

Pre-service Teachers' Conceptions of the Nature of Science and their Attitudes toward NOS Instruction: Implications for Course Development

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ABSTRACT

Conceptualizing the nature of science (NOS) is a crucial component of science education, as it facilitates students' comprehension of how scientific knowledge is developed. Unfortunately, teachers can themselves hold inaccurate views of NOS or assume students can infer NOS ideas from instruction or by undertaking experiments. Building on previous research, this study explores how pre-service primary school teachers conceive NOS and their readiness and attitudes toward teaching NOS in primary school (grades 1-4). Data collected from future primary school teachers using the "Views on Science Education (VOSE)" instrument tend to align with previous studies, indicating that future primary school teachers generally hold positive attitudes toward the need to conceptualize NOS, but continue to believe in a single, universal scientific method, the idea that scientific theories and laws are discovered and the notion that science is entirely objective. Based on these findings, a restructured pre-service science education course is proposed.

KEY WORDS: Course development; nature of science; NOS conceptualization; pre-service primary school teacher attitudes

INTRODUCTION

Today's technological and uncertain world faces numerous science-related issues, such as climate change, virus mutations, as well as political and economic crises driven by technological advancements and disasters (Kaspersen and Egholm, 2021). However, reliance on non-scientific and unverified developments risks disseminating misinformation, diminishing learning quality, misdirecting resources, and eroding public trust when seeking solutions, instead of prioritizing evidence-based, scientifically validated actions (Michal et al., 2021). In preparing future citizens to deal with complex problems (problems that are difficult to define and solve because of their interconnected, evolving and often contradictory aspects), the conceptualizing of NOS is seen as crucial in enabling students to make informed, evidence-based decisions and recognize that NOS refers to the fundamental characteristics and principles that define scientific knowledge and practices (Abd-El-Khalick and Lederman, 2000; Abd-El-Khalick et al., 2008).

Previous research has shown that both students and teachers struggle with conceptualizing NOS (Akerson et al., 2010; Dogan and Abd-El-Khalick, 2008; Lin and Chan, 2018; Rannikmäe et al., 2017). Of particular concern is that teachers often share misconceptions with their students, such as the belief that hypotheses evolve into theories and theories into laws, the idea that science is an entirely objective field, unaffected by prior knowledge or experiences, or the

misconception that there is a single universal scientific method (Cofré et al., 2019; Kampourakis, 2016; McComas, 1998).

Research indicates that while pre-service teachers generally understand the empirical aspects of NOS, they, along with in-service teachers, often maintain naïve views about the relationship between theories, laws and observations (Bugingo et al., 2024; Cofré et al., 2019; Karaman, 2018). Misconceptions regarding the socio-cultural aspects of science, such as the belief that science is culturally neutral and disconnected from ethics and society, are also common (Faikhamta, 2020). Fortunately, targeted interventions have proven effective in addressing such misconceptions (Akerson et al., 2008).

Studies have consistently shown that where pre-service and in-service science teachers hold incomplete or naïve conceptions of NOS (Cofré et al., 2019; Lederman, 2007; Mesci, 2020), this lack is unintentionally passed on to their students. This is particularly the case when teacher education programs do not adequately address NOS (Bugingo et al., 2024). Research has shown that teachers' conceptualization of NOS impacts students' science learning outcomes, and an incorrect portrayal of NOS by teachers can lead to lower student performance and the development of misconceptions (Khishfe, 2025). However, Estonian 14–15-year-old students, as an outcome of the science education provision from the first two school levels, have achieved high results in the past PISA science studies (OECD, 2023).

This study, based on the poor pre-service primary school teachers' conceptualization of aspects of NOS, yet their readiness and positive attitudes toward teaching NOS in primary school (Grades 1-4), seeks to develop a special course for students to prepare them to teach NOS in the classroom. The following research questions are put forward:

1. What are pre-service primary school teachers' conceptions of the nature of science (NOS)?
2. What are the attitudes of pre-service primary school teachers toward teaching the NOS in primary school (grades 1-4)?
3. What is an appropriate course design for pre-service teachers to promote NOS conceptualizations suitable in the teaching of science at the primary school level?

LITERATURE REVIEW

NOS

According to Lederman (1992), NOS refers to the epistemology of science, viewing NOS as a way of knowing that encompasses the roles of scientists and the values and beliefs that shape the development of scientific knowledge. However, Clough and Olson (2008) suggest defining NOS simply as “knowing how science works.”

Conceptualizing NOS is seen as crucial for developing scientific literacy, whereby a scientifically literate person is expected to be able to:

- (a) Pose curiosity-driven questions to solve problems.
- (b) Interpret, analyze and explain natural phenomena.
- (c) Critically evaluate science-related information.
- (d) Distinguish scientifically accurate ideas from misconceptions, and
- (e) Construct evidence-based arguments while solving problems and making decisions (Akerson et al., 2019; Holbrook and Rannikmäe, 2007; OECD, 2023).

The promoting of NOS is typically addressed either through educational standards, or by drawing on insights from philosophy, history, and sociology to inform effective classroom teaching (Kampourakis, 2016). Several researchers (e.g., Abd-El-Khalick and Lederman, 2000; Khishfe and Abd-El-Khalick, 2002) have outlined key elements of NOS that are both teachable and learnable in school settings. These elements are often referred to as the “general aspects” approach to NOS (Kampourakis, 2016) or the “consensus view” (Lederman, 2007).

Key Elements of NOS for School Education

The tentative nature of scientific knowledge

The tentative nature of scientific knowledge indicates that while it is shown to be reliable and persistent, it is never absolute. All forms of knowledge, such as facts, theories, and laws, evolve and are revised in light of new evidence or reinterpretations (Abd-El-Khalick, 2012). Findings by Akerson et al. (2019) indicate that many pre-service teachers hold a simplistic view of this aspect of NOS. A survey of 204 pre-service teachers in

the Philippines has shown that while most (84.8%) recognize the evolving nature of scientific theories, many believe theories derived from accurate experiments are unchanging (Pelaez et al., 2025). Similarly, a pre-intervention study in Turkey has revealed mixed views before undertaking an intervention: 6 students from 56 participants in the pre-intervention believe science is unchanging, others indicated uncertainty or not able to provide examples of scientific evolution (Mesci, 2020).

The distinction and relationship between scientific theories and laws

Studies have shown that many teachers do not fully understand what constitutes a scientific theory and a law, indicating a common misconception that scientific theories transform into laws after repeated validation (Pelaez et al., 2025; Stefanidou and Skordoulis, 2017). Many teachers also mistakenly believe that scientific theories are less certain or reliable than laws. Even after receiving relevant training, teachers continue to struggle with understanding the relationship between theories and laws (Buggingo et al., 2024).

The interplay of observations and inferences

While observations involve directly collecting information about natural phenomena using the senses, or indirectly through instruments, inferences refer to conclusions, or aspects of knowledge that cannot be directly perceived or measured (Buggingo et al., 2024). Observations are often influenced by the observer's expectations and preconceptions, thus meaning they are theory-laden. In other words, the interpretation of observations can be shaped by existing theories or beliefs (Abd-El-Khalick, 2012). Nevertheless, research indicates that following specialized training, participants are able to distinguish between observations and inferences (Mesci, 2020).

The role of creativity and imagination in scientific processes

Both creativity and imagination play a crucial role in scientific processes, as they are employed by scientists to generate ideas, collect and analyze data, and develop theories and models (Buggingo et al., 2024). Research indicates that although many teachers recognize the importance of imagination in science, their understanding of its practical application remains limited. For instance, they often face challenges in articulating their conceptions and providing pertinent examples of how imagination is applied within scientific processes (Karaman, 2018; Mesci, 2020).

The influence of social, cultural, and political contexts on science

The development and validation of scientific knowledge are deeply embedded in social, cultural, and political contexts. Yet research shows that pre-service teacher education students often underestimate the extent of these influences, even while recognizing that cultural values can shape the direction and acceptance of scientific research (Faikhamta, 2020). These contextual influences are profound and multifaceted. The social context includes, for example, the role of societal

needs in shaping research agendas; the cultural context involves the impact of cultural norms on science education; and the political context manifests in policy decisions and international scientific collaboration (Abd-El-Khalick, 2012; Abd-El-Khalick and Lederman, 2000).

The nature and diversity of scientific methods

Scientific methods are inherently diverse, with scientists selecting the most appropriate approach based on the research topic and objectives (Krell et al., 2015). Despite this diversity, a prevalent misconception about NOS is the belief in a universal, step-by-step scientific method (Faikhamta, 2020; McComas, 1998). Research has demonstrated that, while many teachers acknowledge the use of various methods in scientific inquiry, they continue to hold the belief in a precise, sequential process that guarantees accurate and reliable results (Akerson et al., 2008; Pelaez et al., 2025).

Scientific knowledge is based on empirical evidence

Scientific claims are based on observing natural phenomena and plus scientific explanations aligning with the evidence collected (Abd-El-Khalick, 2012). The claims are formed by interpreting these observations. This aspect is more familiar to teachers and can be effectively addressed through appropriate instruction (Mesci, 2020).

The inherent subjectivity of scientific knowledge

Scientific knowledge is inherently shaped by the personal beliefs, values, prior knowledge, creativity, and available opportunities of scientists. This subjectivity may influence various aspects of scientific work, including observations, theory selection, and data interpretation (Chen, 2006b). Empirical studies undertaken with pre-service teachers indicate that targeted instruction can effectively enhance their understanding of the subjective dimensions of science (Valencia Narbona et al., 2022).

Overall Conclusion of Teachers' Understanding about NOS

Previous studies have consistently shown that pre- and in-service teachers often encounter difficulties in understanding key aspects of the NOS. Common challenges include misconceptions about the relationship between scientific methods and theories or laws (Dogana and Abd-El-Khalick, 2008), as well as limited understanding of the distinction between observations and inferences (Cofré et al., 2019). Furthermore, many teachers struggle to recognize the influence of social and cultural contexts on scientific inquiry (Lin and Chan, 2018), despite the recognition that science is not entirely objective and is shaped by scientists' values, backgrounds, and historical contexts.

Lin and Chan (2018) emphasize that teachers' naïve conceptions of NOS can significantly hinder effective science instruction, thereby necessitating sustained professional development. As highlighted by Anderson and Moeed (2017), the successful implementation of NOS-related content in school curricula depends on equipping teachers with the necessary pedagogical tools and conceptual understanding to foster students' scientific literacy. Empirical evidence supports

the use of explicit and reflective approaches as a particularly promising strategy for NOS instruction (Mesci and Schwartz, 2017). Such approaches involve intentional integration of NOS concepts, clear instructional goals, structured opportunities for student reflection, and varied assessment methods (Akerson et al., 2010; Ward and Haigh, 2017). NOS elements are addressed explicitly and connected to students' personal and prior experiences, often through contextualized examples. This supports a deeper understanding of science as a dynamic process, helps overcome misconceptions by inducing cognitive dissonance and fostering conceptual change (Witucki et al., 2024).

Contextualized NOS instruction aligns well with teaching through the history of science, inquiry-based learning, and socio-scientific issues (Fouad et al., 2015; Khishfe and Lederman, 2006; Namakula and Akerson, 2024). The history of science, in particular, offers an effective means to introduce NOS in early education, as diverse historical cases reinforce abstract ideas and provide opportunities for meaningful classroom discussions. Such discussions allow learners to share their perspectives and consider those of their peers (Witucki et al., 2024). Consequently, it is recommended to structure NOS instruction beginning with the history of science (HOS), followed by scientific inquiry (SI), and finally socio-scientific issues (SSI), as this sequence supports both the development and long-term retention of students' NOS understanding, thereby advancing broader goals of scientific literacy (Khishfe, 2023).

In addition to pedagogical knowledge, teachers' intentionality and commitment to NOS instruction have been identified as critical factors for successful implementation. Teachers who value NOS and purposefully embed it in their teaching practices tend to be more effective in conveying its principles to students (Bugingo et al., 2024; Clough, 2018). Furthermore, thoughtful design of the learning environment-including task structure, instructional strategies, and multimodal learning opportunities-has been shown to support students in constructing meaningful understandings of NOS (Cheung et al., 2025).

These principles align closely with the theory of social constructivism, which views learning as an active, contextual process shaped through interaction with others. Within this framework, the teacher's role is to create conditions for meaningful learning by helping students connect new concepts with prior experiences. Such an approach reinforces effective NOS instruction by highlighting the social and cultural dimensions of science and fostering students' critical thinking and scientific literacy (Rannikmäe et al., 2020).

School Education in the Estonian Context

Primary school teaching

In Estonia, primary school teachers are responsible for instructing and guiding the youngest pupils at the basic school level (grades 1–4, ages 7–11) across all core subjects, including the Estonian language and literature, mathematics,

and natural sciences. Typically, they also possess an additional specialization (e.g., a foreign language or crafts), which they may teach throughout the basic school level. In addition to delivering subject content, primary school teachers support students' development by addressing their interests, knowledge, skills and individual needs, in alignment with the goals set forth in the national curriculum. Furthermore, they serve as class teachers, maintaining a positive classroom environment and engaging in regular collaboration with parents. A master's degree and a formal teaching qualification are required to work as a primary school teacher in Estonia (Haridusportaal, n.d.) and teacher education can be pursued through an integrated bachelor's and master's degree program at one of two Estonian universities.

Teacher training and NOS instruction

The primary school teacher curriculum at the University of Tartu (Primary School Teacher, 2025) does not include dedicated courses focused explicitly on the systematic teaching of NOS. Nevertheless, various aspects of NOS are addressed across several subjects. For example, some courses, designed to support the preparation of a master's thesis, cover topics such as research methodology and ethics. In addition, discipline-specific courses incorporate discussions of significant scientific achievements and developments in their respective fields.

Studies on NOS understanding

The Estonian National Curriculum for Basic Schools, adopted in 2011, includes references to aspects of NOS (National Curriculum, 2011a). In its updated 2023 version, the explicit inclusion of NOS instruction is further emphasized (National Curriculum, 2011b).

While relatively few empirical studies have examined NOS understanding in Estonia, a longitudinal study among upper secondary students (aged 16–19) has indicated limited progress in students' understanding of NOS over time. However, the participants are predominantly shown to hold positivist views and to struggle to differentiate between scientific and pseudoscientific claims (Rannikmäe et al., 2017). A comparable research at the primary school level is lacking and overall, teachers' conceptions of NOS have not been systematically explored. This points to a clear need for further investigation into how the NOS is understood and taught in Estonian schools.

METHODOLOGY

This study sought to pilot an adapted instrument determining pre-service teacher's views on NOS and obtain input for the development of a pre-service course focused on improving NOS understanding for students training to become primary school teachers.

The study was based on a purposive sample of integrated (5-year program) bachelor's and master's degree students studying to become primary school teachers. The pre-service primary school teachers were 2nd or 3rd-year students (Table 1). All respondents were female.

Table 1: Participants and time of data collection (total, N=130)

Participants	Time
21 3 rd -year students	2020 spring semester
29 3 rd -year students	2020 autumn semester
21 3 rd -year students	2021 autumn semester
27 2 nd -year students	2022 spring semester
32 2 nd -year students	2023 spring semester

Participants were considered as a single group, with no comparisons made between different years.

Instrument

Previous research showed that quantitative methods were effective in evaluating differences in respondents' understanding of NOS (Krell et al., 2015). Accordingly, an adapted version of the "Views on Science and Education" (VOSE) questionnaire (Chen et al., 2006a) was used to assess students' perceptions of NOS and their attitudes toward incorporating NOS in their teaching. The questionnaire consisted of 14 questions, each followed by 3-9 statements, designed to measure both respondents' NOS perceptions and teaching attitudes about the following NOS aspects:

1. The tentativeness of scientific knowledge;
2. The nature of observation;
3. Scientific methods;
4. Theories and laws;
5. Subjectivity and objectivity;
6. The role of imagination; and
7. The validation of scientific knowledge.

Responses were rated on a 5-point Likert scale (1 = Strongly disagree; 2 = Disagree; 3 = Uncertain or no comment; 4 = Agree; 5 = Strongly agree).

Adaptation

The English version of the VOSE questionnaire was translated into Estonian. For one question (No. 14), a new, extended introductory text was developed using the example of the Estonian Genome Centre, as the original context was not seen as relevant for Estonian respondents. To ensure accuracy and clarity, the questionnaire was back-translated. Only minor discrepancies, such as differences in time expressions and terminology, were identified, none of which required changes to the original content. To ensure content validity, subject-matter experts (the article's co-authors) were involved in the adaptation process. The questionnaire was then piloted with students enrolled in a primary school teacher training program. To assess the comprehensibility of the instructions and items, a focus group interview was conducted with three students who had completed the questionnaire.

Data Collection

The survey was administered online through Google Forms. The survey link was sent to students via email, which

included information about the aims of the study, instructions for completing the questionnaire, and an explanation of how anonymity would be maintained. Participation was voluntary. Respondents were required to rate all statements. To minimize order effects, participants were instructed to read all related statements before responding to each question. Confidentiality was ensured through the use of identification numbers. Data collection was carried out between 2020 and 2023.

Data Analysis

The data for the present study were collected and analyzed quantitatively. Each of the seven aspects of the NOS, as described in the instrument section, was analyzed separately. Accordingly, the statements were grouped into seven subcategories based on the original questionnaire (Chen, 2006b). Individual scores for each respondent were calculated in Excel and subsequently analyzed using JASP 0.18.3 to compute descriptive statistics (frequencies, means, and standard deviations).

To assess internal reliability, McDonald's ω was calculated for each subcategory (12 items were reverse-coded for this purpose). The internal consistency coefficients for the subcategories assessing pre-service teachers' understanding of NOS ranged from 0.45 to 0.81. For teaching attitudes, reliability coefficients ranged from 0.64 to 0.82, which were seen as comparable to the results reported in the original questionnaire (Chen, 2006b). These variations were likely due to some categories containing items reflecting independent views.

RESULTS

Pre-service Primary School Teachers' Understanding of the NOS

To assess pre-service primary school teachers' conceptions of NOS, 9 of the 14 questionnaire items specifically focused on NOS-related concepts. Responses were rated on a five-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (5), with a midpoint value of 3 indicating uncertainty or no opinion. As most NOS issues multifaceted, as reflected in the position categories presented in Table 2, the score for each issue was calculated as the mean of several related items.

The study revealed that pre-service teacher students demonstrated an insufficient understanding of several components of NOS. While most participants acknowledged the tentativeness of scientific knowledge, evidenced by agreement with the statement that scientific knowledge changes through a cumulative process (mean score above 4), they also exhibited several misconceptions in other NOS aspects.

A prevailing misconception among respondents was that scientists do not use their imagination and that science is entirely objective. In addition, many students supported the naive view that there is a single universal scientific method.

The results indicated that respondents tended to:

- Agree with the view that both scientific theories and laws are discovered rather than invented;
- Support the common misconception that scientific laws are more certain than theories;

Table 2: Pre-service primary school teachers' perceptions of different aspects of the nature of science (N=130)

NOS issue	ω	Focus	No. of items	Mean**	SD	% "Uncertain/no comment"
Tentativeness	0.45	Revolutionary	1	3.65	1.00	~20
		Cumulative*	1*	3.94	0.85	~14
		Evolutionary*	1*	3.22	1.13	~19
Nature of observation	0.51	Observations theory-laden	2	3.22	0.63	~23
		Observations theory-independent	2	3.34	0.76	~12
Scientific methods	0.55	There is a diversity of methods	3	3.01	0.54	~37
		The universal scientific method	2*	3.80	0.64	~25
Theories and laws (epistemology)	0.64	Discovered	4	3.79	0.51	~20
		Invented	5	2.81	0.62	~34
Theories and laws (comparison)	0.51	Laws are more certain	2*	3.62	0.76	~24
		Different types of ideas	2	3.19	0.67	~41
Use of imagination	0.83	Yes	2	2.97	0.99	~21
		No	3*	3.18	0.84	~27
Validation of scientific knowledge	0.61	Empirical evidence	1	2.25	1.18	~20
		Paradigm	2	2.67	0.78	~25
		Parsimony	1	1.50	0.66	~7
		Authority	1	2.80	1.10	~34
		Intuition	1	1.65	0.78	~16
Subjectivity and objectivity	0.65	Subjectivity	11	2.60	0.45	~22
		Objectivity	12	3.49	0.41	~22

ω : McDonald's omega, SD: Standard deviation. *Reverse items for reliability analysis. **Rating scale (1=Strongly disagree; 2=Disagree; 3=Uncertain or no comment; 4=Agree; 5=Strongly agree)

- Tend not to take a clear position on whether theories and laws represent different types of ideas.

Pre-service Primary School Teachers' Attitudes toward Teaching Aspects of the NOS in Primary Education

To assess primary school teachers' attitudes toward teaching aspects of the NOS in primary education, five related items were included in the questionnaire and rated using the same five-point Likert scale. The statements associated with each question reflected opposing viewpoints; therefore, the items were organized into subcategories and analyzed separately (Table 3).

Primary school teachers' attitudes toward teaching NOS topics were generally positive (Table 3). The most positive attitude was toward teaching the tentativeness of scientific knowledge. The respondents acknowledged that observations are theory-laden and recognized the importance of teaching this concept to students. The lowest acceptance was regarding the idea that students should be taught to make objective observations.

Overall

The results of the study indicated a need to pay greater attention to various aspects of NOS in teacher training. The data revealed that students possessed simplified understandings of several NOS components (Table 2) and exhibited significant misconceptions. The most challenging for respondents was understanding the epistemology of theories and laws, as well as their interrelationship. A common misconception was that laws were more certain than theories ($M = 3.68$; $SD = 0.96$), with respondents also supporting the view that laws had more supporting evidence and that a theory eventually became a law ($M = 3.56$; $SD = 0.90$). Respondents frequently agreed with the idea that a scientific theory is "discovered because it is based on experimental facts" ($M = 3.72$; $SD = 0.82$). The respondents' uncertainty and lack of awareness on this topic were further indicated by the high frequency of "uncertain or no comment" responses (Table 2).

A further common misconception was that most scientists followed a step-by-step universal scientific method in conducting research because it "guarantees valid and accurate

results" ($M = 3.69$; $SD = 0.82$) and is considered "a logical way of working" ($M = 3.92$; $SD = 0.68$). Similarly, a common belief was that imagination and science did not go together because "imagination lacks reliability" ($M = 3.38$; $SD = 1.08$).

Despite these misconceptions, the respondents expressed a clear appreciation for the importance of teaching NOS topics in schools (Table 3). This indicated recognition of the value of NOS education, even if their own understanding of the topics was still developing.

DISCUSSION

Pre-service Primary School Teachers' Understanding of the NOS

This study investigated how pre-service primary school teachers understood NOS and explored their readiness and attitudes toward teaching NOS in grades 1–4. The findings revealed that pre-service teachers' conceptions of the NOS were often contradictory and frequently misaligned with contemporary scientific views and, as such, the results were consistent with previous international studies (Buingo et al., 2024; Karaman, 2018; Pelaez et al., 2025). Respondents also frequently expressed uncertainty in their responses. For instance, in questions comparing scientific theories and laws, the option "uncertain/no comment" was selected in up to 40% of cases. This was taken to suggest that specific aspects of NOS were not explicitly addressed in their prior education, resulting in underdeveloped or unclear views regarding NOS.

The pre-service teacher education students who participated in the study tended to endorse the idea of a single, universal scientific method. This idea aligned with some of the most common misconceptions in science education (McComas, 1998; Pelaez et al., 2025). This view was seen as stemming from a lack of distinction between "scientific method" and "scientific inquiry." While the scientific method was often presented as a rigid, step-by-step process, commonly found in textbooks and associated with experimental studies, scientific inquiry referred to the broader, flexible, and systematic approaches scientists used to investigate research questions. Scientific inquiry thus

Table 3: Pre-service primary school teachers' attitudes toward teaching aspects of the nature of science in primary school (N=130)

NOS issue	ω	Position on teaching NOS	No. of item	Mean*	SD	% "uncertain/no comment"
Tentativeness	0.72	Teaching the tentativeness of scientific knowledge	2	4.17	0.50	~7
		Avoid teaching the tentativeness of scientific knowledge	3	1.91	0.44	~11
Nature of observation	0.78	Teaching students to make an objective observation	3	2.96	0.91	~16
		Revealing the theory-laden nature of observation	2	3.62	0.77	~19
Scientific methods	0.64	Teaching the universal scientific method	6	3.47	0.50	~22
		Encouraging different methods	3	3.17	0.56	~26
Theories and laws	0.82	Teaching the relationship between theories and laws	2	3.69	0.70	~22
		Avoid teaching the relationship	2	2.21	0.68	~25
Subjectivity and objectivity	0.67	Teaching subjectivity	4	3.86	0.50	~15
		Emphasizing objectivity	2	3.21	0.92	~27

ω : McDonald's omega, SD: Standard deviation. *Rating scale (1=Strongly disagree; 2=Disagree; 3=Uncertain or no comment; 4=Agree; 5=Strongly agree)

encompassed a variety of methods, including descriptive, correlational, and exploratory approaches (Lederman et al., 2013). When future teachers were shown to hold such narrow views, they might unintentionally pass on these misconceptions to their students, limiting their understanding of how science truly functioned.

The study also revealed that the students had difficulty understanding the differences and interrelationships between scientific theories and laws, an area which many researchers identified as one of the most challenging aspects of NOS (Pelaez et al., 2025; Stefanidou and Skordoulis, 2017). The student teachers tended to express a traditional view, believing that theories and laws were discovered, not invented, and that laws were more certain than theories. A more contemporary view of scientific knowledge would regard scientific knowledge as permanent, but not absolute, suggesting that knowledge could evolve over time through revolutionary, evolutionary, or even cumulative processes (Chen, 2006b). A more typical view among primary student teachers (with an average score above 4) was that scientific knowledge changed through a cumulative process. All findings were found to align with those of previous studies (Cofré et al., 2019; Mesci and Schwartz, 2017; Stefanidou and Skordoulis, 2017).

The results of the study indicated that students often held the view that science was objective, which did not fully align with contemporary scientific perspectives (Cofré et al., 2019). A modern conceptualization of science was one which emphasized that researchers were creative agents who used their imagination to formulate questions and conduct research, including data collection, analysis and interpretation. In addition, the literature suggested there was a need to highlight that science was deeply connected to societal and cultural influences as a human endeavor (Sengul, 2023).

In summary, these findings suggested that pre-service primary school teachers demonstrated a lack of awareness regarding several key aspects of NOS. This was taken to indicate that their previous formal education had not sufficiently addressed the epistemology of science. It was suggested that this gap might have arisen from an inadequate emphasis on NOS within the curriculum or from the limited understanding of the teachers themselves. Considering that the study participants were seen as future primary school teachers, laying the foundation for the learning of science, these results emphasized the urgent need to revise the teacher education curriculum, ensuring it integrates the essential topics to ensure an accepted view of NOS.

Pre-service Primary School Teachers' Attitudes toward Teaching Aspects of the NOS in Primary Education

The attitude of pre-service primary school teachers toward teaching the studied aspects of NOS was predominantly positive. The pre-service students placed significant value on teaching both the tentativeness of scientific knowledge and the understanding that observations were theory-laden. While the pre-service primary school teachers' own conceptions of

scientific theories and laws were limited, they nonetheless recognized the importance of teaching these concepts to students in school. Given that the pre-service students endorsed the notion of a single, universal scientific method, it was not surprising that they believed this perspective should also be introduced to primary school students. In summary, it can be inferred that although the pre-service student teachers' conceptualizations of NOS were insufficient for them to teach this component in school, their perceived willingness to do so was high.

Aspects of the NOS Requiring More Comprehensive Coverage in Teacher Training

The results of this study indicated that pre-service primary school teachers had a limited understanding of several key aspects of NOS, underscoring the need for a more comprehensive and structured approach to these topics within teacher training curricula. Specifically, participants demonstrated misconceptions and oversimplified understandings concerning:

- (a) The universality of the scientific method,
- (b) The objectivity of science and
- (c) The hierarchical relationship between scientific theories and laws.

These findings suggested that the treatment of NOS in teacher education required a more systematic and explicit integration. It was seen as essential to incorporate these key NOS aspects in a clear and comprehensive manner into the pre-service curriculum, ensuring that the exploration of scientific knowledge—its formation, evaluation, and evolution over time—was thorough. Such an approach was seen as not only clarifying complex concepts for future educators, but also equipping pre-service students with the necessary tools to effectively teach these concepts to their future students, thereby enhancing both their scientific literacy and pedagogical competences.

To improve future primary school teachers' understanding of the application of the scientific method in various contexts, it was seen as critical to provide concrete examples during pre-service courses that demonstrated how different scientific problems could be addressed using diverse teaching methodologies. By illustrating how scientists applied various approaches to answer different types of questions during pre-service teaching, teachers could gain a deeper appreciation of the flexibility and complexity of teaching approaches inherent in promoting scientific inquiry. Developing such conceptualization could also help teachers convey to their students that science was not a fixed body of knowledge, but rather a dynamic and evolving process that was driven by inquiry, experimentation and revision.

The Need for a Specialized NOS Pre-service Course for Primary School Teachers

Discussing NOS topics was found to be challenging when participants lacked a solid understanding of its key aspects. Thus, while this study found that the students' attitudes toward teaching NOS were generally positive, indicating they were open to teaching NOS, the study revealed a need for curriculum changes in teacher training programs, particularly in the

primary school teacher curriculum, which was the focus of this study.

To facilitate a more systematic and comprehensive conceptualization of NOS, it was considered important to design a specialized course tailored to the needs of pre-service primary school teachers. It was recognized that this course should integrate explicit and reflective teaching strategies, which were shown to be particularly effective in supporting NOS understanding (Khishfe, 2023; Mesci and Schwartz, 2017). Such strategies were seen as allowing pre-service teachers to deeply engage with NOS concepts, promote critical thinking (Puig et al., 2023), and encourage self-reflection on the nature and processes of science.

The findings from this study highlighted a need for a dedicated course in teacher education that systematically addressed the key components of NOS and targeted common misconceptions. Students' responses revealed *uncertainty, ambiguity, and underdeveloped understandings of core NOS themes*. This was seen as indicating the need for an intentional and sustained emphasis on these aspects throughout their training. NOS understanding should be scaffolded through both visual tools and structured discussions, supported by reflective activities (Lederman, 2007).

Students experienced difficulties in understanding the *development of scientific knowledge*—particularly theories and laws—and their interrelationships. In this context, the history of science plays a crucial role. Historical case studies and the stories of scientists help reveal the dynamic and tentative nature of scientific knowledge by placing its development in both local and cultural contexts. This historical lens enables learners to make more meaningful connections and to appreciate science as a creative, evolving, and socially embedded process (Fouad et al., 2015; Allchin, 2011).

The study also revealed a common misconception: *the belief in a single, universal scientific method*. To address this, it is critical to present science as a collection of diverse investigative approaches that vary across disciplines and contexts. Inquiry-based learning, paired with exposure to different scientific practices, historical examples, and interactions with scientists, helps challenge this oversimplified view (Namakula and Akerson, 2024).

Another notable finding was the perception of science as entirely objective, which contrasts with contemporary philosophical perspectives that emphasize the social and cultural embeddedness of science. Therefore, course design should consider incorporating real-world problems and socially relevant issues to illustrate science's societal roles and its impact on different stakeholders.

In a post-truth society, people tend to prioritize emotional personal experiences over scientific facts (Schoor, 2024). However, trust in science depends on how well students understand scientific processes. Thus, it is crucial to teach the distinction between science and pseudoscience through developing critical thinking and the ability to identify misleading information. NOS education needs to equip learners with tools to distinguish reliable science from misinformation.

In conclusion, it is suggested that NOS topics should be addressed systematically and thoroughly within a course through clearly defined modules. Course modules need to support future teachers in developing their understanding of the epistemological foundations of science, the process of knowledge development, and the skills for critical evaluation (Table 4 – Course Module Design). The findings from the current study suggest the need for a dedicated course for pre-service teacher education students which focus on

Table 4: A Proposed structure for a NOS-focused one-semester course

NOS topic	Learning objectives	Example of learning activities
Introduction to NOS*	<ul style="list-style-type: none"> • Illustrate key components of NOS • Distinguish between different conceptions of science 	<ul style="list-style-type: none"> • Group discussion: “What is science?” and “What is NOS?” • Drawing activity: “A picture of a scientist” • Identify the key components of NOS (visual representation)
Scientific knowledge	<ul style="list-style-type: none"> • Understand the differences and interrelations between theories and laws • Explain how scientific knowledge evolves over time • Identify common misconceptions about the nature of scientific knowledge 	<ul style="list-style-type: none"> • Historical case studies of scientific change • Comparative analysis: Theory vs. law • Reflective activity: “Why does science change?”
Scientific methods	<ul style="list-style-type: none"> • Recognize that science does not follow a single universal method; • Scientists from different fields use different methods. 	<ul style="list-style-type: none"> • Black Box activity (Akerson et al., 2008) • Case study: a scientist's workplace
The role of models and imagination	<ul style="list-style-type: none"> • Explain the function of scientific models • Understand the role of creativity and imagination in scientific reasoning 	<ul style="list-style-type: none"> • Group discussion: “Is science creative?” • Create, present and group discussion on a model to explain a phenomenon
Observations and Their Limitations	<ul style="list-style-type: none"> • Analyze the subjectivity of observations • Explore the influence of prior knowledge • Identify strategies to improve observational reliability 	<ul style="list-style-type: none"> • Observation task with varied interpretations • Group discussion: objectivity vs. subjectivity • Introduce tools to reduce bias and enhance reliability
Science vs. Pseudoscience*	<ul style="list-style-type: none"> • Distinguish between scientific and pseudoscientific claims • Identify the characteristics of pseudoscience • Develop skills for evaluating the credibility of information sources 	<ul style="list-style-type: none"> • Critical analysis of real-world examples (e.g. astrology vs. astronomy) • Group discussion: “Is this science?” • Checklist of criteria for identifying pseudoscience

*More time (2–3 weeks) is allocated for these topics

the key components of NOS and seek to address common misconceptions, as proposed in Table 4.

The proposed course is designed to be delivered over one semester (approximately 15 weeks), providing ample time for an in-depth exploration of complex topics and supporting meaningful learning experiences. Course topics are scheduled across specific weeks to ensure a focused and effective learning process. Some topics, such as the *introduction* and *science versus pseudoscience*, serve as standalone modules that frame the course, while the remaining topics make up the core content covered during the intervening weeks. The introduction also involves mapping students' initial understandings. The final weeks are dedicated to review, deepening knowledge, and reflection.

CONCLUSION

This study showed that pre-service primary school teachers expressed positive attitudes toward teaching NOS in the primary classroom, but exhibited an uncertain and, in part, a naive understanding of NOS. While some pre-service students demonstrated an awareness of key aspects of NOS such as the empirical basis of science or its tentative nature, many held misconceptions, particularly regarding the role of creativity, subjectivity and the distinction between scientific theories and laws. These findings underscore the need to integrate explicit and reflective NOS instruction into teacher education programs from the outset.

The findings indicate that key components of NOS – particularly the relationship between theories and laws, the subjectivity of scientific knowledge, and its creative nature – required more explicit emphasis in initial teacher education. The proposed enhanced curricula sought to strengthen NOS conceptualization more thoroughly within the science methods courses, seeking stronger alignment between theoretical understanding and practical pedagogical application.

Limitations of the Study

1. Since the reliability (McDonald ω) of many questions in the first part of the adapted VOSE questionnaire was low (ranging from 0.45 to 0.83), this was seen as a limitation of this study. It was recognized that other methods needed to be used to increase reliability.
2. As it was not possible to interpret the findings in more than a general manner, a further limitation of this study was the small sample size.
3. An additional limitation was the sole use of a written questionnaire as this did not provide a clear overview of student-teacher perceptions. To gain a more comprehensive understanding of teachers' perceptions, future studies could incorporate qualitative data collection methods, such as individual or focus group interviews. Integrating multiple data sources could enhance the validity of the study and offer richer information to inform the development of teacher education curricula.

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