



Exploring pre-service Physical Sciences teachers' conceptions and misconceptions of the nature of science

Halalisani Mngomezulu,¹  Sam Ramaila,¹  Nonhlanhla Nduku² 

¹*Department of Mathematics, Science and Technology Education, Faculty of Education, University of Johannesburg, Johannesburg, Gauteng Province, South Africa*

²*Department of Curriculum Studies and Higher Education, Faculty of Education, University of the Free State, Bloemfontein, Free State Province, South Africa*

Corresponding author, email: samr@uj.ac.za

Abstract

This study investigates pre-service physical sciences teachers' conceptions of the Nature of Science (NOS) within the context of South Africa's educational goal of fostering scientific literacy. Guided by a 21st-century skills framework, the study explores how these future educators perceive and understand NOS—a foundational component for effective science instruction. This study adopted a phenomenographic design. Data were gathered through semi-structured interviews with ten fourth-year physical science and mathematics education majors at a South African university and analysed using thematic analysis. Findings reveal a distinct perspective among participants, who largely view NOS as absolute and objective, contrasting with the nuanced and evolving nature highlighted in existing literature. This study underscores the importance of addressing and rectifying potential misconceptions regarding scientific knowledge among pre-service teachers to better equip them for their roles as science educators, ultimately supporting accurate scientific literacy in their future classrooms.

Keywords: Nature of science, scientific literacy, phenomenography, pre-service teachers, Physical Sciences

Introduction

The nature of science (NOS) is a foundational element in science education, shaping how students and educators understand scientific knowledge, its methods, and its societal impact. In recent years, there has been growing emphasis on equipping pre-service teachers with a robust understanding of NOS, as their conceptions play a critical role in fostering scientific literacy and inquiry-oriented learning among future students (Zhang et al., 2024). For physical sciences teachers, a nuanced understanding of the Nature of Science (NOS) is essential. It allows them to teach not only scientific facts and theories but also the processes and limitations that underpin scientific inquiry (Yeh, Dhurumraj & Ramnarain, 2023). In the South African context, where science education aims to cultivate critical thinking and problem-solving skills, exploring pre-service teachers' conceptions of NOS has become a

priority (Lelliott, 2014). This need is underscored by the goal of the national curriculum to nurture scientifically literate citizens capable of engaging with complex scientific issues in a rapidly evolving world. However, studies suggest that many pre-service teachers may hold incomplete or simplistic views of NOS, often perceiving science as a set of absolute truths rather than a dynamic, iterative process (Boyle et al., 2023; Lekhu, 2023; Napanoy, Gayagay & Tuazon, 2021). Addressing such misconceptions is essential to prepare future educators to foster deeper scientific understanding and curiosity among learners.

The general science standards in the South African context emphasize that future citizens should be scientifically literate, equipped with the necessary knowledge to understand both science and its interactions with society (Ramnarain, 2024; Roberts et al., 2011). This competency is closely linked to understanding the Nature of Science (NOS). The Nature of Science

(NOS) offers a profound understanding of how science functions as a discipline. It reveals that science is not just a collection of facts and laws but a dynamic, human-driven process that constantly evolves (McComas, 2017). At its core, NOS is about comprehending the key characteristics, practices, and principles that govern scientific inquiry and the creation of knowledge (Brock & Park, 2024).

Science, as a human endeavour, is shaped by human perspectives, creativity, and subjectivity (Sammel, 2014). It is influenced by social, cultural, historical, and technological contexts, meaning that scientific knowledge is always in flux. As scientists approach questions, they are guided by their current knowledge, tools, and assumptions, which can lead to new discoveries or shifts in understanding. Science is not static; it is an ongoing pursuit where knowledge is continuously refined, revised, and re-evaluated. A fundamental principle of science is its reliance on empirical evidence (Herfeld & Ivanova, 2021). Scientific inquiry is grounded in observation, experimentation, and measurement. Scientists gather data that is reproducible and verifiable, and conclusions are drawn from this evidence. The ability to replicate experiments and verify results is key to validating scientific claims, ensuring that findings are credible and accurate.

The tentative nature of scientific knowledge is another cornerstone of NOS (Brock & Park, 2024). Unlike absolute truths, scientific knowledge is provisional. It is always open to change as new evidence emerges, or when existing theories are refined or replaced. For example, the shift from Newtonian physics to Einstein's theory of relativity illustrated how even long-established theories could be superseded by new discoveries. This openness to revision is what makes science adaptable and self-correcting. In addition to this, theories and laws are integral to science (Stefanidou & Skordoulis, 2017). Theories explain and predict phenomena, providing comprehensive frameworks for understanding the natural world. While theories can evolve or be replaced as new information comes to light, they remain robust until disproven by new evidence. In contrast, scientific laws describe consistent patterns or relationships observed in nature, often remaining stable unless disproven by extraordinary evidence.

Despite its goal of objectivity, science is also influenced by subjectivity (Stamenkovic, 2022). The process of scientific inquiry is shaped by the values, assumptions, and perspectives of the scientists themselves (Khort, 2025). From the questions they ask to the interpretations they make; scientists bring their own viewpoints to the research process. However, science strives for objectivity by relying on rigorous methods and peer review to minimize bias and ensure reliability (Stamenkovic, 2022). Creativity and imagination are often overlooked aspects of scientific inquiry, but they play a crucial role (Cirkony, 2023). Science is not merely about following prescribed methods but also involves innovation and the generation of new ideas. Scientists use creativity to develop models, analogies, and hypotheses, imagining possibilities and testing them through experimentation (Oh, 2022). This imaginative aspect of science sparks new avenues of inquiry, leading to groundbreaking discoveries.

Ultimately, the tentative nature of scientific knowledge highlights that science is always a work in progress (Mueller & Reiners, 2023). While it provides reliable, evidence-based conclusions, it is never fixed or absolute. New findings, technologies, and perspectives can always challenge existing understandings, driving the continuous evolution of scientific knowledge (Link & Scott, 2019). Understanding the Nature of Science enriches the way learners approach scientific concepts (Khishfe, 2023). It fosters a deeper appreciation for the process of knowledge construction and helps cultivate critical thinking skills. Recognizing that science is a dynamic, human-centred process allows learners to better grasp the complexities of the scientific world, and to engage more meaningfully with the evidence and reasoning behind scientific claims (Murphy, 2021). This knowledge empowers individuals to question, explore, and contribute to the ever-changing landscape of scientific discovery.

Fostering an adequate understanding of NOS is among the most frequently cited goals for science education (Confre et al., 2019). Despite global consensus on the importance of NOS in promoting scientific literacy, research highlights that many science teachers and students still struggle with grasping this concept fully (Lederman & Lederman, 2014). Studies on NOS

instruction and comprehension consistently show that explicit and reflective teaching methods are the most effective in improving both teachers' and students' understanding of NOS (Namakula et al., 2024; Witucki et al., 2024). However, while progress has been made, there is still a need for further work to identify the most effective instructional models for teaching NOS (Lederman & Lederman, 2014).

There is also ongoing debate about the essential elements of an instructional model that could enhance NOS comprehension among students and teachers (Dogan et al., 2013). For instance, teachers are still uncertain about why certain aspects of NOS (i.e., Science as a Human Endeavor, Empirical Evidence, Tentativeness and Change, Theory and Laws, Subjectivity and Objectivity, Creativity and Imagination, Tentative Nature of Scientific Knowledge) are more difficult to understand than others (Mesci & Schwartz, 2017). Additionally, it remains unresolved whether some features of NOS can be learned implicitly (e.g., Seung et al., 2009; Pavez et al., 2016), and teachers are still unsure about the most effective strategies for teaching NOS (Cofré et al., 2019). Furthermore, the relationship between students' understanding of NOS and their ability to learn scientific concepts remains unclear (Lederman & Lederman, 2012; Peters, 2012; Michel & Neumann, 2016; Cofré et al., 2019).

By analysing these conceptions, this research seeks to provide insights into the current state of NOS understanding among pre-service teachers, offering guidance on how teacher education programs might better prepare educators to address the complexities of science in the classroom. Ultimately, this study underscores the importance of strengthening pre-service teachers' comprehension of NOS, paving the way for more authentic and impactful science education. Exploring preservice physical science teachers' understanding of the nature of science and their translation into classroom practice is pivotal to understanding the complex relationship between teachers' conceptions and teaching practices (Cullinane et al., 2023). The main question guiding the present investigation was:

- *What are the conceptions of pre-service physical sciences teachers regarding the*

Nature of Science (NOS) and how do these conceptions influence their understanding and teaching of scientific inquiry?

Literature review

The Concept of the Nature of Science

The evolution of the concept of the Nature of Science (NOS) across philosophical, sociological, and historical contexts reveals how the science education community's understanding of the term has shifted over the past century. This evolving perspective highlights a critical interpretation of science not merely as a set of facts but as a dynamic process shaped by various influences. For instance, Clough (2011) characterized NOS understanding as "knowing how science works," emphasizing the procedural aspects of science. In contrast, Lederman et al. (2014) expanded this definition, framing NOS as encompassing both the epistemology and sociology of science. They argued that science is not only a method of knowing but also a social construct influenced by values, beliefs, and cultural contexts, offering a more nuanced understanding of the complex nature of scientific knowledge and its development. This critical shift underscores the importance of recognizing science as a multifaceted process, shaped by both intellectual rigor and societal influences.

Description of the Nature of Science as a prerequisite for teacher education program

As outlined in the Department of Basic Education (DBE) Curriculum and Assessment Policy Statement (CAPS) for pre-service physical sciences teachers, the Nature of Science (NOS) highlights the dynamic and evolving nature of scientific knowledge (Chuene & Singh, 2024). The CAPS document for Physical Science Grades 10-12 emphasizes that science is not merely a collection of facts but a systematic process of inquiry that involves observation, experimentation, and critical thinking. This perspective encourages pre-service science teachers to help students understand that science is evidence-based and subject to revision as new data emerges, promoting a mindset of curiosity and open-mindedness among both teachers and learners.

Additionally, the NOS underscores the importance of the scientific method, which includes forming hypotheses, conducting experiments, and drawing conclusions (Schwartz et al., 2004). Coleman (2014) stresses that science teachers should guide learners in understanding the significance of each step in the scientific process, fostering their ability to engage in scientific reasoning and problem-solving. Kim et al. (2011) suggest that by incorporating practical experiences and hands-on activities into their teaching, physical sciences teachers can help learners appreciate the relevance of science in everyday life and its role in addressing societal and environmental challenges.

Furthermore, the NOS acknowledges the interaction between science and society, highlighting the ethical implications and responsibilities of scientific work, as noted by Allchin (2011). Teachers are encouraged to explore how scientific advancements can impact social issues, public policy, and environmental stewardship. By promoting a comprehensive understanding of science, including its cultural, historical, and social contexts, teachers can prepare learners to become informed and responsible citizens capable of critically engaging with scientific issues in their communities.

Tenets of the Nature of Science

When examining pre-service physical sciences teachers' understanding of the Nature of Science (NOS), it is crucial to recognize that a deep comprehension of NOS is essential for effective science instruction. The Nature of Science encompasses several core principles that guide the practice and development of scientific knowledge (Caramaschi, 2022). These principles include the understanding that science is empirical, tentative, and evidence-based—meaning that scientific knowledge evolves with new discoveries and is rooted in observation and experimentation (Da Silva, 2022). Additionally, Maknun (2020) highlights that science is creative, involving critical thinking and reasoning to explain and solve complex problems. In agreement with Maknun, Paavola (2023) argues that science is also a social process, where collaboration, peer review, and knowledge sharing are vital to advancing scientific understanding.

Pre-service physical science teachers' awareness of these NOS tenets allows them to better understand how science works and how to effectively communicate its dynamic, evolving nature to students. By recognizing that science is not merely a set of facts, but a method of inquiry grounded in logical reasoning and empirical evidence, teachers can emphasize the importance of critical thinking, inquiry-based learning, and the tentative nature of scientific knowledge. Furthermore, understanding science's human and cultural dimensions—such as how historical and social factors shape scientific knowledge—enables teachers to promote a more inclusive, nuanced perspective of science in their classrooms (Tran, 2023). Namakula et al. (2024) assert that a deeper understanding of NOS ultimately empowers pre-service teachers to cultivate scientific literacy and adopt a more authentic, reflective approach to teaching science.

Science is empirically based

Science is fundamentally grounded in observing the natural world, with the assumption that these observations ultimately determine the validity of scientific claims (Tabish, 2024). However, Höttecke (2020) notes that scientists often lack direct access to many natural phenomena. Instead, their observations are mediated by their perceptual capabilities and advanced instrumentation. These observations are then interpreted within the context of complex theoretical frameworks, which add additional layers of meaning. Amadi (2023) emphasizes that science is empirically based, with various underlying assumptions shaping the operation of scientific tools. These assumptions influence how data is gathered, interpreted, and ultimately affect our understanding of the phenomena being studied.

Scientific knowledge is tentative yet durable

Scientific knowledge, while reliable and enduring, is not absolute or certain (Kinyota, 2020). Facts, principles, theories, and laws in science are subject to change as new evidence emerges, driven by advancements in thought and technology (Betz et al., 2023). As new evidence is introduced, existing information may be reinterpreted considering evolving theories,

cultural shifts, or changes in research priorities. The inherent tentativeness of science arises not only from its inferential and creative nature, which is shaped by social and cultural contexts, but also from the compelling logical arguments that underpin it, as noted by Perk et al. (2020). Contrary to popular belief, scientific hypotheses, theories, and laws can never be definitively proven, regardless of how much empirical evidence supports them (Schauer, 2022). For example, a scientific law must account for every instance of the phenomenon it describes; however, as Greenstein (2022) points out, an unknown future instance could contradict the law, meaning it can never be fully proven. This reasoning extends equally to scientific theories.

There is a difference between scientific theories and laws

Scientific theories are robust, well-supported, and internally coherent systems of explanation (Cartwright et al., 2022). They aim to clarify large groups of seemingly unrelated observations across various fields. For example, the kinetic molecular theory explains phenomena such as changes in the physical states of matter, chemical reaction rates, and heat transfer. More importantly, theories play a pivotal role in generating research questions and guiding future studies. Typically, scientific theories are based on assumptions or axioms and often suggest the existence of unobservable entities, making them indirect in nature (Fuhse, 2022). Additionally, Kuhl (2021) states that theories cannot be tested directly; they rely on indirect evidence to support their validity. Scientists formulate specific, testable predictions derived from these theories and compare them with observable data. Predictions that align with empirical evidence enhance confidence in the theory being tested (Hajovsky et al., 2020).

It is also important to differentiate between scientific theories and laws. Laws are descriptive statements about relationships among observable phenomena (Duc Dat et al., 2024), such as Boyle's law, which describes the relationship between gas pressure and volume at a constant temperature. In contrast, Ayilimba et al. (2024) argue that theories provide inferred explanations for these observable phenomena; for instance, the

kinetic molecular theory explains Boyle's law. Salame and Dong (2021) cautioned that many students hold an oversimplified hierarchical view of theories and laws, believing that theories evolve into laws as evidence accumulates and that laws hold greater status than theories. These beliefs are misleading. Theories and laws represent different types of scientific knowledge, as noted by Recker (2021), and one does not transform into the other; both are equally valid outcomes of scientific inquiry.

Imagination and creativity play a role in science

Science is grounded in empirical observation (Grossmann et al., 2020), as scientific knowledge develops through the process of observing nature. However, this process also heavily relies on human imagination and creativity. Contrary to the common perception that science is a purely rational and orderly endeavour, it often involves inventing explanations and theoretical concepts, which requires significant creativity from scientists (Dorji et al., 2022). For example, the transition from atomic spectral lines to Bohr's model of the atom, with its complex orbits and energy levels, exemplifies this creative aspect of scientific thinking (Dias et al., 2024). This imaginative component of science, coupled with its inferential nature, suggests that entities like atoms and species should be understood as functional theoretical models rather than exact representations of reality.

Scientific knowledge is theory-laden yet partly subjective

Theory inherently shapes scientific knowledge (Kurunarathna et al., 2024). Matthews (2024) argues that a scientist's theoretical commitments, beliefs, prior knowledge, training, experiences, and expectations all significantly influence their work. These background factors create a mindset that affects the problems scientists choose to investigate, what they observe (and what they might overlook), and how they interpret their findings. This individual or collective mindset underscores the critical role of theory in the production of scientific knowledge. Contrary to the common belief that science begins with completely neutral observations (Tabish, 2024), scientific observations and investigations are

driven by specific questions or problems emerging from theoretical frameworks, which provide context and significance to the research.

Research Gap

Understanding the nature of science (NOS) is fundamental to effective science teaching and learning. Research has consistently highlighted the importance of equipping pre-service science teachers with a well-developed understanding of NOS to foster scientific literacy among students (Khaokhajorn & Srisawasdi, 2024). However, despite extensive scholarly discourse on NOS, gaps remain in how pre-service Physical Sciences teachers conceptualize it, particularly in diverse educational contexts (Valencia, Nuñez & Cofré, 2022). Existing studies have primarily focused on in-service teachers' perceptions of NOS, leaving a gap in understanding how pre-service teachers—who are still forming their professional identities—develop their conceptions (Yuan & Lee, 2014). Moreover, while research has explored general science teachers' views on NOS, limited attention has been given to Physical Sciences teachers specifically (Chuene & Singh, 2024). This distinction is crucial, as the epistemological foundations of physics and chemistry often present unique challenges in understanding the nature of scientific knowledge and inquiry (Topcu, 2013).

Additionally, studies on NOS conceptions in pre-service teachers frequently adopt quantitative approaches or rely on standardized assessment instruments, which may not fully capture the depth and complexity of teachers' evolving understandings (Griful-Freixenet, JStruyven & Vantieghem, 2021). There is a need for qualitative research that explores the nuances of how pre-service Physical Sciences teachers construct their conceptions of NOS in relation to their pedagogical practices and experiences in teacher education programs. Furthermore, contextual factors such as curriculum design, instructional approaches, and cultural influences on science education remain underexplored in shaping pre-service teachers' NOS conceptions (Alshumaimeri, 2023). Investigating these dimensions can provide insights into how teacher preparation programs can be optimized to enhance NOS instruction in

science classrooms. This study aims to address these gaps by exploring pre-service Physical Sciences teachers' conceptions of NOS through a qualitative lens, offering a deeper understanding of their perspectives and the factors influencing their views. Findings from this study will contribute to the refinement of science teacher education curricula, ensuring that future educators are better equipped to teach NOS effectively.

Conceptual Framework

The "21st-century skills" framework underpins this study, offering a conceptual lens for examining the competencies essential for success in today's complex and rapidly changing world. According to Namakula et al. (2024), these skills—creativity and innovation, communication and collaboration, research and information literacy, citizenship, and critical thinking—serve as a foundational framework for exploring pre-service physical sciences teachers' understanding of the Nature of Science (NOS). Each of these skills plays a crucial role in shaping how pre-service teachers understand and engage with NOS, influencing not only their teaching practices but also their ability to cultivate similar understandings in their learners.



Figure 1: 21st-century skills" framework

Creativity and innovation are vital in physical science education, as they encourage pre-service physical sciences teachers to think beyond traditional paradigms (Penn, 2022). A deep understanding of the Nature of Science (NOS), including scientific inquiry processes, methodologies, and conceptual foundations, empowers pre-service teachers to develop

innovative instructional strategies. Suyuti (2024) emphasized the importance of fostering an environment where creativity can thrive. In such an environment, science teachers can better engage learners in scientific thinking and problem-solving, facilitating a dynamic and interactive classroom experience.

Communication and collaboration are essential for developing a comprehensive understanding of science (Miranda et al., 2021). In the context of this study, pre-service physical sciences teachers who effectively communicate their ideas and collaborate with peers are likely to gain a richer, more nuanced perspective on the NOS. These skills promote discourse that can lead to deeper insights, as pre-service teachers share diverse viewpoints and challenge each other's assumptions. Effective communication also extends to their future classrooms, where the ability to articulate scientific concepts is crucial for enhancing learners' comprehension (Vieira & Tenreiro-Vieira, 2016).

Research and information skills are integral to studying the NOS, as they encourage pre-service physical sciences teachers to engage with scientific literature and understand the historical context of scientific developments. Benedicto et al. (2022) assert that by honing research skills, pre-service teachers can critically evaluate information, discern credible sources, and appreciate the evolution of scientific thought. This not only aids in their personal development but also equips them to guide learners in becoming discerning consumers of information, fostering a culture of inquiry and skepticism (Shah et al., 2024). Citizenship is essential for helping learners understand the role of science in society and their responsibilities as informed citizens (Tauginienė, 2020). The NOS encompasses the principles, processes, and ethics that define scientific inquiry, highlighting science's impact on society, its ethical dimensions, and the responsibility of scientists and citizens alike.

Critical thinking underpins all aspects of the 21st-century skills framework. In the context of this study, critical thinking is crucial for pre-service physical sciences teachers to evaluate the NOS thoughtfully. This involves questioning assumptions, analysing arguments, and

synthesizing information from various sources. Heystek (2021) notes that by fostering critical thinking, pre-service physical sciences teachers will be better prepared to address complex scientific issues and encourage future learners to engage in analytical and reflective thought processes, promoting a deeper understanding of scientific principles.

Integrating 21st-century skills as a conceptual framework in this study on pre-service physical sciences teachers' understanding of the nature of science offers a holistic approach to teacher education programs. By emphasizing creativity, communication, research, citizenship, and critical thinking, the study highlights the essential competencies that will empower future physical sciences teachers to effectively teach and inspire the next generation of scientists.

Methods

Research design

This study employed a qualitative approach, with data collected through a phenomenographic method. Phenomenography, as defined by Stolz (2020), describes the limited number of qualitatively different conceptions that individuals may hold regarding a given phenomenon. Zayadin (2023) further notes that phenomenography adopts a non-dualistic perspective, which posits that internal (thoughts) and external (real-world) aspects are interconnected, rather than isolated. As such, the meaning an individual assigns to a phenomenon arises from the relationship between the individual and the phenomenon itself. The primary aim of this study was to explore pre-service physical science teachers' understanding of the Nature of Science (NOS), making phenomenography an appropriate methodological framework. It is important to note, however, that the findings of this study are limited in terms of generalizability due to the small sample size.

Participants and sampling procedures

To collect data, ten fourth-year pre-service physical sciences teachers from a South African university were purposively selected and interviewed to explore the various ways in which they understand the Nature of Science (NOS). All

participants were in their final year of the Bachelor of Education (B.Ed.) program, specializing in Physical Science and Mathematics at the Further Education and Training (FET) phase. They had received instruction on the NOS during their third and fourth years of study. This inclusion criterion ensured that all participants shared similar educational experiences within the B.Ed. program.

Data collection

The semi-structured interview sessions were structured around questions derived from the Views of Nature of Science-Form C (VNOS-C), as proposed by Lederman et al. (2002). The open-

ended nature of the questions allowed participants to provide in-depth insights into their understanding of the Nature of Science. Each interview session lasted approximately 50-60 minutes, and pseudonyms were assigned to the participants to maintain anonymity; for example, PST 1 referred to Pre-Service Teacher 1, PST 2 to Pre-Service Teacher 2, and so on, up to PST 10. All interviews were recorded both visually and verbally, with prior consent obtained from the participants. The raw data collected were then transcribed, labelled, and prepared for analysis. Table 1 below outlines the open-ended questions used in the semi-structured interviews.

Table 1: Questions about NOS adapted from VNOS-C (Abd-El et al., 2000) and VOSTS (Aikenhead & Ryan, 1992)

1. In your view, what is science?
2. How is science different from other subjects?
3. Does the development of scientific knowledge require experiments? Explain your answer.
4. After scientists have developed a scientific theory (e.g., atomic theory), does the theory ever change? explain your answer.
5. Some claim that science is infused with social and cultural value
 - *If you believe that science reflects the social and cultural values, explain*
 - *If you believe that science is universal, explain your answer*
6. How do scientists know that atoms exist?
7. Where do you think scientific knowledge comes from?
8. What can you say about the use of imagination and creativity in science classrooms during practicals
9. Why do scientists do experiments?
10. What is the influence of personal beliefs on the perception of scientific inquiry?
11. What is the role of preservice teachers' conceptions in shaping their approaches to scientific inquiry in education?

Data analysis

The analysis of data in this study was conducted thematically, employing a structured coding process to derive meaningful insights from participants' responses. Thematic analysis allows for the identification and interpretation of patterns within qualitative data, and it was particularly well-suited to explore pre-service physical sciences teachers' understanding of the Nature of Science (NOS). The coding process followed a three-stage approach as outlined by De Vos et al. (2011), which included open coding, axial coding, and selective coding.

Open Coding was the first step in the analysis process, where initial categories and themes were identified by breaking down the data into smaller, more manageable units. This

involved closely examining participants' responses to the open-ended questions, highlighting key phrases, concepts, and ideas that emerged naturally from the data. During this phase, the goal was to remain open to all possibilities, allowing the data to speak for itself without preconceived notions or biases. The focus was on identifying core concepts and ideas that were prevalent across the interviews, such as participants' understanding of scientific inquiry, the nature of scientific knowledge, or their views on the tentative nature of science.

Axial Coding followed the initial phase and was used to refine and relate the categories identified in open coding. This phase involved grouping similar codes together to form broader themes, thereby providing a more coherent

understanding of the data. For example, responses related to the process of scientific inquiry, such as experimentation and observation, were grouped under a theme related to empirical observation. Similarly, concepts related to the changing nature of scientific knowledge were clustered under themes such as the tentativeness of science and the influence of new evidence. Axial coding helped to establish connections between different categories and allowed the researcher to identify relationships between them, such as how creativity and critical thinking were linked to participants' understanding of scientific inquiry.

Finally, Selective Coding was the stage in which the researcher focused on identifying the central themes or categories that best represented the participants' collective understanding of the Nature of Science. Selective coding involves integrating and refining the themes identified during axial coding into a narrative that answers the research questions. At this stage, the researcher selected the most salient and significant themes that captured the essence of the participants' perceptions of the NOS. These themes formed the backbone of the findings, highlighting key aspects such as the relationship between creativity and scientific inquiry, the role of communication in understanding science, and the impact of collaboration on developing a nuanced view of the NOS.

Throughout the entire coding process, the researcher remained committed to the principles of trustworthiness and rigor. The themes that emerged from the coding process were cross-checked against the data to ensure their relevance and accuracy, and any discrepancies or inconsistencies were addressed. This process provided a comprehensive, nuanced understanding of how pre-service physical sciences teachers conceptualized the Nature of Science and how they might incorporate this understanding into their teaching practices. Thematic analysis, through its structured yet flexible approach, allowed for an in-depth exploration of participants' views and contributed to the generation of valuable insights into science education and teacher development.

Ethical Considerations

Ethical considerations are fundamental in ensuring the integrity, credibility, and social responsibility of any research study, especially when it involves human participants. The study aimed to gain insight into how pre-service teachers conceptualize the nature of science (NOS) and how these conceptions influence their teaching approaches. Given that the study involves individuals who are part of a specific educational group, careful attention was paid to the ethical considerations surrounding participant consent, privacy, data handling, and the potential impacts on the participants and the educational community.

Informed Consent

The first and most critical ethical consideration in this study was obtaining informed consent from all participants. Preservice teachers were fully informed about the purpose of the study, its objectives, and their role in the research process. They were made aware that participation was voluntary, and they had the right to withdraw from the study at any point without penalty or negative consequences. Clear explanations were provided about the nature of the data to be collected (e.g., interviews), how it would be used, and the anticipated outcomes of the research. Written consent forms were signed by all participants to ensure that their involvement was fully voluntary and based on informed understanding.

Confidentiality and Anonymity

Ensuring the confidentiality and anonymity of participants was paramount in this study. Identifiable information was not included in any of the study's outputs, and all data were anonymized before analysis. Participants were assigned pseudonyms, and any personal or identifying details were removed from the transcripts and records to prevent association with their individual identities. The research adhered to strict protocols for data storage, using encrypted files and password-protected devices, ensuring that all information was secure and accessible only to authorized personnel. This process aimed to protect participants from any potential risks related to disclosure of their personal beliefs or teaching practices.

Respect for Autonomy and Non-Coercion

The study was designed to respect the autonomy of participants, ensuring that no coercion was used to influence their participation. Pre-service teachers were free to decline participation without fear of academic or professional repercussions. They were also assured that their decision to participate—or not participate—would not affect their grades, evaluations, or relationships with their instructors. This approach fostered an environment of mutual respect, where participants felt comfortable expressing their beliefs and experiences openly.

Minimization of Harm

In line with ethical principles of beneficence and non-maleficence, the study sought to minimize any potential harm or discomfort to participants. The research design emphasized a non-threatening and supportive environment for data collection. During interviews and surveys, participants were encouraged to express their views candidly without fear of judgment or criticism. To avoid causing distress or discomfort, sensitive questions were framed with care, and participants were reminded that they could skip any questions they found uncomfortable. Furthermore, participants were informed that the results of the study would be used solely for educational and research purposes, with no direct consequences for their academic progression.

Debriefing and Feedback

Once the study was complete, participants were debriefed and provided with an opportunity to ask questions regarding the study's findings and their participation. They were given feedback on the general outcomes of the research and how their contributions had helped improve the understanding of pre-service teachers' conceptions of the nature of science. This debriefing process was designed to ensure transparency and maintain trust between the researcher and participants. Additionally, any misconceptions or misunderstandings regarding the study were addressed to ensure that

participants left with a full understanding of their role and the research process.

Cultural Sensitivity and Inclusivity

Recognizing the diverse backgrounds of the pre-service teachers, the study made a concerted effort to be culturally sensitive and inclusive. Consideration was given to the cultural, socio-economic, and educational contexts that may influence participants' views on the nature of science. Questions and discussion prompts were designed to be neutral and open-ended, ensuring that the study did not impose any ideological or pedagogical stance on the participants. This approach encouraged a broad range of perspectives and allowed for a more nuanced understanding of how various cultural and educational experiences shaped preservice teachers' conceptions of science.

Avoiding Bias and Maintaining Objectivity

Another key ethical consideration was the avoidance of researcher bias in the interpretation of data. The study ensured that the researcher's personal beliefs or opinions about the nature of science did not influence the responses or interpretation of the findings. Data were analyzed using systematic, objective methods, and efforts were made to ensure that the perspectives of all participants were treated with equal respect and consideration. Triangulation, involving multiple data sources, was employed to strengthen the credibility and validity of the findings.

Ethical Use of Results

Finally, the study was mindful of the ethical use of the research results. The findings were presented in a way that maintained the confidentiality and anonymity of participants, and the data were used solely for the purpose of contributing to the field of education and science teacher training. Any publications resulting from the study were carefully crafted to ensure that the findings were shared in a way that would benefit the educational community while adhering to ethical standards.

In summary, this study adhered to rigorous ethical standards to ensure the well-being and rights of the preservice teachers involved. By obtaining informed consent, ensuring

confidentiality and anonymity, respecting participants' autonomy, minimizing harm, providing debriefing, and being culturally sensitive, the research maintained ethical integrity throughout the process. These ethical considerations were integral to ensuring the trustworthiness, transparency, and credibility of the study's findings while promoting the responsible use of research in the field of science education.

Findings

The discussion and findings centre around the two major themes that emerged from the data: participants' views on the Nature of Science (NOS) and their understanding of its key concepts. These themes represent the core areas that shaped the participants' perceptions of science and its role in education.

Theme 1: Pre-service physical science teachers' conceptualization of NOS

The data collected reveal that participants hold diverse and sometimes conflicting conceptions of the Nature of Science (NOS), which lack coherence. When asked to explain their understanding of the concept, some participants articulated views that aligned with contemporary perspectives on NOS, while others expressed ideas that diverged from these views. For example, participants stated:

“The nature of science is a tool used to empower and develop science teachers. Hence science is not dependent on our knowledge of specific laws and how to apply them, but it depends on the ideas and assumptions that relate to science, thus indicating the depth of understanding science.” PST 1

The statement from PST 1 highlights that scientific understanding is grounded in foundational concepts and assumptions, rather than simply memorizing laws or facts. This viewpoint aligns with key tenets of the NOS, which assert that science is a dynamic and evolving process driven by creativity, critical thinking, and the integration of various ideas. Additionally, it reflects the 21st-century skills framework, particularly the emphasis on the importance of critical thinking. The participant's

conceptualization supports the NOS principle that science is not merely the accumulation of knowledge, but an active engagement with the scientific method and its philosophical foundations, promoting a deeper understanding of how science operates in the real world.

Similarly, PST 2 conceptualizes the NOS as a guiding framework for knowledge construction, underscoring the significance of critical and problem-solving skills. This participant highlights the importance of hands-on activities, which support active learning and foster a deeper connection with scientific principles.

“I understand the nature of science as the guidance that fosters understanding of sciences to learners and how science is supposed to be taught. The nature of sciences it foster critical thinking and problem solving. Also, the nature of science is characterized by our beliefs and assumptions about scientific knowledge and processes. I understand that the nature of science gives us ways to teach science, and we must not rely on theory. We must do hands-on experiments so learners can see that theory can be practically done”. PST 2

Participant PST 2 emphasizes the importance of actively engaging learners in the scientific process. Their recognition that beliefs and assumptions shape the Nature of Science (NOS) underscores the need for teachers to reflect on their own understandings and biases in the classroom. Additionally, the emphasis on hands-on experimentation reflects a belief in the value of experiential learning, highlighting that scientific theories are not mere abstract concepts but can be demonstrated and validated through practical application. This approach aligns with effective science pedagogy, which fosters inquiry-based learning and encourages the development of a deeper, more contextualized understanding of scientific concepts.

“The Nature of Science describes the essential traits and ideas that characterize scientific knowledge and investigation. It includes systematically using observation, experimentation, and evidence-based reasoning to study the natural world.” PST 3

This narrative from PST 3 effectively captures the core elements of the Nature of Science (NOS) by highlighting the essential traits that define scientific knowledge and inquiry. The emphasis on systematic observation, experimentation, and evidence-based reasoning reflects the foundational practices that drive scientific investigation. This approach reinforces the idea that science is not simply a collection of facts, but a rigorous process of inquiry aimed at understanding the natural world. The participant suggests that scientific knowledge is constructed through careful examination and analysis, which underscores the importance of empirical evidence in validating scientific claims. This perspective aligns closely with educational goals that foster critical thinking, and a deeper understanding of how scientific knowledge is developed, validated, and applied in real-world contexts.

“The nature of science defines or addresses how we view science according to our own personal views and beliefs without consulting the scientific knowledge or process.” PST 4

Participant 4's statement suggests that people's understanding of science is often shaped by their personal beliefs rather than by the objective scientific method. This highlights the tension between subjective views and the evidence-based nature of science, where individuals may interpret scientific information through the lens of their own biases, potentially leading to misinterpretations or even rejection of established scientific knowledge. The narrative emphasizes the importance of scientific literacy, stressing the need for individuals to engage with science based on its core principles of empiricism, skepticism, and objectivity, rather than personal opinions or selective data. This approach fosters a more accurate and comprehensive understanding of scientific concepts.

Theme 2: Nature of science as a tool to foster understanding over memorization

Traditionally, science education has often placed greater emphasis on memorizing facts rather than on fostering a conceptual understanding of the scientific inquiry process. However, promoting a deeper understanding of the Nature of Science (NOS) encourages critical

thinking, enhances engagement, and equips teachers with the tools to convey the complexities of scientific processes to their students. During the semi-structured interviews, pre-service teachers were asked how their understanding of the NOS could help teachers focus on comprehension and understanding rather than rote memorization.

The responses revealed that pre-service teachers hold varying views on how the NOS can foster deeper understanding. However, it can be concluded that their perspectives share similar implications for the NOS and 21st-century skills framework central to this study. For instance, PST 7 and PST 10 noted that:

“As I have mentioned, science enforces theories and claims to be proven through demonstrations. This enforces or allows teachers to open a room for practical sessions to explain the reason behind concepts being taught to the learners. This allows learners to interact with the concepts kinaesthetically, which is the best approach to take when understanding is a priority of the lesson” PST 7

“The Nature of Science (NOS) framework emphasizes the procedures and methods that form the basis of scientific knowledge, which helps teachers encourage comprehension over memorization. By including NOS in the curriculum, teachers can help learners think critically about scientific ideas and develop an awareness of how scientific knowledge is created, verified, and used. This method shifts the emphasis from memorization to inquiry-based learning, where learners investigate current issues, develop theories, conduct experiments, and evaluate data. As a result, learners develop deeper cognitive skills, such as critical thinking and problem-solving, which are essential for true comprehension” PST 10

The notion that science relies on theories and claims supported by demonstrations aligns closely with 21st-century skills, particularly in promoting critical thinking, collaboration, and hands-on learning, as reflected in the participants' responses above. By incorporating practical sessions into the science curriculum, teachers create opportunities for students to engage with kinesthetic concepts, fostering deeper

understanding and retention. This experiential learning approach encourages learners to think critically about scientific principles, formulate hypotheses, and conduct experiments—skills that are crucial in today’s rapidly evolving world.

From a more pragmatic perspective, participant PST 6 viewed the NOS as a tool that helps learners apply scientific concepts to real-life situations while also fostering a critical stance toward scientific laws and principles that lack valid evidence. PST 6 emphasized:

“The nature of science helps teachers reflect on their teaching strategies, whether they teach learners to know or understand. So, the nature of science is based on understanding rather than knowledge. If you understand a certain concept, you can easily apply the concept to real-life situations. This is because all aspects of science are supported by valid evidence. It might be hard to memorize something that needs you to experiment first and then apply your imagination and creativity” **PST 6**

Another participant highlighted that the NOS benefits teachers in teaching science effectively and supports learners in becoming independent thinkers as they engage in inquiry-based learning. This approach enables students to develop a meaningful understanding of how science operates. PST 8 encapsulated this perspective by stating:

“The Nature of Science promotes allowing learners to do the work for themselves, not to be spoon-fed feed, so in this way, learners learn to understand. For example, inquiry-based learning encourages learners to investigate and find answers independently, hence developing a deep understanding of the content or collaborative learning, allowing learners to share information among themselves and develop their communication and teamwork skills. Again, NOS says learners should be asked or given real-world questions in order for them to be able to apply what they have learned in the real-world context” **PST 8**

The Nature of Science supports a learner-centred approach, as indicated by the participant above, emphasizing the importance of inquiry-based and collaborative learning. By encouraging

learners to explore topics independently, they deepen their understanding while developing key skills such as communication and teamwork through peer interactions. Additionally, incorporating real-world problems into the learning process enables students to apply their knowledge in practical contexts, enhancing the relevance and impact of their education. This approach nurtures critical thinking and problem-solving skills, effectively preparing learners for real-life challenges, as advocated by the 21st-century skills framework.

Theme 3: Integration of the nature of science into policy documents

Integrating the Nature of Science (NOS) into policy documents is essential for shaping science education, as it emphasizes both content knowledge and the development of critical thinking and inquiry skills. For pre-service physical science teachers, understanding NOS extends beyond simply learning scientific facts or methods; it involves recognizing science as a dynamic human endeavour influenced by creativity, culture, and societal values.

When pre-service teachers were asked if the Physical Sciences Grade 10-12 CAPS document adequately addresses NOS, PST 6 shared a different perspective. The participant noted that some key aspects of NOS are missing, making it challenging for learners to relate scientific concepts to real-life situations. As PST 6 expressed:

The Physical Sciences Grade 10-12 CAPS document, at least, provides the needs and interests of NOSs to some extent through scientific inquiry, the role of theories and laws, and meaningful empirical evidence for the physical connection. The format widely focuses on thinking critically and solving problems that students must develop to understand the scientific method. However, as a guide to the NOS framings, there may be an absence of concrete applications and real-world contexts that would help boost students’ understanding of how science works outside the classroom. **PST 6**

In agreement with the above assertion from PST 6, PST 5 also expressed dissatisfaction, stating that NOS is not sufficiently addressed in

the curriculum. They highlighted that most topics in Physical Sciences are taught in a theoretical manner, leaving practical aspects underrepresented. This gap, according to PST 5, limits students' ability to fully engage with the NOS and understand its real-world applications.

The CAPS document does address NOS but not adequately because it only covers some aspects as it is theory-based, meaning learners are just learning content or theory with few practicals. Again, the CAPS assignment does not test or measure learners' understanding because most of the questions are repeated, meaning learners can cram from past papers. So, the CAPS document does need to be improved to cover or address the NOS adequately. PST 5

Drawing from the above narratives, understanding how pre-service teachers perceive NOS is crucial for shaping future curricula and teacher preparation programs. Policy documents that emphasize NOS can provide a framework for teachers to cultivate a more comprehensive view of science, ensuring they are not only equipped with subject knowledge but also with the pedagogical tools necessary to convey the nature, limitations, and strengths of scientific inquiry. This approach will better prepare teachers to foster critical thinking and a deeper understanding of how science operates in real-world contexts.

Theme 4: The Role of Preservice Teachers' Conceptions in Shaping Their Approaches to Scientific Inquiry in Education

Scientific inquiry, as a pedagogical approach, demands that preservice teachers not only understand the procedural aspects of science but also grasp the underlying principles that define the nature of scientific knowledge. A key determinant of how preservice teachers conceptualize and teach scientific inquiry lies in their personal beliefs and prior knowledge about science, particularly the nature of science (NOS). Their conceptions influence the way they design lessons, interact with students, and guide them in developing critical scientific inquiry skills. In this discussion, we explore how preservice teachers' conceptions shape their approaches to scientific inquiry and highlight the challenges they face in bridging theory with practice.

Influence of Conceptions on Teaching Practices

Preservice teachers' conceptions of science and scientific inquiry significantly shape their instructional practices. Teachers with a traditional view of science often emphasize rote memorization of facts and procedures, rather than fostering a deeper understanding of how scientific knowledge is developed. As one preservice teacher noted, "*I used to think science was all about finding answers, but now I realize it's more about asking the right questions*" (PST 5). This shift in perspective can profoundly influence the teaching of inquiry-based lessons. When preservice teachers view science as a dynamic, evolving process, they are more likely to design lessons that emphasize investigation, exploration, and hypothesis generation, rather than just delivering predefined content.

Additionally, preservice teachers who embrace the concept of scientific inquiry as a method of learning are better able to facilitate student-centred approaches. Inquiry-based learning places emphasis on students' active engagement, critical thinking, and problem-solving. One preservice teacher stated, "*I now see my role as a facilitator, guiding students as they explore, question, and seek answers, rather than just presenting them with information*" (PST 6). This approach fosters an environment where students are encouraged to construct their own understanding of scientific concepts, thus promoting skills that are critical to scientific inquiry, such as questioning, reasoning, and evaluating evidence.

Bridging Theory and Practice

A significant challenge for preservice teachers is bridging the gap between theoretical knowledge of scientific inquiry and practical application in the classroom. Preservice teachers often enter teacher preparation programs with preconceived notions about the nature of teaching and learning. These conceptions can create difficulties when trying to align their teaching strategies with inquiry-based pedagogies. One preservice teacher reflected, "*At first, I thought inquiry-based learning was just giving students an experiment and hoping they figured it out. But I*

now understand it requires careful planning and scaffolding” (PST 8).

Teacher preparation programs are crucial in helping preservice teachers move from theoretical knowledge to practical application. Preservice teachers must not only understand the principles of scientific inquiry but also gain hands-on experience in implementing inquiry-driven lessons. These programs often provide opportunities for preservice teachers to observe inquiry-based teaching practices, engage in discussions with mentor teachers, and design their own inquiry lessons. One participant in a professional development workshop shared, “*Seeing inquiry-based lessons in action really helped me understand how to implement them effectively in my own teaching*” (PST 4). Through this exposure, preservice teachers gain confidence in applying their knowledge in real classroom settings, thus helping them overcome the challenges of integrating theory with practice.

Impact of Conceptual Understanding on Student Learning

The conceptual understanding that preservice teachers have about scientific inquiry also has a direct impact on how they engage students in the learning process. Teachers who understand the nature of scientific inquiry as an evolving process—one that involves critical thinking, experimentation, and reflection—are better equipped to guide students in developing similar skills. As one preservice teacher mentioned, “*When I understood that science isn’t about just finding answers, but about exploring and questioning, I became more comfortable letting my students explore and make mistakes along the way*” (PST 7).

This perspective enables preservice teachers to create a classroom environment that encourages curiosity and experimentation. By fostering an atmosphere in which students feel comfortable asking questions and seeking solutions, teachers can help cultivate an appreciation for the iterative nature of scientific inquiry. Students, in turn, develop stronger inquiry skills, such as formulating testable hypotheses, analysing data, and drawing evidence-based conclusions.

Shifting Conceptions through Professional Development

Professional development plays a vital role in helping preservice teachers shift their conceptions of science and scientific inquiry. Through exposure to evidence-based teaching strategies, hands-on experiences, and reflective practices, preservice teachers could reframe their views about science education. One participant shared, “*Through this program, I began to understand the importance of fostering curiosity in students rather than just teaching them facts*” (PST 3). Professional development opportunities, such as workshops, collaborative learning groups, and inquiry-based activities, can encourage preservice teachers to examine their own beliefs and biases. These experiences offer a platform for preservice teachers to challenge their assumptions about science and refine their understanding of inquiry-based teaching practices. As preservice teachers engage in reflective practices, they may begin to recognize the value of inquiry in fostering lifelong learning skills in their students. These shifts in thinking are essential for developing teachers who are not only capable of teaching scientific inquiry but also passionate about instilling a love of exploration and critical thinking in their students.

Connecting Personal and Pedagogical Beliefs

The alignment between preservice teachers' personal beliefs about science and their pedagogical practices is critical for effective science teaching. Preservice teachers who view science as a dynamic, evolving process that involves questioning, testing, and revising knowledge are more likely to adopt constructivist teaching strategies that emphasize inquiry. This connection between personal and pedagogical beliefs creates a coherent framework for teaching scientific inquiry in a way that reflects modern educational goals, such as fostering critical thinking, creativity, and problem-solving skills.

One preservice teacher explained, “*I believe science is a journey of discovery, and teaching it as an inquiry process makes it more engaging for students. It shows them that science isn’t just about learning facts; it’s about exploring the world and understanding how things work*”

(PST 6) Interview excerpt). When preservice teachers' personal beliefs align with inquiry-based teaching methods, they are more likely to feel confident in implementing inquiry-driven lessons and creating environments that nurture students' curiosity and scientific thinking.

In summary, preservice teachers' conceptions about science and scientific inquiry are pivotal in shaping their approaches to teaching. Their personal beliefs, prior knowledge, and evolving understandings influence how they design lessons, engage with students, and implement inquiry-based teaching strategies. Bridging the gap between theory and practice is essential for the effective application of scientific inquiry in the classroom, and professional development programs play a significant role in fostering these shifts in conception. By connecting their personal beliefs with pedagogical practices, preservice teachers can cultivate an inquiry-driven learning environment that encourages students to question, explore, and critically engage with the world of science.

Discussion

The study aimed to explore the conceptions of pre-service physical sciences teachers regarding the Nature of Science (NOS) and how these perceptions influence their understanding of scientific inquiry and teaching practices. The key findings from this study reveal both congruence and divergence in participants' views, offering valuable insights into the current state of NOS understanding among pre-service teachers and the implications for science education.

Diverse Conceptions of NOS

One of the most striking findings was the diversity of conceptions regarding the NOS among the pre-service teachers. While some participants demonstrated a contemporary understanding of NOS, characterized by an appreciation for the dynamic, evolving, and empirical nature of scientific knowledge, others exhibited more traditional or incomplete views. For example, several participants associated science primarily with factual knowledge and theoretical content, overlooking the importance of the scientific process, inquiry, and the role of creativity and

human values in scientific practice. These findings align with previous studies that highlight a mismatch between teachers' understanding of NOS and the more progressive views promoted in contemporary science curricula (Lederman et al., 2002). The diversity in conceptions points to a need for targeted interventions in teacher education programs, particularly focusing on deepening teachers' understanding of the epistemological foundations of science, including the distinction between science as a process and as a collection of facts.

Emphasis on the Empirical Nature of Science

A consistent theme across participants' responses was the emphasis on the empirical nature of science. Many participants noted that scientific knowledge is grounded in observation, experimentation, and evidence. This conception aligns with the principle that scientific knowledge is developed through systematic inquiry and is subject to revision based on new evidence (Lederman & Lederman, 2019). Participants who held this view appeared to recognize the importance of critical thinking, skepticism, and inquiry-based learning in the science classroom, which are core elements of 21st-century skills. The focus on empiricism also speaks to the potential for fostering deeper understanding in students when pre-service teachers themselves fully appreciate how scientific knowledge is built through empirical evidence and experimentation. However, this focus was sometimes narrowly framed, with limited discussion of the social, cultural, and ethical dimensions of science—key aspects of a holistic NOS view.

Lack of Awareness of the Tentative Nature of Science

Another important finding was the limited recognition of the tentative nature of science among some participants. Although the NOS framework highlights that scientific knowledge is provisional and subject to change, this concept was not fully integrated into many participants' responses. Some pre-service teachers struggled to understand how scientific knowledge evolves and is influenced by new findings, historical context, and social values. This lack of understanding is concerning because it can affect

how pre-service teachers approach teaching science. Without a clear understanding of science as a dynamic, evolving field, teachers may present scientific knowledge as static and unchangeable, potentially stifling students' critical thinking and their ability to engage with science as an ever-evolving discipline ((Lederman & Lederman, 2019).

The Role of Creativity and Critical Thinking

In line with the 21st-century skills framework, a significant number of participants emphasized the importance of creativity and critical thinking in science education. These pre-service teachers recognized that science is not only about learning established facts but also about engaging students in the process of scientific inquiry, problem-solving, and creative thinking. For example, participants who viewed NOS as fostering critical thinking tended to support inquiry-based and hands-on teaching strategies that encourage students to question, experiment, and explore scientific concepts in a more interactive and engaging manner. This finding is particularly significant because it suggests that pre-service teachers who embrace the role of creativity in science teaching are more likely to foster dynamic learning environments that mirror the real-world processes of scientific discovery. Incorporating these skills into teacher education programs can better prepare future educators to inspire their students to think critically and engage actively with scientific concepts (Varas et al., 2023).

Disconnect Between NOS and Curriculum Frameworks

Another key finding emerged from discussions on how the NOS is integrated into national curriculum frameworks, particularly the South African CAPS (Curriculum and Assessment Policy Statement) for Physical Sciences. Participants expressed mixed opinions about whether the NOS is adequately represented in the curriculum. Some felt that the curriculum framework focuses too heavily on theoretical content, with insufficient emphasis on the scientific process, inquiry, and the contextual and ethical dimensions of science. This gap in the curriculum is troubling, as it suggests that pre-

service teachers may not be fully equipped to teach NOS effectively unless the curriculum explicitly integrates these concepts. Some participants, however, did see the value of inquiry-based learning and the integration of NOS principles in curriculum design. They suggested that an increased focus on practical experiments and real-world scientific problems would provide learners with a more comprehensive understanding of NOS. This highlights a disconnect between policy and practice, with implications for both curriculum development and teacher preparation programs (Romijn, Slot & Leseman, 2021).

The Evolving Role of Preservice Teachers' Conceptions in Shaping Inquiry-Based Science Education

The role of preservice teachers' conceptions in shaping their approaches to scientific inquiry in education was a critical area of focus in teacher education, as these conceptions influenced how future educators approached teaching and learning in science classrooms. Preservice teachers entered their training with pre-existing ideas and beliefs about science, scientific inquiry, and how knowledge was constructed. These beliefs were often shaped by their personal experiences with science education, cultural background, and exposure to various teaching methods.

Scientific inquiry, which emphasized questioning, experimentation, observation, and evidence-based reasoning, was a fundamental approach in science education. However, how preservice teachers perceived and understood this process significantly impacted their ability to implement it effectively in their future classrooms. Teachers with a limited or rigid understanding of scientific inquiry relied on traditional, teacher-centred methods, focusing on rote memorization and passive learning. In contrast, those with more sophisticated conceptions of inquiry-based learning were likely to engage students in active, student-centred practices that encouraged exploration, critical thinking, and problem-solving.

Conceptions of scientific inquiry were not static; they evolved over time through experience, reflection, and professional

development. Preservice teachers' engagement with inquiry-based activities during their training challenged and refined their initial conceptions, fostering a deeper understanding of the inquiry process. When preservice teachers actively participated in hands-on scientific inquiry, they began to see it not just as a set of techniques, but as a mindset that encouraged curiosity and critical thinking.

In addition, preservice teachers' conceptions were influenced by the models of inquiry they encountered during their training. For example, exposure to constructivist teaching methods that emphasized student-led inquiry helped preservice teachers adopt more progressive views of science teaching. Conversely, if their training focused primarily on more conventional, didactic models, preservice teachers struggled to envision how inquiry could be integrated into their future classrooms.

Reflecting on and discussing their conceptions of scientific inquiry in professional learning communities or during mentor-guided sessions was also instrumental in shaping preservice teachers' approaches. These reflective practices allowed preservice teachers to confront misconceptions and gain insights into how scientific inquiry could be used to foster a deeper understanding of science concepts.

Ultimately, preservice teachers' conceptions played a pivotal role in determining the ways they approached scientific inquiry in their classrooms. A shift towards more open, inquiry-based practices required both the development of conceptual understanding and the application of these concepts in real-world teaching scenarios. By fostering these conceptions during teacher education programs, educators were able to better prepare preservice teachers to integrate inquiry as a powerful pedagogical tool, enhancing both teaching effectiveness and student learning in science.

The key findings of this study emphasize the importance of addressing the diverse and sometimes incomplete conceptions of NOS among pre-service physical sciences teachers. A more nuanced understanding of science as a dynamic, evolving, and socially situated endeavour is

essential for fostering a generation of teachers who can effectively teach scientific inquiry and critical thinking skills. Teacher preparation programs must continue to integrate NOS principles in a more deliberate and comprehensive way, ensuring that pre-service teachers are equipped with the knowledge and pedagogical strategies to teach science not only as a body of knowledge but as a process of inquiry and discovery. Additionally, the integration of NOS into curriculum frameworks must be strengthened to bridge the gap between theory and practice in science education.

Conclusion

This study has provided valuable insights into the conceptions of pre-service physical sciences teachers regarding the Nature of Science (NOS). The findings reveal that while some participants demonstrated an understanding of NOS consistent with contemporary views of science, others exhibited misconceptions or limited conceptions. These varied perceptions highlight the need for a more comprehensive and integrated approach to NOS within teacher preparation programs. The study emphasized the importance of incorporating NOS into curricula, not just as a set of facts or methods, but as a dynamic, evolving process shaped by creativity, societal influences, and critical inquiry. Drawing from these findings, teacher preparation programs must adopt practical instructional strategies that can address the diverse conceptions of NOS among pre-service teachers. To ensure these teachers develop a more robust understanding of NOS, curriculum content could be enriched with opportunities for pre-service teachers to engage in inquiry-based learning. For example, integrating case studies that explore the evolution of scientific ideas, conducting experiments that highlight the nature of scientific inquiry, or facilitating discussions on how science is shaped by social, political, and cultural contexts would deepen their comprehension of NOS as an ongoing, dynamic process.

Aligning NOS with 21st-century skills, such as critical thinking, creativity, collaboration, and inquiry, can help teacher preparation programs better equip pre-service teachers to engage students in scientific thinking and problem-solving. Specifically, pre-service teachers could be

encouraged to design lessons that foster student inquiry and collaboration, allowing students to actively participate in the construction of scientific knowledge. Furthermore, more emphasis should be placed on hands-on, experiential learning to bridge the gap between theoretical knowledge and practical application, ensuring that future educators are not only familiar with NOS but can also teach it in a way that engages students with real-world scientific challenges.

The research further suggests that educational policies and curriculum frameworks must prioritize NOS in science education to effectively prepare future teachers. Such an emphasis will enable pre-service teachers to nurture scientifically literate students capable of critically engaging with the world around them. By incorporating these NOS-focused strategies into teacher preparation programs, educators will be better equipped to cultivate a generation of learners who can apply scientific principles to address the complex challenges of the 21st century. Ultimately, the findings of this study reinforce the need for a well-rounded, practical approach to NOS instruction, which will better prepare pre-service teachers to integrate NOS into their classrooms and teach science in a way that promotes critical thinking, inquiry, and innovation.

Recommendations

Based on the findings of this study, several critical recommendations are made to enhance the understanding of the Nature of Science (NOS) among pre-service physical sciences teachers and improve science teacher preparation programs:

Deeper Integration of NOS in Teacher Education Programs

The study underscores the need for explicit and continuous instruction on NOS throughout teacher training. Curricula should not only cover subject content but also emphasize the philosophical foundations of science, its limitations, and its evolving nature. This would help pre-service teachers appreciate science as a dynamic process shaped by creativity, societal influences, and critical inquiry.

Adoption of Inquiry-Based and Experiential Learning Strategies

Teacher preparation programs should adopt more hands-on, inquiry-based approaches to teaching NOS. This would allow pre-service teachers to engage directly in scientific inquiry, fostering critical thinking, problem-solving, and a deeper understanding of the scientific process. Programs should equip teachers with the skills to guide students in understanding how scientific facts are derived, tested, and refined through inquiry.

Ongoing Professional Development to Address Misconceptions

Given that some pre-service teachers hold misconceptions about NOS, professional development opportunities such as workshops or reflective activities should be incorporated into teacher education programs. These opportunities should focus on addressing common misconceptions and helping teachers align their understanding with contemporary views of science.

Policy Revisions to Strengthen NOS in Curriculum Frameworks

The study highlights the need for better integration of NOS in national curriculum guidelines, such as South Africa's CAPS for Physical Sciences. Policymakers should revise curriculum frameworks to ensure that NOS is explicitly addressed across all levels of science education, providing teachers with the necessary tools to help students connect scientific concepts to real-world applications.

Encouragement of Collaborative Learning and Reflective Practices

Pre-service teacher programs should foster collaborative learning environments where teachers can share ideas, challenge assumptions, and engage in critical discussions about NOS. Reflective practices, where teachers assess their own understanding of NOS and teaching experiences, should also be incorporated to deepen their understanding and enhance instructional quality.

Further Research into NOS Conceptions

The study reveals diverse conceptions of NOS among pre-service teachers, indicating the need for further research to investigate the factors influencing the development of these conceptions. Longitudinal studies and research on the impact of different instructional strategies on NOS understanding would provide valuable insights for improving NOS teaching practices.

In summary, integrating NOS more deeply into teacher education programs, aligning it with experiential learning, and supporting professional development can better prepare pre-service teachers to foster scientific literacy in their students. By making these changes, teacher education programs can ensure that future educators are equipped to teach science as an evolving process, grounded in creativity and critical inquiry.

Disclosures

Conflict of interest

The authors declare no competing interests.

ORCID

Mngomezulu H: <https://orcid.org/0000-0001-6902-6223>

Ramaila S: <https://orcid.org/0000-0002-7351-477X>

Nduku N: <https://orcid.org/0009-0002-6970-9571>

References

- Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching*, 37(10), 1057–1095. [https://doi.org/10.1002/1098-2736\(200012\)37:103.0.CO;2-C](https://doi.org/10.1002/1098-2736(200012)37:103.0.CO;2-C)
- Aikenhead, G. S., & Ryan, A. G. (1992). The development of a new instrument: "Views on science-technology-society" (VOSTS). *Science Education*, 76(5), 477–491.
- Alshumaimeri, Y. (2023). Understanding context: An essential factor for educational change success. *Contemporary Educational Research Journal*, 13(1), 11–19. <https://doi.org/10.18844/cerj.v13i1.8457>
- Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education*, 95(3), 518–542.
- Amadi, A. (2023). Integration in a mixed-method case study of construction phenomena: From data to theory. *Engineering, Construction and Architectural Management*, 30(1), 210-237.
- Ayilimba, A., Tindan, T. N., & Dorsah, P. (2024). The Myth of Theory and the Theory-Laden Nature of Scientific Knowledge: Views of Senior High School Students. *European Journal of Contemporary Education and E-Learning*, 2(3), 117-130.
- Benedicto, P., & Andrade, R. R. (2022). Problem-based learning strategies and critical thinking skills among pre-service teachers. *International Journal of Science Technology Engineering and Mathematics*, 2(2), 1–28. <https://doi.org/10.53378/352885>
- Betz, U. A., Arora, L., Assal, R. A., Azevedo, H., Baldwin, J., Becker, M. S., ... & Zhao, G. (2023). Game changers in science and technology and beyond. *Technological Forecasting and Social Change*, 193, 122588.
- Boyle, C., Barrell, C., Allen, K.A., & She, L. (2023). Primary and secondary pre-service teachers' attitudes towards inclusive education. *Heliyon*, 9(11), e22328. <https://doi.org/10.1016/j.heliyon.2023.e22328>
- Brock, R., & Park, W. (2024). Distinguishing nature of science beliefs, knowledge, and understandings. *Science & Education*, 33, 495–516. <https://doi.org/10.1007/s11191-022-00368-6>
- Caramaschi, M., Cullinane, A., Levrini, O., & Erduran, S. (2022). Mapping the nature of

- science in the Italian physics curriculum: from missing links to opportunities for reform. *International Journal of Science Education*, 44(1), 115-135.
- Cartwright, N., Hardie, J., Montuschi, E., Soleiman, M., & Thresher, A. C. (2022). *The tangle of science: Reliability beyond method, rigour, and objectivity*. Oxford University Press.
- Chuene, K. J., & Singh, S. K. (2024). Exploring science teachers' views about the nature of science and the implications on their pedagogical content knowledge: A case of 11 in-service South African teachers. *EURASIA Journal of Mathematics, Science and Technology Education*, 20(1), em2384.
- Cirkony, C. (2023). Flexible, creative, constructive, and collaborative: the makings of an authentic science inquiry task. *International Journal of Science Education*, 45(17), 1440–1462. <https://doi.org/10.1080/09500693.2023.213384>
- Clough, M. P. (2011). Teaching and assessing the nature of science. *The Science Teacher*, 78(6), 56.
- Cofré, H., Núñez, P., Santibáñez, D., Pavez, J. M., Valencia, M., & Vergara, C. (2019). A Critical review of Students' and Teachers' Understandings of the nature of Science. *Science & Education*, 28, 205–248. <https://doi.org/10.1007/s11191-019-00051-3>
- Coleman, E. B. (2014). Using explanatory knowledge during collaborative problem-solving in science. In *Learning Through Problem Solving* (pp.387-427). Psychology Press.
- Cullinane, A., & Erduran, S. (2023). Nature of science in preservice science teacher education—Case studies of Irish pre-service science teachers. *Journal of Science Teacher Education*, 34(2), 201-223.
- Da Silva, J. G. C. (2022). Science and Scientific Method. *International Journal of Science and Research (IJSR)*, 11(4), 621-633.
- De Vos, A. S., Delport, C. S. L., Fouche, C., & Strydom, H. (2011). *Research at grass roots: A primer for the social science and human professions*. Van Schaik Publishers.
- Dias, L. A., Cardozo, T. M., & Faria, R. B. (2024). The role of jj coupling on the energy levels of heavy atoms. *Química Nova*, 48(1), e-20250006.
- Dogan, N., Cakiroglu, J., Bilican, K., & Cavus, S. (2013). What NOS teaching practices tell us: A case of two science teachers. *Journal of Baltic Science Education*, 12(4), 424–439.
- Dorji, K., Jatsho, S., Choden, P., & Tshering, P. (2022). Bhutanese science teachers' perceptions of the nature of science: a cross-sectional study. *Disciplinary and Interdisciplinary Science Education Research*, 4(1), 4.
- Duc Dat, N., Van Bien, N., & Kraus, S. (2024). The impact of the curriculum on pre-service physics teachers' nature of science conceptions. *Science & Education*, 33(5), 1231-1256.
- Fuhse, J. A. (2022). How can theories represent social phenomena?. *Sociological Theory*, 40(2), 99-123.
- Greenstein, S. (2022). Preserving the rule of law in the era of artificial intelligence (AI). *Artificial Intelligence and Law*, 30(3), 291-323.
- Griful-Freixenet, J., Struyven, K., & Vantieghem, W. (2021). Exploring pre-service teachers' beliefs and practices about two inclusive frameworks: Universal Design for Learning and differentiated instruction. *Teaching and Teacher Education*, 107, 103503. <https://doi.org/10.1016/j.tate.2021.103503>

- Grossmann, I., Weststrate, N. M., Ardel, M., Brienza, J. P., Dong, M., Ferrari, M., ... & Vervaeke, J. (2020). The science of wisdom in a polarized world: Knowns and unknowns. *Psychological Inquiry*, 31(2), 103-133. <https://doi.org/10.3390/philosophies10010004>
- Hajovsky, D. B., Chesnut, S. R., & Jensen, K. M. (2020). The role of teachers' self-efficacy beliefs in the development of teacher-student relationships. *Journal of School Psychology*, 82, 141-158.
- Herfeld, C., & Ivanova, M. (2021). Introduction: First principles in science—their status and justification. *Synthese*, 198(Suppl 14), S3297–S3308. <https://doi.org/10.1007/s11229-020-02801-1>
- Heystek, S. E. (2021). *The implementation of problem-based learning to foster pre-service teachers' critical thinking in education for sustainable development* (Doctoral dissertation, North-West University (South Africa)).
- Höttecke, D., & Allchin, D. (2020). Reconceptualizing nature-of-science education in the age of social media. *Science Education*, 104(4), 641-666.
- Khaokhajorn, W., & Srisawasdi, N. (2024). Assessing pre-service science teachers' understanding of the nature of scientific inquiry to develop a sustainable technology-infused pedagogical program in teacher education. *Cogent Education*, 11(1), 2439160. <https://doi.org/10.1080/2331186X.2024.2439160>
- Khishfe, R. (2023). Improving students' conceptions of nature of science: A review of the literature. *Science & Education*, 32(10), 1887–1931. <https://doi.org/10.1007/s11191-022-00390-8>
- Khort, M. (2025). Epistemic goals of scientific inquiry: An explanation through virtue epistemology. *Philosophies*, 10(1), 4.
- Kim, M., & Tan, A. L. (2011). Rethinking difficulties of teaching inquiry-based practical work: stories from elementary pre-service teachers. *International Journal of Science Education*, 33(4), 465-486.
- Kinyota, M. (2020). The status of and challenges facing secondary science teaching in Tanzania: a focus on inquiry-based science teaching and the nature of science. *International Journal of Science Education*, 42(13), 2126-2144.
- Kuhl, J. (2021). The expectancy-value approach within the theory of social motivation: Elaborations, extensions, critique. *Expectations and Actions*, 125-160.
- Karunarathna, I., Gunasena, P., Hapuarachchi, T., & Gunathilake, S. (2024). The role of scientific hypotheses in shaping modern research and innovation.
- Lederman, J., Bartels, S., Lederman, N., & Gnanakkan, D. (2014). Demystifying nature of science. *Science and Children*, 52(1), 40.
- Lederman, N. G., & Lederman, J. S. (2012). Nature of scientific knowledge and scientific inquiry: Building instructional capacity through professional development. *Second International Handbook of Science Education*, 335-359.
- Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497–521. <https://doi.org/10.1002/tea.10034>
- Lederman, N. G., & Lederman, J. S. (2019). Teaching and learning nature of scientific knowledge: Is it déjà vu all over again? *Disciplinary and Interdisciplinary*

Science Education Research, 1, Article 6.
<https://doi.org/10.1186/s43031-019-0002-0>

- Lekhu, M. (2023). Pre-service science teachers' preparedness for classroom teaching: Exploring aspects of self-efficacy and pedagogical content knowledge for sustainable learning environments. *Journal of Curriculum Studies Research*, 5(1), 113–129.
<https://doi.org/10.46303/jcsr.2023.9>
- Lelliott, A. D. (2014). Scientific literacy and the South African school curriculum. *African Journal of Research in Mathematics, Science and Technology Education*, 18(3), 311–323.
<https://doi.org/10.1080/10288457.2014.967935>
- Link, A. N., & Scott, J. T. (2019). Technological change in the production of new scientific knowledge: a second look. *Economics of Innovation and New Technology*, 30(4), 371–381.
<https://doi.org/10.1080/10438599.2019.1705004>
- Maknun, J. (2020). Implementation of Guided Inquiry Learning Model to Improve Understanding Physics Concepts and Critical Thinking Skills of Vocational High School Students. *International Education Studies*, 13(6), 117-130.
- Matthews, M. R. (2024). Thomas Kuhn and science education: Learning from the past and the importance of history and philosophy of science. *Science & Education*, 33(3), 609-678.
- McComas, W. F. (2017). Understanding how science works: The nature of science as the foundation for science teaching and learning. *The School Science Review*, 98(365), 71–76.
- Mesci, G., & Schwartz, R. S. (2017). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education*, 47, 329-351.
- Michel, H., & Neumann, I. (2016). Nature of science and science content learning: The relation between students' nature of science understanding and their learning about energy. *Science & Education*, 25, 951-975.
- Miranda, J., Navarrete, C., Noguez, J., Molina-Espinosa, J. M., Ramírez-Montoya, M. S., Navarro-Tuch, S. A., ... & Molina, A. (2021). The core components of education 4.0 in higher education: Three case studies in engineering education. *Computers & Electrical Engineering*, 93, 107278.
- Mueller, S., & Reiners, C. S. (2023). Pre-service chemistry teachers' views about the tentative and durable nature of scientific knowledge. *Science & Education*, 32, 1813–1845.
<https://doi.org/10.1007/s11191-022-00374-8>
- Murphy, B. (2021). Science is a human endeavour. *Connected Science Learning*, 3(1), 12318674.
<https://doi.org/10.1080/24758779.2021.12318674>
- Namakula, E.K. & Akerson, V.L. (2024). Explicit incorporation of the nature of science (NOS) in an undergraduate preservice teacher science content course: Action research. *International Journal of Research in Education and Science (IJRES)*, 10(2), 241-278.
<https://doi.org/10.46328/ijres.3354>
- Napanoy, J., Gayagay, G. C., & Tuazon, J. R. C. (2021). Difficulties encountered by pre-service teachers: Basis of a pre-service training program. *Universal Journal of Educational Research*, 9(2), 342–349.
<https://doi.org/10.13189/ujer.2021.090210>
- Oh, J. Y. (2022). Understanding the scientific creativity based on various perspectives of science. *Axiomathes*, 32, 907–929.

<https://doi.org/10.1007/s10516-021-09553-8>

- Paavola, S., Lipponen, L., & Hakkarainen, K. (2023, January). Epistemological foundations for CSCL: A comparison of three models of innovative knowledge communities. In *Computer Support for Collaborative Learning* (pp. 24-32). Routledge.
- Pavez, J. M., Vergara, C. A., Santibañez, D., & Cofré, H. (2016). Using a professional development program for enhancing Chilean biology teachers' understanding of nature of science (NOS) and their perceptions about using history of science to teach NOS. *Science & Education*, 25, 383-405.
- Park, W., Wu, J. Y., & Erduran, S. (2020). The nature of STEM disciplines in the science education standards documents from the USA, Korea and Taiwan: Focusing on disciplinary aims, values and practices. *Science & Education*, 29(4), 899-927.
- Penn, M. (2022). *Pre-service Natural Sciences Teachers' Experiences of Virtual and Augmented Reality-enhanced Inquiry Learning* (Doctoral dissertation, University of Johannesburg).
- Peters, E. E. (2012). Developing content knowledge in students through explicit teaching of the nature of science: Influences of goal setting and self-monitoring. *Science & Education*, 21, 881-898.
- Ramnarain, U. (2024). The inclusion of nature of science in South African Life Sciences and Physical Sciences school curricula. *International Journal of Science and Mathematics Education*, 22(6), 1151–1165. <https://doi.org/10.1007/s10763-023-10415-5>
- Recker, J. (2021). *Scientific research in information systems: a beginner's guide*. Springer Nature.
- Roberts, D. A., & Bybee, R. W. (2011). Scientific literacy, science literacy, and science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. II, pp. 545–558). New York, NY: Routledge. <https://doi.org/10.4324/9780203097267.ch27>
- Romijn, B. R., Slot, P. L., & Leseman, P. P. M. (2021). Increasing teachers' intercultural competences in teacher preparation programs and through professional development: A review. *Teaching and Teacher Education*, 98, 103236. <https://doi.org/10.1016/j.tate.2020.103236>
- Salame, I. I., & Dong, S. (2021). Examining Some of Students' Views on the Nature of Science (NOS) in Traditional Lecture Format Teaching Environment. *IJ CER (International Journal of Chemistry Education Research)*, 69-77.
- Sammel, A. J. (2014). Science as a human endeavour: Outlining scientific literacy and rethinking why we teach science. *Creative Education*, 5(10), 849–857. <https://doi.org/10.4236/ce.2014.510098>
- Schauer, F. (2022). *The proof: Uses of evidence in law, politics, and everything else*. Harvard University Press
- Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88(4), 610–645.
- Seung, E. S., Bryan, L. A., & Nam, J. H. (2009). Korean pre-service teachers' understanding about the nature of science (NOS). *Journal of The Korean Association For Science Education*, 29(3), 314-328.
- Shah, N. Z., Hamid, N. S., Mariadass, M. E., & Aziz, N. S. A. (2024). Fostering Critical Thinking Skills in Tertiary-Level Students for Media and Information

Literacy. *International Journal of Advanced Research in Education and Society*, 6(3), 107-123.

- Stamenkovic, P. (2022). Facts and objectivity in science. *Interdisciplinary Science Reviews*, 48(2), 277–298. <https://doi.org/10.1080/03080188.2022.2150807>
- Stefanidou, C., & Skordoulis, C. (2017). Primary student teachers' understanding of basic ideas of nature of science: Laws, theories, and models. *Journal of Studies in Education*, 7(1), 127. <https://doi.org/10.5296/jse.v7i1.10599>
- Stolz, S. A. (2020). Phenomenology and phenomenography in educational research: A critique. *Educational Philosophy and Theory*, 52(10), 1077–1096.
- Suyuti, S. (2024). The Importance of Creativity and Innovation in Education: How to Prepare Students for the 21st Century Workforce. *Education Studies and Teaching Journal (EDUTECH)*, 1(1), 80-92.
- Tabish, S. A. (2024). Scientific research. In *Health care management: Principles and practice* (pp 559–591). Springer. https://doi.org/10.1007/978-981-97-3879-3_27
- Tauginienė, L., Butkevičienė, E., Vohland, K., Heinisch, B., Daskolia, M., Suškevičs, M., ... & Prūse, B. (2020). Citizen science in the social sciences and humanities: The power of interdisciplinarity. *Palgrave Communications*, 6(1), 1-11.
- Topcu, M. S. (2013). Preservice teachers' epistemological beliefs in physics, chemistry, and biology: A mixed study. *International Journal of Science and Mathematics Education*, 11, 433–458. <https://doi.org/10.1007/s10763-012-9353-9>
- Tran, K. Q. (2023). *Towards A Culturally Nurturing Integrated Science And Engineering Education: Narrative Exploration Of Middle School Science Teachers* (Doctoral dissertation, Purdue University Graduate School).
- Valencia, M., Nuñez, P., & Cofré, H. (2022). Understanding of nature of science (NOS) in pre-service teachers with different science content knowledge, before and after an intervention. *International Journal of Science Education*, 45(16), 1–19. <https://doi.org/10.1080/09500693.2022.2152294>
- Varas, D., Santana, M., Nussbaum, M., Claro, S., & Imbarack, P. (2023). Teachers' strategies and challenges in teaching 21st century skills: Little common understanding. *Thinking Skills and Creativity*, 48, 101289. <https://doi.org/10.1016/j.tsc.2023.101289>
- Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education*, 14(4), 659–680. <https://doi.org/10.1007/s10763-014-9605-2>
- Witucki, A., Beane, W., Pleasants, B., et al. (2024). An explicit and reflective approach to teaching nature of science in a course-based undergraduate research experience. *Science & Education*, 33, 1371–1399. <https://doi.org/10.1007/s11191-023-00441-8>
- Yeh, Y. F., Dhurumraj, T., & Ramnarain, U. (2023). Representations of the Nature of Science in South African Physical Sciences Textbooks on Electricity and Magnetism. *Science & Education*, 32, 1537–1559. <https://doi.org/10.1007/s11191-022-00370-y>
- Yuan, R., & Lee, I. (2014). Pre-service teachers' changing beliefs in the teaching practicum: Three cases in an EFL context. *System*, 44, 1–12. <https://doi.org/10.1016/j.system.2014.02.002>

- Zayadin, R. (2023). Understanding the Entrepreneurs Context: A Phenomenographic Approach (Doctoral dissertation, Anglia Ruskin Research Online (ARRO)).
- Zhang, Y., Zhou, S., Wu, X., & Cheung, A. C. K. (2024). The effect of teacher training programs on pre-service and in-service teachers' global competence: A meta-analysis. *Educational Research Review*, 45, 100627. <https://doi.org/10.1016/j.edurev.2024.100627>