		Post-test		Z	p	Effect Size (r)*
		n	%	n	%			
NOSI 1 Begin with a question	Naive	12	25.53	3	6.38	-3.64	< .001	.38
	Mixed	22	46.81	18	38.30			
	Informed	13	27.66	26	55.32			
NOSI 2 Multiple methods	Naive	10	21.28	0	0	-4.05	< .001	.42
	Mixed	26	55.32	18	38.30			
	Informed	11	23.40	29	61.70			

Aspect of NOSI	Category	Pre-test		Post-test		Z	p	Effect Size (r)*
		n	%	n	%			
NOSI 3 Questions guide procedure	Naive	10	21.28	0	0	-3.68	< .001	.38
	Mixed	17	36.17	12	25.53			
	Informed	20	42.55	35	74.47			
NOSI 4 Same procedures may not get same results	Naive	23	48.94	10	21.28	-3.40	< .001	.35
	Mixed	19	40.43	28	59.57			
	Informed	5	10.64	9	19.15			
NOSI 5 Procedures influence results	Naive	14	29.79	4	8.51	-3.87	< .001	.40
	Mixed	24	51.06	23	48.94			
	Informed	9	19.15	20	42.55			
NOSI 6 Conclusions consistent with data	naive	11	23.40	0	0	-3.55	< .001	.37
	Mixed	16	34.04	15	31.91			
	Informed	20	42.55	32	68.09			
NOSI 7 Data differs from evidence	Naive	14	29.79	9	19.15	-2.56	.010	.26
	Mixed	26	55.32	22	46.81			
	Informed	7	14.89	16	34.04			
NOSI 8 Explanations based on data and existing knowledge	Naive	19	40.43	12	25.53	-3.18	.001	.33
	Mixed	24	51.06	20	42.55			
	Informed	4	8.51	15	31.91			

Note. Effect size *r* was calculated using the formula $r = Z / \sqrt{N}$ ($N = 94$). Interpretation is based on Cohen's guidelines: small effect ($r < .10$), medium effect ($.30 \leq r < .50$), and large effect ($r \geq .50$) (Fritz et al., 2012).

NOSI 1: All Scientific Inquiry Begins with a Question

According to Table 3, the pre-test results on this aspect showed that 12 PSTs (25.53%) held naive understanding, 22 (46.80%) PSTs demonstrated mixed views, and 13 (27.66%) PSTs demonstrated informed perspectives. Those with naive views failed to recognize that posing a question is fundamental to starting a scientific inquiry, instead prioritizing observation and curiosity. Those with mixed views recognize the role of a question but provide unclear explanations. For example, PST #7's response focused on problem-solving without explaining why a guiding question is crucial.

[Pre-test, PST #7] I agree with "yes". Because scientific inquiry is a problem-solving activity. [Mix view]

After the intervention, the post-test results indicated a significant improvement, with only 3 PSTs (6.4%) holding naive views, 55.32% of the PSTs held informed perspectives, recognizing the key role of questions in initiating scientific inquiry, as shown in the quotes below:

[Post-test, PST #7] Yes, to conduct research, we must first define a specific question, and then we can know what methods and procedures are needed to answer the research question. [Informed view]

NOSI 2: Multiple Methods in Scientific Inquiry

Regarding this aspect, most PSTs' responses fell into the "mixed" category ($n=26$, 55.32%), with fewer participants holding either naive ($n=10$, 21.3%) or informed views ($n=11$, 23.40%). Participants who held naive views often described scientific inquiry as following a general or fixed set of steps. For example:



[Pre-test, PST #23]: 1b: The bird research is an experiment. He followed the general steps of experiments, such as planning, collecting data, and drawing conclusions. 1c: There is a single method that all research can use, just as the steps mentioned above. [Naive view]

This response reveals a misunderstanding, where the participant equates any structured scientific activities with experimentation, showing a lack of distinction between experimentation and observation as different methods of scientific inquiry.

By the post-test, no PSTs held naive views, and 61.70% of participants demonstrated informed views. The informed responses demonstrated a clearer understanding of the differences between observational and experimental approaches. For example, the previously naive response from PST #23 evolved into an informed view in the post-test.

[Post-test, PST #23]

1b: It's not an experiment. He just observed it naturally, there are not any control. 1c: Yes. For example, in animal behavior studies, one can observe in a natural environment. One can also control different conditions using an experiment method. [Informed view]

NOSI 3: Questions Guide Inquiry Procedures

This aspect is assessed through a specific contextualized question, which requires PSTs to evaluate two inquiry plans and determine which is more appropriate for addressing a given research question. Before intervention, a substantial number of PSTs (42.55%) demonstrated informed views, where they made the correct choice and provided clear explanations connecting the procedure to the research question. For example:

[Pre-test, PST #5]: The design of Team A is better because the research question focuses on different tire brands, so the independent variable should be the brand type. [Informed view]

After the intervention, no PSTs held naive views, and the percentage of PSTs holding informed views increased to 74.47%. Notably, some PSTs offered more refined and critical evaluation of the inquiry process. For instance, PST #11's post-test response reflected an advanced level of reasoning:

[Post-test, PST #11]: In the context of the research question, Team A's design demonstrates a relative advantage; however, both designs exhibit inadequacies. Team A considered different tire types, while Team B included different road types. Road type is also an important factor, so the experimental designs of both teams should be combined. [Informed view]

PST #11's post-test response highlighted an increased awareness of the complexity of experimental design, showing the ability to critique both procedures and suggest a more comprehensive approach.

NOSI 4: Same Procedures May Not Get Same Results

The pre-test results showed nearly half (48.93%) held naive views, which showed most PSTs struggled to understand that scientists might reach different conclusions even when following the same procedure, being unaware that subjective interpretation can also influence results. PSTs who held mixed views (40.42%) acknowledged the possibility of varying results, but their explanations were often vague and lacked depth. For instance:

[Pre-test, PST #32]: Not necessarily obtain the same results, as external factors can significantly impact the outcomes. [Mixed view]

In contrast, by the post-test, a notable shift in understanding was observed. Over half of the PSTs with naive views transitioned to either mixed or informed views. PSTs with informed views understood that scientists might obtain varying results from identical procedures because of individual differences like prior knowledge, experience, and perspectives. As illustrated by PST #17's response,

[Post-test, PST #17]: The results could be different. Because different people may have different prior knowledge and experience, they may have different perspectives when interpreting collected data or observed phenomena. [Informed view]



NOSI 5: Procedures Influence Results

This aspect examines whether PSTs recognized that differences in procedures could lead to different results. At the beginning of the study, the pre-test results indicated that 14 PSTs (29.79%) held naive views, 24 PSTs (51.10%) demonstrated mixed views, and only 9 PSTs (19.15%) exhibited informed views. These results suggest that while a significant number of PSTs acknowledge procedural influence on results, most were unable to provide adequate explanations for how this influence operates. For instance,

[Pre-test, PST #23]: The results may be different because they collected the data in different ways. [Mixed view]

While acknowledging that results could vary due to procedural differences, PST #23's response merely repeated information from the question without providing further explanation or insight.

In the post-test, significant improvements were observed. The number of PSTs with naive views dropped to just 4 (8.51%), while those holding informed views increased to 20 (42.55%). Informed PSTs not only recognized that different procedures could lead to different outcomes but also provided clear and reasonable explanations for why this occurs. For instance, PST #23's response in the post-test clearly explained how procedures influence the results.

[Post-test, PST #23]: They may get different results because using different procedures can lead to different data sets, which in turn can result in different conclusions. [Informed view]

NOSI 6: Conclusions Should Be Derived from and Consistent with the Data

To assess PSTs' understanding of this aspect, the VASI questionnaire presents a dataset showing conflicting information between plant growth and sunlight exposure, which contradicts the common belief that more sunlight leads to greater plant growth. For this aspect, it was surprising that 42.55% of participants held informed views before the intervention. After the intervention, no PSTs held naive views, and the percentage of PSTs with informed views increased to 68.09%. For example, PST #18's responses illustrate this development in comprehension. In the pre-test, PST #18 drew a conclusion based solely on prior knowledge, disregarding the data in the table:

[Pre-test, PST #18]: I agree with a. Because more sunlight can enhance photosynthesis, helping the plant grow better. [Naive view]

[Post-test, PST #18]: I agree with b. Although this conclusion is inconsistent with my experience, the data shows this trend; according to the data, we can only draw this conclusion. [Informed view]

In the pre-test, PST #18 drew a conclusion based solely on prior knowledge. By the post-test, the response clearly acknowledged that although the data contradicted prior experience, the conclusion should be based on the data. This response reflects a shift from relying on prior knowledge to drawing conclusions based on the data, which is a key aspect of scientific inquiry.

Additionally, some PSTs with informed views showed deeper critical thinking by interpreting the same data in different ways and providing reasonable justifications for their conclusions. PST #6's response was an example,

[Post-test, PST #6]: I agree with c. Because the data in the table does not show a specific pattern. From the data for the first 4 weeks, it can be found that as the light time increases, the growth of the plants decreases, but in the 5th week, it shows the opposite situation. [Informed view]

NOSI 7: Scientific Data and Evidence Are Not the Same

According to Table 3, before the intervention, 14 PSTs (29.78%) held naive views, 26 PSTs (55.32%) showed mixed views, and only 7 PSTs (14.89%) demonstrated informed perspectives. Participants with naive understandings tended to conflate data with evidence, not recognizing that evidence involves interpretation beyond the raw data. Although they acknowledged that data and evidence were different, their responses lacked clarity and depth, suggesting uncertainty about the exact nature of this difference. For example:

[Pre-test, PST #9]: Data is different from evidence. Data is the information one needs to obtain through observation or measurement. Evidence is already there and can be used. [Mixed view]

After the intervention, fewer PSTs demonstrated naive understandings, whereas the proportion exhibiting informed views showed a twofold increase. This change suggests an enhanced understanding among PSTs regarding the separate roles of data and evidence, especially in relation to analyzing and interpreting scientific data. For instance, PST #9, who initially demonstrated a mixed view, developed a more nuanced understanding of data and evidence in the post-test, incorporating insights from the inquiry-based activities completed during the course:

[Post-test, PST #9]: Data is different from evidence. The data are the phenomena we directly observe or the numbers we measure during the experiment, such as the magnitude of the magnetic force and the number of coils. But evidence is the trend or pattern obtained after analyzing the data, which can support our conclusions. For example, as the number of coils increases, the magnetic force of the electromagnet becomes stronger. [Informed view]

NOSI 8: Explanations are Constructed Based on Data and Existing Knowledge

To assess this aspect, the VASI questionnaire presents two figures of dinosaur skeletons and notes that most scientists agree with the structure shown in Figure 1. The first sub-question asks PSTs to provide at least two reasons to explain this consensus. The second sub-question requires them to delineate the forms of evidence scientists rely on to justify their conclusions. In the pre-test, 40.43% of PSTs exhibited naive views, 51.06% displayed a mixed level of understanding, and only 8.51% demonstrated informed comprehension. This indicates that most PSTs failed to recognize that scientific research requires not only using collected data but also drawing explanations based on existing knowledge from previous studies.

At the post-test, there was significant improvement. The proportion of PSTs with naive views dropped to 25.53%, while the number of PSTs with informed views rose significantly to 31.91%. PST #13's post-test response illustrates an informed understanding.

Post-test, PST #13 [Informed view]:

7a: In Figure 2, the hind legs of the skeleton are short, and the body's weight would need to be supported by the front legs. The entire body looks unstable. Additionally, the body structure in Picture 1 is better suited for hunting.

7b: Scientists can explain their conclusions using principles of center of gravity and balance. They can also draw analogies from the skeletons of known large animals, such as kangaroos.

In this response, PST #13 not only provides a well-reasoned explanation for the structural stability of the dinosaur skeleton but also connects their explanation to prior scientific knowledge about the center of gravity and analogies to known animals, reflecting an informed view.

Discussion

The results showed that prior to the intervention, PSTs demonstrated a better understanding of “questions guide procedures (NOSI 3)” and “conclusions consistent with data (NOSI 6)” compared to other aspects, with over 40% of PSTs holding informed views on these dimensions. Similar findings have been reported in studies such as Leblebicioğlu et al. (2020) and Özer and Sarıbaş (2023), which also identified these two as the most developed NOSI aspects. One possible explanation is that the VASI questionnaire presents these aspects in a contextualized format, requiring respondents to select and justify the most appropriate option—a format that aligns with regular and high-stakes tests, making it more familiar to participants. Additionally, logical reasoning likely contributes, as the correct answers often align with the most logical choice (Leblebicioğlu et al., 2020).

In contrast, over 70% of PSTs held naive or mixed views on the remaining six aspects of NOSI. This may be due to several factors. On one hand, some aspects of NOSI are relatively abstract and difficult to grasp, such as variability of scientific conclusions (NOSI 4) (Lederman et al., 2021; Metin Peten, 2022) and explanation constructed based on data and existing knowledge (NOSI 8) (Güngören & Öztürk, 2021). On the other hand, this may also be attributed to PSTs' limited learning experiences related to NOSI. First, although NOSI is somewhat emphasized in Chinese science curriculum standards, it rarely appears in science textbooks and is seldom explicitly mentioned in science classrooms (Gai et al., 2022; Yang et al., 2019). Second, many science teachers have limited understanding



of NOSI (Kan et al., 2024; Wang & Zhao, 2016), which leads them to emphasize scientific inquiry skills more than fostering students' understanding of NOSI.

After the intervention, PSTs demonstrated significant improvements in their understanding of all NOSI aspects, with increased proportions of informed views and corresponding declines in naive views. Notably, no PSTs retained naive views regarding NOSI 2, NOSI 3, and NOSI 6. These outcomes indicate that the intervention, grounded in the 5E model and explicit-reflective NOSI teaching, effectively supported the development of more sophisticated NOSI understanding among PSTs. This improvement can be attributed to the 5E model, which actively engaged PSTs in scientific inquiry and structured their learning experiences through explicit teaching and reflective discussion to reinforce key aspects of NOSI.

The engagement phase played a crucial role in improving PSTs' understanding that scientific inquiry begins with a question (NOSI 1). Each activity started with a real-world scenario and thought-provoking questions, prompting PSTs to recognize that inquiry is a question-driven process. This experience, combined with the lecturer's explicit guidance on the role of questions in scientific inquiry, helped shift PSTs' understanding from naive to informed.

During the exploration phase, PSTs actively designed and conducted inquiry activities, making decisions about variables, procedures, and data collection. Meanwhile, the lecturer explicitly prompted PSTs to justify their methodological choices in light of their research questions, reinforcing the link between question type and method selection. This hands-on experience deepened their understanding of how research questions shape inquiry approaches (NOSI 3) and how scientific questions may require different inquiry strategies (NOSI 2). Exposure to a range of inquiry formats—from controlled experiments to field observations—demonstrated the diversity of scientific methods and how each must be tailored to the nature of the question under research.

The explanation phase, which incorporated explicit-reflective NOSI teaching, contributed to gains in multiple NOSI aspects. Guided discussions following data analysis allowed PSTs to distinguish raw data from evidence (NOSI 7), recognize the importance of grounding conclusions in empirical findings (NOSI 6), and understand that scientific knowledge involves both new evidence and existing theoretical frameworks (NOSI 8). Group presentations further supported reflection on differences in interpretations (NOSI 4) and highlighted how individual choices during data collection influence outcomes (NOSI 5). The lecturer facilitated reflective discussion by posing targeted NOSI questions (e.g., "How did your evidence support your conclusion?" or "Would others reach the same result using your procedure?"), explicitly drawing attention to the underlying NOSI principles. These structured opportunities for reflection and peer dialogue provided critical support for PSTs in recognizing the fundamental characteristics of scientific inquiry, such as the importance of scientific questions, the diversity of inquiry methods, the logical relationship between evidence and data, and the empirical basis for drawing conclusions (Antink-Meyer, 2016; Lederman et al., 2014; Metin Peten, 2022), thereby enabling a deeper understanding of NOSI.

While the intervention significantly enhanced PSTs' understanding of all NOSI aspects, two aspects—NOSI 4 (the variability of scientific conclusions) and NOSI 7 (the distinction between data and evidence)—showed relatively limited improvement. The percentage of PSTs holding informed views increased from 10.64% to 19.15% for NOSI 4, and from 14.89% to 34.04% for NOSI 7, both showing smaller gains compared to other aspects. From the perspective of conceptual change theory (Posner et al., 1982; Pacaci et al., 2024), conceptual difficulties often arise from deeply rooted misconceptions that are unlikely to be replaced unless meaningfully challenged. Regarding NOSI 4 and NOSI 7, both prior studies (Gai et al., 2022; Gyllenpalm et al., 2022; Metin Peten, 2022) and findings from the present study indicate that such misconceptions are particularly persistent. Without sufficient cognitive conflict and appropriate scaffolding, these misconceptions are unlikely to be fully replaced by informed understandings.

Beyond conceptual misconceptions, the limited conceptual restructuring may also relate to the design of the inquiry activities. According to cognitive load theory (Sweller, 1988; Sweller et al., 2019), learning is influenced by the balance between intrinsic, extraneous, and germane cognitive load. In this study, most activities followed similar procedures and yielded consistent results, offering few chances for PSTs to experience the variability and subjectivity of scientific interpretation. While the structured design may have reduced extraneous load, it lacked sufficient intrinsic complexity to prompt deeper epistemological development. Similarly, the data analysis tasks were relatively simple, which primarily consisted of identifying basic patterns, rather than engaging in advanced reasoning. This likely limited opportunities for the development of a more nuanced understanding of how scientific evidence is constructed. These findings suggest that promoting deeper NOSI understanding, especially of aspects that are conceptually demanding or resistant to change, requires the design of inquiry activities that include sufficient cognitive challenge and explicit teaching support.

The findings of the current study support the effectiveness of the 5E model in enhancing PSTs' understanding of NOSI, aligning with Mesci et al. (2020), that has demonstrated the potential of the 5E model in NOSI teaching,



showing notable gains in three NOSI aspects. However, while both studies employed the 5E model and demonstrated its effectiveness, their findings differ in some NOSI aspects. Mesci et al. (2020) reported limited improvement in aspects, such as “questions guide procedures (NOSI 3)”, “conclusions must be consistent with data (NOSI 6)”, and “procedures influence results (NOSI 5)”, whereas the present study observed substantial improvements in these areas. A possible explanation for this difference lies in the teaching design. In Mesci et al. (2020)’s study, PSTs primarily engaged in lesson planning using the 5E model, emphasizing how to teach NOSI rather than directly experiencing it. In contrast, the present study immersed PSTs in inquiry-based activities, requiring them to formulate research questions, design data collection procedures, and analyze data. This hands-on approach, combined with explicit-reflective discussions, may have been more effective in deepening PSTs’ understanding of how research questions shape procedures, how data support conclusions, and how procedural variations can influence results.

The effectiveness of inquiry-based methods in NOSI education has been documented across various teaching models. Beyond the 5E model, studies have explored approaches such as argument-driven inquiry (ADI) and problem-based learning (PBL), demonstrating their effect on different aspects of NOSI understanding. For instance, Erenler et al. (2024) employed argument-driven inquiry (ADI) in a climate change education context, leading to significant improvements, such as multiple aims of scientific research and outlier data detection and handling. Similarly, Özer & Doğan (2024) found that integrating creative problem-based learning (PBL) strategies with historical perspectives on science significantly enhanced PSTs’ understanding of how questions guide procedures (NOSI 3) and how scientific explanations are constructed based on data and existing knowledge (NOSI 8). These studies, like the present study, highlight the value of inquiry-based teaching methods enriched with an explicit-reflective strategy in fostering PSTs’ NOSI understanding. The 5E model provides a structured and progressive learning experience, systematically integrating explicit-reflective teaching within inquiry-based learning. Compared to other inquiry-based strategies, such as ADI and PBL, the 5E model ensures a coherent teaching sequence that guides PSTs from exploration to reflection, reinforcing their NOSI understanding in a systematic manner.

Conclusions and Implications

This study demonstrates that integrating explicit-reflective NOSI teaching within the 5E model effectively enhances PSTs’ understanding of NOSI. As an early attempt to use the 5E model as a contextual framework for NOSI teaching in PST education, this study provides a new perspective on NOSI pedagogy. As a well-established and widely adopted teaching model, the 5E model provides a promising framework for the broader integration of NOSI teaching, particularly in contexts similar to the Chinese education system.

Based on the findings of this study, several recommendations can be made for curriculum development in teacher education. First, NOSI aspects should be systematically embedded across the 5E phases, aligning each phase with relevant NOSI concepts (e.g., emphasizing the role of questions during Engage and the data–evidence distinction during Explain). To reinforce this integration, reflective prompts should be incorporated to guide PSTs in analyzing their inquiry experiences in relation to NOSI concepts. Moreover, course activities can be purposefully designed to support the simultaneous development of procedural inquiry skills and epistemic understanding of NOSI. Course assessment should likewise include evaluation of NOSI understanding. Finally, the findings suggest that beyond the structural support of the 5E model, the nature of learning activities is crucial. As previously discussed, PSTs showed relatively limited improvement in NOSI 4 and NOSI 7, possibly due to persistent misconceptions and low cognitive challenge. Therefore, inquiry activities should intentionally introduce cognitive conflict, provide appropriate scaffolding, and incorporate sufficient epistemic complexity to support conceptual change and deeper NOSI understanding.

This study represents an early effort to establish the 5E model as a contextual framework for NOSI teaching in PST education. Future research should explore its effectiveness across different educational settings, including K–12 classrooms and teacher education programs situated in different educational system contexts. Comparative studies could examine how the 5E model performs relative to other inquiry-based approaches, such as ADI or PBL. Additionally, longitudinal studies are needed to assess whether improvements in PSTs’ NOSI understanding translate into sustained changes in their inquiry-based teaching practices. Future research could also employ clustering or typological analyses to identify patterns of NOSI understanding at the individual level, offering insights for more targeted teaching interventions that better support diverse PSTs.

However, there are several limitations to consider. First, the sample consisted of 47 PSTs from a single Chinese university, which may limit the generalizability of the findings. Future research should include a more diverse sample across different institutions and regions. Second, this study was conducted within a teacher-centered



Chinese teacher education system, which differs from educational systems where inquiry-based teaching is more prevalent. This difference in initial exposure to inquiry-based learning and NOSI teaching may impact the efficacy of integrating the 5E model with an explicit-reflective strategy. Future research should explore how cultural and institutional contexts affect the implementation and outcomes of such teaching strategies and examine whether this approach yields comparable results in different educational systems.

Declaration of Interest

The authors declare no competing interest.

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