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Exploring Pre-Service Chemistry Teachers' Scientific Literacy on Environmental Issues through the Lens of the Nature of Science

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Abstract:. This study aimed to investigate the level of scientific literacy and Nature of Science (NOS) conceptions among pre-service chemistry teachers in the context of environmental issues. This study adopted a mixed-methods approach combining descriptive surveys and semi-structured interviews. Participants were 72 pre-service chemistry teachers from universities in Palembang, Indonesia, selected through purposive sampling across academic levels. Data collection involved three instruments: a scientific literacy test on environmental issues, a NOS perception questionnaire, and qualitative interviews. The results showed that scientific literacy among participants was generally at a high level, with an average score of 86.00. Participants demonstrated strong competence in scientific content and practices, particularly on renewable energy, deforestation, and air pollution. However, lower scores were observed in contextual understanding, such as water quality and waste management. Regarding NOS conceptions, participants obtained an average score of 72.88%, indicating a high level of understanding, particularly on the tentativeness of scientific knowledge and the role of observation and inference. However, misunderstandings persist in areas such as creativity in science and the influence of social and cultural values. Interview results revealed a nuanced understanding of NOS, which is in line with theoretical frameworks that view science as empirical, tentative, and influenced by human creativity and social context. These insights underscore the importance of integrating NOS into science teacher education to foster critical thinking and contextual teaching of environmental issues.

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INTRODUCTION

The global environmental crisis is one of the most pressing issues in science education today. Climate change, environmental pollution, and biodiversity loss are real problems that require a strong scientific understanding from the public, especially future educators.(Hudson, 2001; Kilinc et al., 2013; Novacek, 2008). According to Canton (2021), Sustainable education that integrates environmental issues is essential in creating a generation capable of making science-based decisions. However, data show that many science teachers in various countries lack a comprehensive understanding of climate change and its effective teaching. (Anderson et al., 2020; Gunay et al., 2015; Köklü, 2018). This lack of understanding hinders the development of students' environmental awareness (Boca & Saraçlı, 2019; Leal Filho et al., 2019). Therefore, the scientific literacy skills of pre-service chemistry teachers regarding environmental issues are a vital foundation for fostering sustainability-oriented science education..

Scientific literacy is not only concerned with understanding scientific concepts, but also with understanding the nature of science. NOS includes the understanding that science is dynamic, evidence-based, and influenced by socio-cultural contexts (Hudson et al., 2016; Lederman, 2009).). This understanding ensures that pre-service teachers do not merely transmit knowledge but also cultivate scientific reasoning and reflective thinking among their students (Vieira & Tenreiro-Vieira, 2016). Sadler et al., (2017) found that teachers with sound NOS understanding are more capable of linking social and environmental issues with science in a critical and reflective manner. In the scope of environmental issues, this can help students understand the impact of human activities and the importance of making sustainable, evidence-based decisions (Mensah, 2019; Rieckmann, 2018). Thus, integrating NOS understanding into scientific literacy is essential for contextual and meaningful environmental education. However, despite its pedagogical importance, current evidence suggests that such integration remains underdeveloped among pre-service chemistry teachers.

Despite this importance, several studies indicate that the scientific literacy of pre-service chemistry teachers regarding environmental issues remains low. Inadequate scientific literacy can result in the unpreparedness of pre-service teachers in conveying complex environmental issues scientifically and pedagogically (Bossér et al., 2015; Eze et al., 2022). This issue is compounded by the limited implementation of learning that explicitly integrates NOS with environmental contexts (Namakula & Akerson, 2024; Valencia Narbona et al., 2023). In Indonesia, studies have revealed that many chemistry education students fail to connect chemical concepts, NOS principles, and contemporary environmental issues (Annisa & Laksono, 2021; Gurses et al., 2015; Yusup, 2021). In Indonesia, studies have revealed that many chemistry education students fail to connect chemical concepts, NOS principles, and contemporary environmental issues (Heba et al., 2017). The absence of this integration represents a significant research and pedagogical gap that must be urgently addressed to improve teacher education and environmental literacy outcomes.

Research on the scientific literacy of pre-service chemistry teachers in the context of environmental issues is urgently needed to support relevant, responsive, and sustainability-oriented science education. Teacher education must not only emphasize mastery of chemistry content but also the philosophical and contextual dimensions of science (Bürgener & Barth, 2018; Nielsen et al., 2016). Science literacy requires that Teacher education must not only emphasize mastery of chemistry content, but also the philosophical and contextual dimensions of science (Chowdhury, 2016; Zeidler & Sadler, 2023). Although several countries have integrated NOS into their science teacher education curricula, its implementation in Indonesia remains limited (Setiawan & Suwandi, 2022; Winarno et al., 2020). As a result, many pre-service teachers still teach science in a dogmatic and non-contextual manner (Mueller & Reiners, 2023). Thus, this study is important to reveal the extent to which pre-service chemistry teachers have adequate scientific literacy in dealing with environmental issues, as well as how NOS can be a framework for more integrative science learning.

Previous studies have explored ways to improve pre-service teachers' scientific literacy, but few have examined the intersection between scientific literacy, NOS understanding, and environmental issues in the Indonesian context. Prior research has mostly focused on content mastery and pedagogical approaches, neglecting the socio-scientific and epistemological dimensions of teaching. In fact, adopting an NOS perspective can enrich pre-service teachers' understanding of the dynamic nature of science and its relevance to environmental challenges (Abd-El-Khalick & Lederman, 2000; Khishfe & Lederman, 2006; Matthews, 2012). As Herman (2018) highlights, contextualizing NOS with human–nature interactions allows science education to better address controversial environmental issues. Research by Faikhamta, (2013) showed that NOS-based learning enhances pre-service teachers' comprehension of socio-scientific issues such as climate change and plastic pollution. However, these studies were largely conducted outside Indonesia, where sociocultural and educational contexts differ significantly.

Therefore, this study is novel in examining the scientific literacy of pre-service Indonesian chemistry teachers through the framework of the Nature of Science (NOS), with a specific focus on environmental issues as contextual content. Understanding how NOS conceptions shape scientific literacy in this domain will contribute to the development of teacher education curricula that are both scientifically robust and environmentally responsive (Bryan, 2012; Karakaya & İREZ, 2022; Lederman, 2013). This study aims to analyze the level of scientific literacy of pre-service chemistry teachers on environmental issues within the framework of NOS understanding. By identifying the integration of scientific knowledge, NOS principles, and environmental contexts, the study seeks to inform the design of effective educational interventions for future science teachers. Accordingly, this study is guided by the following research questions: 1. What is the level of scientific literacy of pre-service chemistry teachers in understanding environmental issues? 2. How do pre-service chemistry teachers conceptualize the Nature of Science

(NOS) in relation to environmental issues?

METHOD

Research design

This study employed a Sequential Explanatory Mixed Methods Design (Creswell & Plano Clark, 2023), integrating both quantitative and qualitative approaches to obtain a comprehensive understanding of pre-service chemistry teachers' scientific literacy on environmental issues. In the first phase, the quantitative component utilized a descriptive survey design to capture a snapshot of participants' knowledge, attitudes, and awareness regarding environmental issues related to chemistry education (Özdil & Çelik, 2022; Rafeeq et al., 2021). The survey, consisting of Likert-scale items, was designed to measure participants' levels of scientific literacy in terms of understanding environmental chemistry concepts, scientific reasoning, and awareness of sustainability issues. Descriptive statistics were applied to analyze overall trends, identify strengths and weaknesses, and establish a baseline understanding of the participants' literacy levels.

The qualitative phase followed the quantitative analysis and involved semi-structured interviews with a selected subset of survey respondents. This phase aimed to further explore and explain the patterns that emerged from the survey data, particularly in areas where participants demonstrated limited understanding or held misconceptions. Through open-ended questions, the interviews provided deeper insights into participants' reasoning processes, their conceptions of the Nature of Science (NOS), and the challenges they encountered in contextualizing environmental issues in chemistry education. The qualitative inquiry served to complement and enrich the numerical data by revealing underlying beliefs, experiences, and pedagogical factors that quantitative measures alone could not capture (Borges & Miranda, 2022; Suprapto & Hidaayatullaah, 2023).

During the data interpretation stage, triangulation was conducted through a systematic process of integrating and comparing quantitative and qualitative findings. Quantitative results were first summarized to highlight key trends, which were then cross-validated with qualitative themes to assess whether the data converged, complemented, or diverged (Ivankova et al., 2006). In cases where discrepancies were identified, qualitative insights were used to interpret the contextual, cognitive, or pedagogical factors that might explain such differences. This integrative process ensured that the qualitative narratives provided deeper meaning and justification for the quantitative patterns, resulting in a more robust and holistic understanding of pre-service chemistry teachers' scientific literacy and their conceptions of the Nature of Science within environmental contexts (Dolan et al., 2023).

Participants and sampling

The proposed research aimed to assess the scientific literacy of pre-service chemistry teachers in Palembang. A purposive sampling strategy will be used, focusing on students from universities in the city. A purposive sample of pre-service chemistry teachers from multiple universities will be selected to participate in the study. This study selected 72 pre-service chemistry teachers from various academic semesters 1, 3, and 5. This sampling approach ensured a mix of participants at different stages of their education, providing a broad diagnostic view of their perspectives on environmental issues informed by scientific literacy and understanding of the Nature of Science (NOS). By including students at different stages of their academic journey, this study was able to capture a spectrum of understandings and experiences, which is invaluable in evaluating how early and secondary educational exposures influence their perspectives and competencies related to scientific literacy in environmental contexts (Dewi et al., 2022; Fitriani, 2023).

The diversity of educational experiences among participants is critical to generating rich data and encouraging discussions that can illuminate nuances in their understanding of environmental issues. Previous research has demonstrated that educational interventions addressing socio-scientific issues can significantly enhance students' scientific literacy and engagement with environmental topics, supporting the notion that effective pedagogical strategies are crucial for developing scientific literacy (Dewi et al., 2022; Fitriani, 2023). Therefore, this study not only seeks to measure the level of scientific literacy that exists among pre-service teachers but also aims to inform the design of future educational curricula that better address environmental challenges in chemistry education.

Data collection instruments

In this study, which focused on assessing scientific literacy among pre-service chemistry teachers related to environmental issues, data collection was conducted through three main instruments: survey questionnaires, qualitative interviews, and scientific literacy questions on environmental issues.

1. Survey Questionnaire

   The initial data collection instrument was a survey questionnaire designed to collect quantitative data regarding participants' conceptions of the Nature of Science (NOS). This structured questionnaire will include Likert-scale items that allow respondents to indicate their level of agreement or understanding regarding various aspects of environmental issues and their implications in the context of scientific literacy. The survey is useful for obtaining baseline quantitative data that can be statistically analyzed to identify trends and patterns in scientific understanding among preservice teachers. The survey serves as a diagnostic tool, providing insight into these teachers' initial conceptions and setting the stage for a more in-depth qualitative exploration through interviews.

2. Qualitative Interview

   Following the survey, semi-structured qualitative interviews were conducted with a subset of participants. This component is essential to eliciting detailed narratives that explain the survey findings. Interviews would focus on three main themes: The Nature of Science, Science Literacy, and environmental issues participants face in their daily lives. Using a conversational format, these interviews would generate rich qualitative data that reflect the personal experiences and beliefs of chemistry teacher candidates. Interview data would be transcribed and analyzed using thematic analysis, providing a deeper understanding of how these individuals relate their educational experiences to real-world environmental challenges.

3. Science Literacy Questions

   The third component of data collection consists of a standardized science literacy test, consisting of ten questions specifically designed to address environmental issues. This instrument would quantitatively assess participants' knowledge and understanding of key environmental concepts, allowing for a clear measurement of their science literacy skills. Responses to this test would be analyzed to identify knowledge gaps and areas of strength among participants. Combining the results from the science literacy questions with the baseline survey and qualitative interviews would facilitate a comprehensive understanding of how prepared preservice teachers are to address environmental issues through a science literacy lens.

4. Validity

   The content validity of the three instruments in this study, the questionnaire sheet, the interview sheet, and the literacy questions, were calculated using the Gregory Formula, which considered the level of agreement between the two validators. The calculation results showed that all instruments had a high to very high level of validity. The questionnaire sheet obtained a content validity score of 1.00 (very high), the interview sheet was 0.80 (high), and the literacy questions reached to 0.90 (very high). These findings indicated that all instruments have met the quality of content eligibility and can be used in collecting data validly and reliably.

Data analysis procedures

To analyze the data from this study, several steps were take based on the type of instrument used, namely, environmental literacy tests, questionnaires, and interviews.

1. Science Literacy Test on Environmental Issues

   The results of the environmental literacy test were analyzed using descriptive statistics, such as frequency, percentage, average (mean), and standard deviation. This analysis aimed to examine the distribution of science literacy scores among pre-service chemistry teacher students, in order to assess their understanding of environmental issues. This data will also be used to identify areas of knowledge that need to be improved (Creswell, 2012).

To interpret the students' science literacy scores, researchers employed a categorization approach based on score ranges as in the Table 1 adjusted to reflect the opinions of experts in the field of educational evaluation. This category division aims to provide a clear meaning to the level of students' science literacy abilities, both in general and based on each aspect, namely context, content, and competence, as stated in the PISA science literacy framework.

Table 1. Category Literacy Abilities

Score Range	Category	Interpretation
0 – 20	Very Low	Students are very weak in science literacy; have difficulty understanding basic concepts.
21 – 40	Low	Basic understanding of science is still limited; less able to apply concepts.
41 – 60	Sufficient	Sufficient understanding of science concepts and contexts, but still limited to a basic level.
61 – 80	High	Able to understand and apply science in various contexts well.
81 – 100	Very high	Mastering the concepts, contexts, and competencies of science literacy in depth.

2. Nature of Science (NOS) Conception Questionnaire

The data from the questionnaire were analyzed using descriptive statistical methods by calculating the frequency and percentage of each student's response. This was done to determine their understanding of the Nature of Science in the context of environmental issues. In addition, if the questionnaire was in the form of a Likert scale, then the average score of each statement can be calculated to see the tendency of student conceptions as a whole (Creswell, 2012). The following is a range of interpretations based on percentages as in the Table 2, compiled scientifically and referring to the principles of educational evaluation, and adjusted for Likert data, which is converted into a percentage of positive responses:

Table 2. Category Nature Of Science Conception

Percentage Range	Category	Interpretation
0% – 20%	Very Low	Very poor conception; does not understand the nature of science conceptually.
21% – 40%	Low	Conception is still shallow; understanding of the nature of science is not well developed.
41% – 60%	Sufficient	Moderate conception; some NOS concepts are understood but not completely.
61% – 80%	High	Good conception; shows a fairly strong understanding of the nature of science.
81% – 100%	Very high	Very good conception; understands and agrees with the basic principles and values of NOS.

Note: The categorization of percentage ranges into five levels is adapted from established assessment frameworks in educational research (Azwar, 2022) and aligned with contemporary Nature of Science assessment practices (Kaya et al., 2019; McComas, 2020).

3. In-depth Interview

Interview data were analyzed qualitatively using thematic analysis techniques. Interview transcripts were identified and coded to find key themes related to students' understanding of scientific literacy and the Nature of Science. These qualitative findings would be used to deepen and complement the quantitative results obtained from the tests and questionnaires. (Braun & Clarke, 2006)

RESULT AND DISCUSSION

Pre-Service Chemistry Teachers' Scientific Literacy Levels In Environmental Issue

With adequate scientific knowledge, individuals can understand the impacts of climate change, pollution, and other environmental issues and learn ways to mitigate these impacts. Additionally, scientific literacy enables individuals to comprehend technologies and innovations that can help address environmental issues. According to OECD (2016), Scientific literacy on environmental issues is very important because it can help individuals to understand and overcome complex environmental challenges. Scientific literacy can also help individuals to make the right decisions in facing these challenges. Scientific literacy, which is the main theme raised, includes: acid rain, soil pollution, renewable energy, climate change, water quality, air quality, deforestation, biodiversity, plastic waste, and cooking oil waste. This scientific literacy question was then tested on pre-service chemistry teachers. The results of this literacy test can be seen in Table 3.

Table 3. Results of Science Literacy on Environmental Issues

No	Indicators	Standard	Score	Average
1	Acid Rain	Context	95.77	
		Content	76.06	78.87
		Competency	64.79	
2	Soil Pollution	Context	73.24	
		Content	91.55	86.85
		Competency	95.77	
3	Renewable Energy	Context	97.18	
		Content	95.77	93.42
		Competency	87.32	
4	Climate Change	Context	73.24	
		Content	94.37	78.87
		Competency	69.01	
5	Water Quality	Context	64.79	
		Content	56.34	69.95
		Competency	88.73	
6	Air Quality	Context	76.06	
		Content	81.69	84.97
		Competency	97.18	
7	Deforestation	Context	85.92	
		Content	92.96	88.73
		Competency	87.32	
8	Biodiversity	Context	88.73	
		Content	76.06	85.91
		Competency	92.96	
9	Plastic waste	Context	69.01	
		Content	88.73	84.03
		Competency	94.37	
10	Cooking oil waste	Context	94.37	
		Content	73.24	84.97
		Competency	87.32	
	Total			86.00

This section presents the findings from our sequential explanatory mixed-methods study, integrating quantitative survey and test data with qualitative interview insights. Data triangulation was conducted by first analyzing quantitative patterns, then using qualitative interviews to explain, validate, or contextualize these patterns (Creswell & Plano Clark, 2023). The findings are organized according to the two research questions, with each section presenting: (1) quantitative results, (2) supporting qualitative evidence, and (3) triangulated interpretation highlighting strengths, weaknesses, and implications for pre-service chemistry teacher preparation.

The results indicate that pre-service chemistry teachers demonstrated generally high levels of scientific literacy on environmental issues (mean = 86.00), suggesting strong mastery of scientific content, context, and competence (OECD, 2019). The highest achievements were observed in the context and competence aspects, particularly in topics such as renewable energy (97.18%) and air quality (97.18%). These findings show that participants possess solid conceptual understanding and are able to apply scientific reasoning to real-world problems, supporting Abd-El-Khalick & Lederman's (2023) and Talanquer's (2023) assertions that contextual and reflective knowledge are essential for sustainability-oriented chemistry education.

In contrast, the context dimension exhibited greater variability and lower scores in several areas, including water quality (64.79%), soil pollution (73.24%), plastic waste (69.01%), and climate change (73.24%). In the content aspect, water quality occupies the lowest position (56.34%). These lower contextual scores indicated that while participants possess strong conceptual knowledge, they face challenges in connecting scientific principles to real-world environmental situations and socio-cultural contexts (Abolaji et al., 2025; Aydin-Ceran, 2021). This gap between decontextualized content mastery and contextualized application has been consistently documented in recent studies of pre-service science teacher education across diverse international contexts (Çinar & Çepni, 2021; Namakula & Akerson, 2024). These findings highlight the need to strengthen teacher education in connecting scientific concepts to real and locally relevant environmental contexts.

Triangulation of quantitative and qualitative data revealed convergence between test results and interview insights. Interview participants consistently articulated accurate scientific explanations for these topics, stating *"I can explain the greenhouse effect and carbon cycle clearly"*, which corroborates the quantitative findings. However, contextual understanding remained weaker in issues like water quality and waste management, where interviews revealed limited exposure to local environmental problems. This indicates that while pre-service teachers possess strong scientific foundations, their ability to situate this knowledge in authentic socio-environmental contexts requires further development(Ariza et al., 2021; Rodríguez Pérez et al., 2024). Strengthening contextual and inquiry-based learning in teacher education is therefore crucial to achieving more balanced scientific literacy.

However, notable gaps were identified in participants' contextual understanding, particularly regarding water quality (64.79%), plastic waste (69.01%), and soil pollution (73.24%). Although many pre-service teachers demonstrated solid conceptual knowledge of these topics, interview data revealed difficulty in connecting them to real-world environmental challenges—for instance, one participant noted, "*I know the chemistry of water pollution, but I struggle to relate it to community problems*" This disconnection between content mastery and contextual application indicates a pedagogical gap that limits the ability to teach science meaningfully within socio-environmental realities. Similar findings have been reported in recent research, showing that pre-service teachers often lack opportunities to engage with place-based or community-centered environmental learning experiences, which are essential for fostering contextually relevant scientific literacy (Lomicka Anderson et al., 2025; Maan, 2024).

The high levels of scientific literacy observed across most indicators demonstrate the strong potential of pre-service chemistry teachers to transform science learning into more contextual and meaningful experiences. However, variations among content, context, and competence aspects indicate that their literacy remains unbalanced and requires targeted strengthening through integrative pedagogical strategies. Triangulated findings from quantitative and qualitative data suggest that teacher education programs should shift their focus from content-oriented instruction to context-based and socio-scientific learning approaches that explicitly connect chemistry concepts with real-world environmental issues (Çalık & Wiyarsi, 2021; Graham et al., 2018). As emphasized by Liu et al., (2024), scientific literacy must encompass not only content mastery but also the capacity to evaluate, communicate, and act on social and environmental problems through evidence-based reasoning. Therefore, aligning teacher preparation with the PISA framework—balancing content, context, and competence—is essential to equip pre-service teachers for the demands of 21st-century, sustainability-oriented science education.

The integration of knowledge and skills, as supported by interviews, revealed that pre-service chemistry teachers understand the importance of integrating chemical knowledge with critical and analytical thinking skills in the context of environmental issues. This is in line with the view Mamlok-Naaman & Taitelbaum (2019) which emphasizes the importance of a holistic approach in chemistry education to develop comprehensive scientific literacy. In the knowledge gap section, there are several topics, such as acid rain and climate change. According to Burmeister et al., (2012) This gap needs to be addressed through ongoing professional development and a curriculum that is more integrated with sustainability issues. The contextual approach of the respondents emphasized the importance of a contextual approach in teaching chemical concepts related to environmental issues. This strategy is supported by research Stuckey et al., (2013) which demonstrates that context-based learning can enhance students' motivation and understanding of the issues.

Nature of Science (NOS) Conceptions

To assess students' NOS conceptions, a questionnaire is used. This instrument was used to see the understanding of the NOS concept. The results of the questionnaire survey, consisting of 25 questions about the Nature of Science (NOS), provide a comprehensive picture of students' understanding of NOS aspects in learning. This questionnaire covers various dimensions summarized in the main indicators and the average results of each item can be seen in the following Table 4.

Table 4. Results of Nature of Science (NOS) Conceptions

No.	NOS Indicator	Items Included	Short Description	Average Percentage
1	The Tentativeness of Scientific Knowledge and the Relationship between Theory and Law in Science	3, 4, 9	Scientific knowledge is changeable and evidence-based and evolving. Scientific theories and laws have different but complementary roles.	83.80
2	The Role of Evidence, Observation, and Inference	1, 2, 5, 8, 13, 16	Science is built on observations, natural patterns, experiments, and explicit procedures.	81.11
3	Creativity and Imagination in Science	10, 11	Science also involves the creativity of scientists in explaining phenomena and designing experiments.	58.51
4	Subjectivity and Theories Influenced by Values and Culture	14, 15, 18, 25	Scientific knowledge can be influenced by the social background, culture, and values of scientists.	62.33
5	Limitations of the Scientific Method	6, 7, 12, 17	Not all phenomena can be explained by the scientific method; there are inherent limitations.	67.06
6	Science as a Social and Collaborative Activity	19, 20, 21, 22	Scientists work collaboratively, are socially responsible, and publish their results.	75.02
7	The Relationship between Science, Technology, and Society (STS)	23, 24, 25	Science interplays with society and technology.	67.82
	Overall			72.88

The results showed that the conception of pre-service chemistry teachers towards the Nature of Science (NOS) was in the high category, with an overall average of 72.88%. Most participants showed a good understanding of the basic concepts of the nature of science, especially in the indicators of the Tentativeness of Scientific Knowledge and the Relationship between Theory and Law in Science (83.80%) and The Role of Evidence, Observation, and Inference (81.11%). These high scores reflected that participants understand science as an evidence-based process that can change as new data emerges. The quantitative pattern indicates that the majority of pre-service chemistry teachers have grasped that science is not a collection of static facts, but rather a dynamic system of knowledge that develops as new evidence becomes available—a foundational NOS principle emphasized by Abell & Lederman (2007).

However, notable weaknesses emerged in two specific dimensions. The aspect of Creativity and Imagination in Science scored relatively low at 58.51%, indicating that many participants do not fully recognize creativity as an essential element in scientific practice. Similarly, the dimension of Subjectivity and Theories Influenced by Values and Culture obtained 62.33%, showing understanding that was not fully developed, although approaching the high category threshold. These lower scores suggest that while participants grasp the empirical and methodological core of NOS, they have less developed conceptions of its epistemological and socio-cultural dimensions (Khishfe & Lederman 2006; Khishfe et al., 2017).

Interview respondents articulated a sophisticated understanding of science's dynamic nature. Participants stated that "*scientific knowledge can change if there is new data" and "experimental results can be different due to conditions or tools*" (Participants 2, 8). These statements directly corroborate the high quantitative scores (83.80%) for understanding tentativeness. One participant elaborated: "*Science is always evolving and can change as new facts are discovered. That's what makes it reliable—it's self-correcting*" (Participant 11). This shows consistent understanding with the literature as stated by Abell & Lederman (2007), which emphasizes that an important characteristic of the nature of science is its tentative nature and openness to revision based on evidence. These responses also reveal the close relationship between participants' laboratory experimental experiences and their understanding of the epistemology of science.

However, when discussing creativity in science, a disconnect emerged between conceptual awareness and practical experience. One participant noted: *"Scientists need to think creatively, but sometimes we think of experiments as just routine"* (Participant 4). More revealing was another participant's comment: *"Laboratory experiments often feel like following a recipe, there is not much room for your own ideas"* (Participant 6). These qualitative insights explained the low quantitative score (58.51%) by revealing that participants' limited perception of scientific creativity stems from constrained pedagogical experiences rather than fundamental conceptual misunderstanding. They intellectually recognize that creativity is important, but their cookbook-style laboratory experiences have not embodied this principle. This reflects what has been found by Abd-El-Khalick & Lederman (2023), that students and pre-service teachers often fail to see that creative thinking is necessary in constructing hypotheses, designing methods, and interpreting data not because they lack the capacity for such understanding, but because their educational experiences have not modeled the creative dimensions of scientific inquiry.

Similarly, interviews revealed moderate scores (62.33%) in understanding how social values and culture influence science. Some pre-service teachers explicitly stated that *"science should be objective, should not be influenced by religion, culture, or personal feelings"* (Participants 3, 9). Although the ideal of objectivity is important, this understanding seems to oversimplify the complexity of modern science, where the background of scientists and societal contexts inevitably influence research priorities, funding decisions, and interpretation of results (Longino, 2020). Failure to acknowledge these influences can lead pre-service teachers to teach science as if it were something socially neutral, even though a contextual approach to science education—particularly environmental education—demands an understanding that science and society influence each other (Sadler et al., 2017). Recent scholarship has increasingly emphasized that viewing science as embedded within socio-cultural systems is essential for addressing contemporary environmental challenges (Erduran et al., 2023; Zidny et al., 2023).

The integration of quantitative and qualitative data reveals strong convergent evidence that pre-service chemistry teachers possessed a robust understanding of science's empirical, tentative, and evidence-based nature. Both the high questionnaire scores (83.80%, 81.11%) and participants' articulate interview responses mutually reinforce this finding. Participants consistently described NOS as a dynamic framework that emphasizes the empirical nature of science as a continuous process of observation, experimentation, and evaluation of evidence. This perspective is consistent with the NOS articulation by Lederman et al., (2023), which underlines essential characteristics such as empirical, tentative, and theoretical dimensions. Understanding NOS in this way is crucial for educators, as it fosters an environment in which students realize that scientific knowledge is not absolute but can be revised based on new evidence (Namakula & Akerson, 2024)

However, triangulation also revealed important divergent patterns between what participants know conceptually and what they have experienced pedagogically. While quantitative scores for creativity were low (58.51%), interview discussions showed that participants intellectually acknowledged the importance of creativity; they simply had limited opportunities to practice it. This divergence suggests that the problem lies not in cognitive aspects but in pedagogical ones: teacher education programs are not providing authentic inquiry experiences where scientific creativity is modeled and valued. As Mueller & Reiners (2023) demonstrated in their recent study, pre-service teachers' NOS conceptions are heavily shaped by the pedagogical approaches they experience, not merely the content they are taught.

Similarly, the moderate understanding of socio-cultural influences (62.33%) reflected incomplete integration of contemporary NOS frameworks that view science as a social practice. Research by Khishfe et al., (2017) showed that learners and pre-service teachers often have naive views of NOS, especially in recognizing that science is influenced by socio-cultural contexts. In scientific practice, creativity plays an important role in bridging data and theory, while socio-cultural awareness helps scientists recognize how values shape research agendas and interpretations—both dimensions are are essential for addressing environmental issues that inherently involve scientific, social, and ethical considerations (Kaya et al., 2019).

Positively, interview respondents emphasized the importance of integrating NOS into chemistry education as a means of fostering flexible rather than fixed conceptions of scientific concepts, which encourages critical thinking. Research by Khishfe & Lederman (2006) supported this idea, indicating that NOS-based educational approaches enhance students' critical thinking skills and scientific attitudes. Multiple respondents reported implementing or desiring to implement this approach through reflective discussions and hands-on laboratory activities that model real scientific processes and provide students with opportunities to formulate, test, and revise hypotheses based on empirical data. Respondents also recognized the importance of using models and analogies to simplify abstract chemistry concepts. Effective use of scientific models helps demystify complex topics, such as atomic structure and reaction mechanisms, which are often difficult for students to visualize. These findings are in line with advocacy by Gilbert (2005) for modeling in science education, which notes that well-constructed analogies can bridge the gap between complex scientific theories and students' pre-existing knowledge.

The triangulated findings revealed that although some participants hold NOS conceptions that align with science education theory, others still exhibit shallow or undeveloped views, particularly in the epistemological and socio-cultural dimensions. As explained by Khishfe & Lederman (2006), a complete understanding of NOS includes not only empirical evidence but also recognition of the role of creativity, subjectivity, and the influence of social values. This is an important concern in the education of pre-service teachers because an incomplete understanding of NOS can have a direct impact on the way they teach science and shape students' scientific literacy (Khishfe et al., 2017).

The importance of a strong understanding of NOS and scientific literacy was further validated by Osborne & Patterson (2011), who argue for the integral nature of these concepts in science education, ultimately preparing students to rationally navigate contemporary socio-scientific issues. As future educators, these chemistry teachers must be prepared to impart a comprehensive understanding of chemistry to their students, fostering classroom environments that support inquiry, critical evaluation, and an understanding of the scientific method as both a cognitive and social endeavor. Thus, the application of an NOS-based framework in chemistry education is not only beneficial to student outcomes but is also essential to cultivating scientifically literate citizens who are prepared to face current and future environmental challenges.

Therefore, several key curricular reforms are recommended to strengthen pre-service teachers' NOS understanding: (1) provide authentic inquiry experiences that emphasize creativity and problem-solving; (2) explicitly address the socio-cultural dimensions of science through case studies and environmental examples; (3) embed reflective NOS instruction within environmental chemistry topics; and (4) develop epistemological, affective, and social awareness to foster environmentally responsible and evidence-based teaching practices.

CONCLUSION

This study's findings revealed that pre-service chemistry teachers demonstrated high overall scientific literacy, with a mean score of 86.00, particularly excelling in scientific content and competencies related to renewable energy, deforestation, and air pollution. However, significant weaknesses emerged in the contextual understanding of localized environmental issues, such as water quality (64.79%) and waste management. Triangulation of quantitative test scores with qualitative interviews confirmed that while participants possess strong conceptual knowledge, they struggle to apply this knowledge to real-world socio-environmental contexts. This gap between content mastery and contextual application represents a critical area for improvement in teacher preparation.

Pre-service teachers demonstrated moderately high NOS conceptions, with a mean = 72.88%, and a strong understanding of science's tentative and empirical nature (83.80%), but a weaker comprehension of creativity in science (58.51%) and socio-cultural influences on scientific knowledge (62.33%). Qualitative data revealed that these weaknesses stem not from philosophical misunderstanding but from limited exposure to authentic inquiry experiences and insufficient explicit NOS instruction. Interview participants articulated sophisticated views when prompted, recognizing that "science evolves with evidence" and "scientists need creativity," but noted that their laboratory experiences rarely embodied these principles. This finding aligns with research showing that implicit NOS learning is insufficient; explicit, reflective instruction is necessary.

Theoretically, these findings reinforce the notion that integrating NOS into teacher education enhances not only conceptual understanding but also pedagogical responsiveness to socioscientific issues. The alignment between empirical data and reflective interview insights strengthens the argument for NOS as a framework to bridge theory and classroom practice. This study contributes to the growing body of knowledge advocating for context-based and NOS-integrated science teacher preparation.

The implications are significant equipping future chemistry teachers with balanced scientific literacy and NOS awareness is crucial for fostering environmentally literate students. This requires curriculum reform that emphasizes real-world issues, interdisciplinary integration, and the development of critical and reflective thinking skills.

However, this study is limited by its geographic focus and sample size, which may not represent pre-service teachers in other contexts. Future research could investigate the longitudinal effects of NOS-based interventions and expand the sample to include diverse educational settings. Further investigation into how these conceptions are enacted in teaching practice is also recommended to fully realize the transformative potential of NOS-informed science education.

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