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Explicit Incorporation of the Nature of Science (NOS) in an Undergraduate Preservice Teacher Science Content Course: Action Research

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Abstract

This study aimed to address the gap in an environmental science undergraduate course by investigating the impact of explicitly integrating the Nature of Science (NOS) into the instruction of scientific inquiry. The lab-based course focused on developing an understanding of the natural world, as well as the processes scientists use to study that world. Through action research, data collection methods included the Views of Nature of Science Questionnaire (VNOS-B) and analysis of students' reflections on assignments and open inquiry projects for 37 students. Pre- and post-questionnaires were analyzed using NVIvo12, categorizing responses into five levels of NOS understanding thematically. Descriptive statistics were used to assess NOS views. Class reflective assignments and open inquiry projects were coded and evaluated using the revised NSI rubric employing a mixed methods analysis. The results reveal a notable shift in students' NOS understanding following the intervention which demonstrates the significance of deliberate NOS instruction. The research also pinpoints areas where students require focused instruction, offering valuable insights for educators with an emphasis on the impact of NOS integration in enhancing scientific literacy and highlighting the role of action research in refining instructional practices.

Introduction

Science education, as a scholarly discipline, pertains to the formal and informal instruction and acquisition of scientific knowledge across various educational levels (Taber, 2017). This global endeavor aims to enhance science education for all children and youth, with a focus on preparing students for future employment opportunities through the modernization of teaching methods (Owens, 2018). Science education has a goal for individuals to develop scientific literacy, provide students with knowledge and skills, increase students' awareness of science, technology, and engineering, and engage them in sustainable development efforts (Howell & Brossard, 2021, Knekta et al., 2022; Kyle, 2020). Science education is critically important today due to the prevalence of misinformation (Scheufele & Krause, 2019; West & Bergstrom, 2021). It is essential for developing critical thinking skills, promoting a spirit of inquiry, and enhancing conceptual understanding (Faize et al., 2017). Hadzigeorgiou (2017) further highlights the role of science education in developing students' cognitive perspective and awareness of the practical and emotional significance of scientific knowledge. Reforming traditional science teaching to emphasize scientific inquiry and trust in authority is vital, particularly for marginalized communities seeking social justice through science education (Alberts, 2022; Greenberg, 2017; Solomon, 2021).

Despite challenges in evaluating evidence, science education can empower informed decision-making (Shah et al., 2017). Scientifically literate individuals can understand and use scientific concepts, facts, and theories can apply science process skills to carry out a scientific inquiry, and can comprehend how science functions and how knowledge and evidence are validated and justified (Metin Peten, 2022). The highest level of inquiry, open inquiry, simulates and reflects the type of research and experimental work that is performed by scientists, and demands high-order thinking capabilities (i.e., questioning, designing an experimental array, critical and logical thinking, and reflection) (Bacak & Byker, 2021). Zion & Mendelovici (2012) assert that students who participated in an open inquiry project demonstrated ownership and responsibility for determining the purpose of the investigation and the question to be investigated as a scientist would. Many international curricular movements have made the Nature of Science (NOS) a core theme (AAAS, 1993; Kelly, 1990), and it has been seen that the Nature of Science (NOS) has and is receiving increasing attention among researchers who are increasingly emphasizing its importance. The ability to comprehend the nature of science (NOS) has been identified as a critical component of scientific literacy for everyone (Ucar, 2011). The National Science Education Standards claims that inquiry teaching can be identified by the presence of the following five features (NRC 1996): (1) Learners are engaged by scientifically oriented questions, (2) give priority to evidence, (3) formulate explanations from evidence, (4) evaluate their explanations considering alternative explanations, and (5) communicate and justify their proposed explanations.

The field of science education is struggling with how to frame issues associated with the nature of science (NOS) and the link between NOS and scientific inquiry (Holbrook & Rannikmae, 2007). A review by Sadler of literature focused on student understanding of NOS and offered examples of how scientific inquiry-based education can support the development of more sophisticated ideas of NOS (Sadler, 2011; Lederman, 2013). He asserted that providing opportunities for students to consider NOS themes in the context of scientific inquiry is certainly recommended for quality scientific inquiry science instruction but not necessarily essential. Lederman et al., (2002) contend that what has become the standard account of NOS with a focus on specific NOS tenets adopts a perspective in which NOS understandings are cognitive learning outcomes of science instruction. According to current research, "doing science" is insufficient in and of itself for establishing informed NOS concepts. Cook and Buck (2014) and Driver et al (1996) agree with academics who indicate, and experimentally demonstrate, that NOS must be understood as a cognitive learning result and addressed explicitly and reflectively within the learning environment to be effectively taught (Driver et al., 1996). Learners' perceptions of NOS are likely to remain constant if key components of NOS are not explicitly addressed within the framework of inquiry experiences, as studies have pointed out. NOS conceptualizations affect the interpretation of scientific knowledge upon which decisions about scientific Inquiry are made (Cook & Buck, 2014). Previous research has highlighted the importance of NOS understanding (Bell et al., 2010; Lederman et al., 2013; Sadler, 2011), but there remains a need to explore the effects of incorporating NOS into specific instructional contexts to enhance student learning outcomes, attitudes toward science, and engagement in scientific inquiry (Minstrell & van Zee, 2000; NRC, 1996;

Schwartz et al., 2004). Learners' perceptions of NOS are likely to remain constant if key components of NOS are not explicitly addressed within the framework of inquiry experiences, as studies have pointed out (Capps & Crawford, 2013; Celik & Bayrakçeken, 2006; Wahbeh & Abd-El-Khalick, 2013). NOS conceptualizations affect the interpretation of scientific knowledge upon which decisions about scientific Inquiry are made (Akerson & Donnelly, 2010). Research into the understanding of NOS and Scientific Inquiry with embedded explicit-reflective NOS instruction shaped the theoretical framework of this study. In recent years, science education has undergone a significant shift toward teaching scientific inquiry and process skills, in addition to scientific facts and concepts (NRC, 2012). The economics and entrepreneurship of science (Kaya et al., 2018), the necessity of a material-dialogic approach (Hetherington et al., 2018), and the significance of addressing sustainable development and social transformation (Kyle et al., 2020) are just a few of the many societal goals and meanings of science education. As demonstrated by the framework for implementing evidence in policymaking (Kano et al., 2021) and the development of a deep understanding of science practices (Kuhn et al., 2017), these goals are pertinent to evidence-based practice and decision-making. Science education must incorporate the nature of science, with particular attention to the social dimensions of science (Kaya et al, 2018), the wider implications of science (Keiler et al., 2017), and the character of scientific practice (García-Carmona & Acevedo-Díaz, 2018).

Researchers and practitioners have looked at various theories and approaches to guide instructional practices that promote scientific inquiry skills. This study focused on incorporating the Nature of Science (NOS) in an open scientific Inquiry study in an environmental science course and employed Action Research. The theoretical framework guiding the study draws on key concepts and theories in the field of science education, such as NOS (Lederman, 1992), social constructivism (Vygotsky, 1978), and Action Research (Lewin, 1946). The nature of science is a fundamental concept in science education that refers to the underlying assumptions, principles, and methods that guide scientific inquiry. Typically, NOS refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). Researchers have focused on developing frameworks for teaching and assessing NOS in science education (Lederman et al., 2014). Including contributions of the Views of Nature of Science (VNOS) questionnaire, developed by Lederman et al (2002), which assesses students' understanding of NOS. According to Lederman (1992), NOS can be characterized by key aspects such as empirical evidence, tentativeness, creativity, and subjectivity. These aspects of NOS can be integrated into science instruction through explicit instruction and inquiry-based activities that emphasize the process of scientific inquiry and the nature of scientific knowledge. This study focused on eight tenets of the nature of science. On the other hand, the constructivist approach, which emphasizes the idea that knowledge is not passed straight from the teacher to the student but is actively generated by the student, is consistent with inquiry learning. According to Vygotsky (1978), learning is a social process that is mediated by social interactions and cultural tools. The integration of these theories in the study will allow for a comprehensive investigation of the effectiveness of explicitly incorporating NOS in an open scientific inquiry study in an environmental science course.

According to Schwartz et al. (2004), the procedures and actions that contribute to the production of scientific knowledge are referred to as "scientific inquiry." This involves making observations; posing questions; examining books and other sources empirically based to see what is already known; planning investigations; reviewing what is already known while considering experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry necessitates the recognition of assumptions, the application of critical and logical reasoning, and the examination of alternative answers (NRC, 1996, p. 23). Scientific inquiry in the classroom entails student-centered projects in which students actively participate in inquiry processes and meaning construction under the leadership of the instructor to obtain meaningful comprehension of scientifically recognized notions targeted by the curriculum (Minstrell & van Zee, 2000; NRC, 1996). The National Science Education Standards (NSES) (NRC, 1996) emphasize the significance of constructing explanations based on evidence on numerous occasions. "Scientists evaluate the explanations proposed by other scientists by examining evidence, comparing evidence, identifying faulty reasoning, pointing out statements that go beyond the evidence, and suggesting alternative explanations for the same observations," the NSES states in a section on understanding scientific inquiry. These standards emphasize the importance of explanation in scientific inquiry projects, with students actively involved in inquiry processes and meaning construction under the leadership of the instructor to attain meaningful comprehension of scientifically accepted ideas targeted by the curriculum (McNeill & Krajcik, 2008). The amount of autonomy granted to students in inquiry-based teaching/learning varies, and it spans a wide range of techniques, from teacher-directed organized and guided inquiry to student-directed open inquiry (NRC, 2000). According to Akerson et al. (2000), teachers specify the knowledge framework in which the inquiry will be performed in open inquiry, the most complicated level of inquiry-based learning, but students are free to choose from a wide range of inquiry topics and methodologies. As a result, students are involved in continuous decision-making at every stage of the open inquiry process, beginning with the discovery of an interesting phenomenon to be investigated.

Students who participate in an open inquiry project demonstrate ownership and responsibility for determining the purpose of the investigation and the question to be investigated as a scientist would. Open inquiry does not divide teaching and learning but rather fosters a collaborative learning community of teachers and students that is essential to the inquiry's success (Zion & Slezak, 2005). The ability of teachers to help students develop relevant, difficult questions that will take them through their inquiry process and inspire student-generated investigation and learning is critical to open inquiry. Thus, in open inquiry, students' participation in generating an appropriate inquiry question is critical, while teachers scaffold and enable their students at each stage so that they make choices and exercise decision-making for the many stages of inquiry (Zion & Mendelovici, 2012). The cognitive ability of the students is also a factor in open inquiry. Teachers who are familiar with the cognitive abilities of their students will be able to assist them appropriately (Akerson et al., 2000). The open inquiry depends on the ability of the teachers to facilitate the students to raise the appropriate, challenging questions that will guide students during their inquiry process, and trigger student-generated investigation and learning. Thus, the participation of students in formulating an appropriate inquiry question in open inquiry is considered crucial, while the teachers scaffold and facilitate their students in every stage so that the students make choices and exercise decision-making for the different stages of inquiry.

Course Context

The course in which the action research was done was a constructivist scientific inquiry where constructivist pedagogy is a belief about learning that is based on the notion that reality cannot be seen as a set of truths to be given to the learner (Glaser & Bassok, 1989). In this course, Inquiry is being defined as a complex process encompassing a range of activities, including making observations, formulating questions, consulting various information sources to assess existing knowledge, designing investigations, critically evaluating established information considering experimental evidence, employing tools to collect, analyze, and interpret data, offering solutions, explanations, and forecasts, and effectively conveying the outcomes (Longino, 1990; Roehrig et al., 2012). To conduct effective inquiry, you need to uncover the underlying assumptions, employ critical and logical thinking, and be open to exploring alternative explanations (Tan et al., 2022). The students in a course were expected to actively create understandings through scientific investigations. This requires that they 1) be engaged in scientifically oriented questions, 2) give priority to evidence in responding to questions, 3) formulate their explanations from evidence, 4) connect explanations to scientific knowledge, and 5) communicate and justify their explanations.

The course was delivered in an in-person format, with lectures that corresponded to reading chapters (mostly focused on content) that were assessed through weekly Quizzes to guarantee material mastery. These 10 content-related quizzes in total, were due on the same day and time each week for the chosen sections. Quizzes varied between 3 to 20 questions and a 30–60-minute time limit. They were submitted individually via the university's learning management system and results are recorded immediately. The other submissions were five scientific explanations on environmental topics that had been assigned by the instructor. Eight of the NOS components were addressed at the beginning of the semester and were significant to their scientific inquiry projects. The NOS aspects that were targeted were that scientific knowledge is tentative (subject to change), empirically based (based on and derived from observations of the natural world), subjective (theory-laden), and partly the product of human inference, imagination, and creativity (involves explanation invention), and socially and culturally embedded.

During the class-assigned activities, the students came up with scientific explanations where all the scientific inquiry aspects were made explicit, and reflective discussions were conducted to provide them with opportunities to discuss and deepen their understanding of scientific Inquiry. The last submission that the Preservice teachers worked on was their open Scientific inquiry project which required individual attempts as a step-by-step project to come up with a study. The biggest gap that this study addresses is that the students were exposed to the learning of the tenets of the nature of science at the beginning of the course (only the first week) but would not explicitly show their understanding of NOS in written scientific explanations and independent Inquiry study projects. As teacher educators are concerned with adequately preparing pre-service teachers in doing their scientific inquiry, it is necessary to provide opportunities for them to experience how they can explicitly incorporate NOS, an aspect that was missing in the instruction in the independent Inquiry.

Purpose of the Study

The main goal of this action research was to engage students in authentic scientific inquiry about science inquiry concepts and to provide them a basis for reflection on NOS tenets on top of the Scientific Inquiry tenets that the students had been taught in the previous science explanations. By explicitly incorporating NOS into scientific inquiry instruction, preservice teachers (PSTs) can develop a deeper understanding of the scientific process and improve their abilities to evaluate scientific evidence and communicate their findings effectively. It is crucial to offer opportunities for preservice teachers to incorporate these ideas explicitly, as shown in prior research (Cakmakci, 2012; Erduran & Kaya, 2018; Salinas, 2022; Saribas & Akdemir, 2020). The students conducted investigations on a topic of their choice on environmental issues during which they incorporated the Scientific inquiry tenets and the NOS tenets. To do this, we asked the following questions.

1) How does the explicit incorporation of the Nature of Science affect students' NOS understanding?
2) Does incorporating the Nature of Science in preservice teacher science courses affect their scientific inquiry skills?
3) Which NOS ideas did students conceptualize best at the end of the course?

Methods

At the beginning of each semester, preservice teachers participated in an intensive two hours of instructional activities designed to explicitly address the eight target aspects of NOS that are emphasized in the reforms (Duggan-Hass & Enfield, 2000; Lederman & Abd-El-Khalick, 1998). Different activities address the aspects of the NOS and Inquiry. For example, ‘‘Tricky tracks’’ addressed differences between observation and inference, and the empirical, creative, imaginative, and tentative nature of scientific knowledge. Four other activities, ‘‘The Aging President,’’ and “The Young or Old Woman” targeted the theory and the social and cultural embeddedness of science. Another activity, a Dalmatian dog, showed Objectivity and Subjectivity/Social and Cultural Embeddedness where researchers must know that background knowledge influences how scientists view data. Finally, two black-box activities, ‘The tube’ and ‘‘The cubes’ were used to reinforce participants’ understanding of the above NOS aspects.

The activities were purposefully selected to be generic and not content-specific, given the participants’ limited science content backgrounds. In-depth descriptions of these activities were done, and each activity was followed by a whole-class discussion that aimed to explicitly highlight the target aspects of NOS and involve students in active discourse concerning the ideas presented. Usually, not all activities were explored in two hours. The next written activities after introducing the NOS were focused on scientific inquiry and did not explicitly reflect the NOS aspects. This means that the NOS was not established as a theme throughout the rest of the semester as suggested and described by Akerson et al. (2000), and students leave the course without having fully understood the NOS.

Additionally, the course activities, readings, and most scientific explanations’ simplicity bring out the NOS aspects, but students rarely have these reflection activities directed toward the NOS for the rest of the semester. As students write out their explanations, they need to reflect on the NOS aspects in all these activities and be able to note where and how these aspects are illustrated in all the activities. It is therefore important to engage students in an authentic scientific inquiry regarding scientific environmental science concepts to provide them a basis for reflection on NOS tenets. Understanding NOS can positively impact preservice teachers' perceptions of scientific inquiry and their abilities to integrate it into their scientific explanations, assignments, and inquiry projects.

Design and Procedure

The study was conducted at the School of Education at a public mid-west university in the United States, during the fall semester in the Introduction to Scientific Inquiry course. Consent was sought from IRB at Indiana University and from the students to take part in this study by explaining to them the study's purpose. The lab-based course is a General Education Natural and Mathematical Sciences Course that focuses on developing an understanding of the natural world, as well as the processes scientists use to study the world. The study was done in two classes, each with 24 students. The first author taught both classes which facilitated data collection through direct instruction.

Method of Studying Action

We used action research (Fazio, 2005; Lewin, 1946) to explore the explicit incorporation of NOS in an environmental course for elementary preservice teachers. Action research is considered a promising methodology (Laudonia et al., 2018) for enhancing instructional methods and supporting innovative teaching practices (Eilks & Ralle, 2002). It involves changing something, assessing its success, and then changing it again (Eilks, 2018). The change brought about by this study was to investigate how the explicit incorporation of NOS affects the development of scientific inquiry skills among preservice teachers in an environmental science course. This is because before the explicit Instruction, the NOS was implicitly taught in just the first week of the semester, for a two-hour lecture and not mentioned again. We used an embedded mixed method design (Greene, 2007, Page 125) in which quantitative data was used to support the qualitative findings. We integrated subjective (perceptions and experiences) and objective (measurable outcomes) data to explore the impact of explicitly incorporating NOS on elementary preservice teachers' understanding of scientific inquiry. The two methods were integrated at the analysis stage to gain insight into how the intervention works, and assumptions were made about the representativeness of the participants and the accuracy of their responses.

Data Collection and Analysis

Data was collected through a Survey questionnaire (Appendix A and B), assignment reflections, and an individual open inquiry project. The questionnaire used was the Views of Nature of Science Questionnaire form B (VNOS-B) (Lederman et al., 2002), which was administered before and after the explicit NOS instruction. Student assignment reflections were used to look for instances of students showcasing NOS understandings within the scientific explanations. We used the revised NSI rubric (Appendix C) for students' reflections on the inquiry project to assess the students' understanding of NOS within the Inquiry. The data were used to assess which NOS tenets were more pronounced in the students' explicit understanding, the ease with which the students understood the NOS, and how the NOS could be incorporated into their chosen topic. The pre-and Post Questionnaires were collectively analyzed using NVIvo12 software for thematic and content analysis. The responses to the VNOS-B questionnaire were coded in NVIvo12 using apriori codes for the participants' views about NOS. The coding focused on revealing the participants' views about the aspects of the NOS, and the analysis classified student responses into five levels of understanding. The classification of student responses on their understanding of the nature of science tenets ranged from naive to informed views. 'Naïve' responses lacked understanding or were at the level of beginning understanding, 'Towards Adequate' responses showed progress or developing understanding, 'Adequate' responses depicted that a student had some knowledge, 'Towards Informed' responses showed that the student had a proper understanding of the NOS but not fully articulated, and 'Informed' responses showed that the student had a well-articulated knowledge and accurate answers. To mitigate subjectivity, two of the researchers were engaged as evaluators and inter-rater reliability checks were conducted periodically. Descriptive statistics were used to analyze all data independently for themes indicating naive, towards adequate, adequate, toward informed, or informed views of NOS for each aspect evaluated for each participant. The author used NVIvo12 to code class assignments and the NSI rubric to analyze Inquiry Projects both qualitatively and quantitatively. Statistical analyses were performed on some submitted assignments and Open Inquiry project reflections using descriptive statistics in Microsoft Excel and SPSS software at a 95% level of significance. The percentage of students with an acceptable understanding of each aspect of NOS pre- and post-instruction and assertions were calculated with supporting quotes from qualitative responses. The findings were merged and interpreted using a mixed-method complementarity approach to identify areas of convergence, divergence, or complementarity between the qualitative and quantitative data.

Results and Discussion

The results were organized by first sharing quantitative and then qualitative findings for all respondents to the Questionnaire and then for the assignments and inquiry projects that each student had to do with still quantitative and qualitative findings.

Survey Results

Pre-Questionnaires Results

Only 37 of the 48 students answered the pre-questionnaire. Based on the answer keys provided, we calculated the average score for each student across all questions and the results are presented (see Table 1).

Table 1. Analysis of Students' Responses to Nature of Science (NOS) Questions by Category, NOS Tenet, and Frequency

VNOS B Question (Q)	Category	Average score	NOS tenet	Frequency
1	Towards Adequate	1.7	Tentative	30
			Theories & Laws	21
2	Towards Adequate	1.89	Theories and laws	9
3	Towards Adequate	1.86	Empirical Evidence	3
4	Naive	1.62	Observations	1
5	Towards Adequate	2.05	Creativity & Imagination	26
6	Naïve	1.03	Empirical Evidence	3
7	Naive	0.92	Social Cultural Biases	3

In terms of category analysis, "Towards Adequate" appeared to be the dominant category, as it has the highest frequency in the responses (30 times) compared to the "Naive" category. The average scores for "Towards Adequate" questions range from 1.7 to 2.05, suggesting a moderate to positive response from students in this category.

Post Questionnaire Results

To analyze the data, we first computed the meaning of each question response. Then, they categorized each student's response based on the answer keys provided (naive, towards adequate, adequate, towards informed, informed).

From the data, we noted that for Q1, most students were categorized as "informed" with the notion that scientific theories can change, while for Q7, the majority were categorized as "naive" or "towards adequate." For the other questions, the categories were more evenly distributed. Only a small minority were naive in this regard e.g. *'I believe that theories are tentative and are open to change in all aspects of life. Just like how opinions can change, theories can also be changed to reflect the amount of development going on'.* For Q2, most students had an informed view that scientists had a good understanding of what an atom looks like, with a sizeable minority being informed. No students were categorized as naive or adequate in their understanding of atomic structure e.g. *An atom is the smallest particle. It has a nucleus with protons, neutrons, and electrons. Scientists are pretty sure about the structure of an atom because they have discovered methods and tools that help see atoms.* This is also because, during the instruction, part of the content covered the atomic structure. For Q3, the categories were evenly distributed, with most students having an adequate understanding of the difference between scientific theory and scientific law e.g. *A scientific law is an explanation of what happens in the natural world, such as Newton's Laws of Gravity. A scientific theory is an explanation of why specific happens in the natural world, such as the atomic theory*. However, a significant minority were adequate or even naive in their understanding. For Q4, most students had an adequate understanding that science and art are different, but a significant minority was informed in their understanding of how they are similar. For Q5, most students had an adequate understanding that scientists use creativity and imagination during and after data collection, with a significant minority being informed or even informed in their understanding of this. For Q6, most students had an adequate understanding that scientific knowledge and opinion are different, but a minority are informed or even informed in their understanding e.g. *I feel like there is a difference. Scientific knowledge must undergo methods and steps that result in evidence that then is interpreted into knowledge. Opinions don't require that same methodology. While scientific knowledge can be subjective and contradict itself, it is different from opinions.* For Q7, the categories are heavily skewed towards naive and towards adequate, with only a small minority being adequate, towards informed or informed in their understanding of how astronomers can have different conclusions.

Analysis of the Pre and Post Questionnaires

For the pre-questionnaire, the frequency column indicates how often a specific NOS tenet is mentioned in students' responses. The higher frequencies suggest that certain tenets are more commonly addressed by students, potentially reflecting the emphasis or focus of the curriculum or the students' understanding. Students seem more comfortable with or inclined toward responding to questions related to "Tentative Theories & Laws," "Theories and Laws," and "Creativity & Imagination." The lower scores in the "Naive" category, particularly for "Social Cultural Biases," may indicate areas where students need more guidance or education.

A t-test was conducted to determine whether there was a significant difference between the means of the two groups. In this case, the t-test was used to compare the mean pre-test and post-test scores for student perception of the nature of science. There was a statistically significant difference between the pre-test and post-test scores, indicating a change in participants' perception of the nature of science. The proportion of students categorized as "Naive" about the understanding of science dropped from 15% on the pre-test to 5% on the post-test. The number of those classified as "Towards Adequate" decreased slightly from 40% to 35% over the same period. Those in the "Adequate" category showed an increase from 25% to 30%. Students classified as "Towards Informed" grew from 15% to 20%.

Lastly, the group labeled "Informed" saw an increase from 5% to 10%. On average, PSTs scores increased from 2.62 on the pre-test to 3.65 on the post-test, which corresponds to a shift from "Towards Adequate" to "Adequate" perception of the nature of science. Looking at the key answer code, most participants moved from "Naive" or "Towards Adequate" perceptions to "Adequate," "Towards Informed," or "Informed" perceptions after completing the course. This suggests that the intervention was effective in improving participants' understanding of the nature of science. In essence, the findings suggest that the Intervention had a positive impact on participants' perception of the nature of science and highlights the importance of science education in promoting a more accurate understanding of the scientific process.

Discussion of the Pre and Post Questionnaires

These changes suggest that the intervention had a positive impact on students' understanding of the nature of science, with fewer students holding naive or inadequate views and more students achieving higher levels. This finding is consistent with (Dogan & Abd-El-Khalick, 2008; McDonald, 2017), which found that an intervention designed to teach NOS tenets explicitly led to significant improvements in pre-service science teachers' NOS views. A range of studies have demonstrated the positive impact of incorporating the nature of science (NOS) in undergraduate scientific inquiry courses. For example, Khazaei et al (2018) and Soslu (2022) both found that studying the NOS led to significant improvements in students' understanding of scientific knowledge and the dynamic nature of science. Both studies investigated the influence of specific educational interventions, including the study of philosophy and history of science in one case and the Nature of Science and Teaching (NSAT) course in another, on undergraduate students' perspectives regarding the Nature of Science (NOS). Agustian (2020) further supported these findings, showing that undergraduate students have transitional views of the nature of science, a level between naïve and informed views. The findings led to a substantiated argument for incorporating the nature of science in undergraduate science curricula.

Similarly, Zion et al (2018) and Wheeler et al (2019) highlighted the importance of personal experiences and reflective instruction in shaping students' understanding of NOS. Their findings revealed that the course substantially improved participants' NOS conceptions, particularly in understanding theories and laws and the tentative nature of scientific knowledge, highlighting the efficacy of embedding NOS instruction within teaching methods courses for graduate students. Erumit et al (2019) and Yıldırım and Şimşek (2020) both conducted action research studies where they emphasized the role of explicit teaching of philosophy and learner-directed scientific investigations in promoting students' understanding of the NOS. Their results also suggest that reflecting on NOS aspects during content-related inquiry activities enhances students' NOS understandings. These studies support the current study's finding that using action research can be an effective way of improving students' understanding of the nature of science. The findings of the study showed that students' understanding of the NOS improved significantly after completing the course. We found that the incorporation of the NOS in the course helped students develop a more sophisticated understanding of the NOS and its role in science education.

In comparing the pre-and post-survey data, some similarities and differences were observed for example, both surveys identified Tentativeness as a key theme, with 30 students in the pre-survey and 28 students in the post-survey mentioning it. Next to that was the empirical evidence theme, however, it was mentioned by fewer students in the pre-survey (9) compared to the post-survey (18). On the other hand, there were also notable differences in the themes identified in each survey for example, in the pre-survey, Theories and Laws, Creativity and imagination, and Social Cultural biases were mentioned by 21, 26, and 3 students respectively, while in the post-survey, these themes were either not mentioned or had much lower frequency (13, 13, and 10 respectively). In contrast, the post-survey identified Objectivity and Scientific Method as themes, which were not mentioned in the pre-survey. These differences suggest that the explicit incorporation of the NOS in the course impacted students' understanding and perception of certain NOS tenets. It highlighted the potential for targeted instruction and activities to improve students' understanding of specific NOS tenets.

Assignments Reflection Results and Discussion

Four scientific explanation reflections were considered for data in helping to assess if the students had a good understanding of the Nature of Science. We used a qualitative measure developed by us (the researchers) with open-ended questions (Appendix D) integrated into the class, aligning with the convenience and structure of the learning environment. While this approach may not adhere to traditional quantitative reliability measures, it allowed us to gather rich, context-specific data reflecting the nuances of the study participants' experiences. The reliability of the measure was rooted in its ability to capture in-depth insights and perspectives, contributing to the overall rigor and trustworthiness of our qualitative research design.

Oil Spill Graphing Activity

Before taking students into this activity, they were given a lecture on water pollution and oil properties. In the assignment, a scenario in which Several ships encountered a hurricane in the Gulf of Mexico, with an oil tanker and a cruise ship among them. Small amounts of crude oil washed up on the coastline in Morrocoy Park, Venezuela, a few days after the storm. Multiple sources of crude oil samples, including Lake Maracaibo wells, deep-sea seep sites, the cruise ship's fuel source, the oil tanker, and oil from Morrocoy Park, were being investigated to determine the source of the oil and assess potential environmental actions needed. The student's task was to Graph and compare data from the different samples, and then determine the most likely source of the oil washed up on the reefs of Morrocoy. At the end of the activity in groups of four, the students were asked to trace any tenets of the nature of science and how they were evident within the activity (Appendix D).

The students' responses demonstrated a good understanding of how the nature of science principles were applied in the investigation of the oil spill scenario. In their responses, they emphasized the systematic collection and analysis of data, forming hypotheses, making inferences, and creatively using various sources of information to conclude. This reflects a sound application of scientific thinking and methods to a real-world problem. The students' answers provided insight into how they perceived and applied the nature of science in the context of the oil spill scenario especially when they were able to identify three key tenets of the nature of science i.e., Empirical Evidence, Scientific Methods, and Creativity and Imagination as they pointed to the hypothetical scenario, which were indeed relevant in this situation. They mentioned the use of empirical evidence to collect and analyze quantitative data from various sources, including different oil samples, which was essential for making informed conclusions. They stress the importance of using empirical evidence to support their claims is a fundamental aspect of the scientific process.

The students further referred to the "Observe, Infer, and Predict" tenet as a process that was a clear demonstration of how they understand the scientific method in action. They observed where the oil spill was found, inferred that it was marine oil, and predicted that it came from the oil tanker ship, forming a hypothesis based on their observations and inferences. This aligns with the scientific method's emphasis on making hypotheses and predictions based on observations. The students went ahead to mention "Hypotheses, Laws, and Theories" which indicated that they recognized the importance of developing hypotheses to guide the investigation and that scientific theories might come into play in explaining the causes of the crude oil spill. Finally, the students correctly pointed out the role of data analysis, including quantitative and qualitative data, in concluding the source of the oil spill which depicted the scientific inquiry skills that they had acquired from the activity.

Science and Scientific Inquiry

In this assignment, students were given a task to explore and present authentic and contemporary scientific inquiry. Specifically, they were to identify authentic examples of the various common characteristics of scientific inquiry, and their exploration would include current publications and/or presentations by scientists, webpages (university sites, scientific organizations, videos), and reports on scientists. As they did the assignment, they were to identify which aspects of the Nature of Science would apply to their topic of choice and they had to discuss how that would apply (Appendix D). Based on the revised General Education Curriculum (NSI) Rubric (Appendix C), the analysis of the students' responses revealed the following distribution by performance level: High Level (Articulate/Explain): Approximately 40% of the students consistently demonstrate a high level of understanding, accurately articulating and explaining the Nature of Science (NOS) concepts within the context of their research. Moderate Level (Describe/Define): Roughly 55% of the students perform at a moderate level, effectively identifying NOS concepts in their research and providing descriptions of the meanings of these concepts. While their explanations may not always be entirely accurate, they exhibit a reasonable understanding of how NOS aspects relate to their chosen topics. Low Level (Identify): About 5% of the students fall into the low level, merely identifying NOS concepts without providing substantial explanations. Their responses lacked depth in connecting NOS aspects to their research, indicating a more basic understanding. Limited Evidence (No): None of the students fell into the "Limited Evidence" category, signifying that all students have demonstrated at least some level of understanding in identifying NOS concepts in their research, with none entirely unable to do so.

Climate Change Scientific Explanation NOS Reflection

In this assignment, the students were tasked to think about climate change and come up with a scientific explanation that included the claim, evidence, reasoning, and argumentation for what was going on. In addition to that, the students were required to include a reflection on the nature of science in their answers following a prompt as in Appendix D. Based on the students' reflections, it's evident that the Nature of Science (NOS) aspects play a significant role in their understanding of climate change and their ability to explain it using scientific concepts. The rubric for Learning Outcome 1 (LO1) focused on how well students incorporate NOS aspects into their explanations of the natural phenomenon, which in this case was climate change.

Approximately 45% of the students demonstrated a high level of understanding (Articulate/Explain) by effectively identifying NOS concepts related to their scientific research on climate change and providing accurate and insightful descriptions of these concepts. These students not only recognized the NOS aspects but also adeptly explained their meanings within the context of their study. Their ability to link NOS concepts with climate change showcases a deep understanding of the relationship between the nature of science and the scientific phenomenon they were investigating.

Roughly 50% of the students performed at a moderate level (Describe/Define) by identifying NOS concepts in their climate change research and providing descriptions of these concepts. While their explanations may not always be entirely accurate or detailed, they still exhibited a reasonable understanding of how NOS aspects relate to their chosen topic. These students acknowledged the importance of NOS in their study but might benefit from further clarification and accuracy in their descriptions. About 5% of the students fell into the low-level (Identify) category. They identified NOS concepts without providing substantial explanations. Their responses lacked depth in connecting NOS aspects to their research, indicating a more basic understanding. None of the students fell into the "Limited Evidence" category, signifying that all students demonstrated at least some level of understanding in identifying NOS concepts in their research. In terms of the NOS aspects students found most pronounced, empirical evidence was highlighted by nearly 70% of the students, emphasizing the reliance on data, graphs, and statistics to support claims about climate change. Social and cultural embeddedness, exploring the societal perspectives on climate change, was identified by 20% of the students. Finally, tentativeness was noted by approximately 10% of the students, recognizing the ever-evolving nature of scientific knowledge regarding climate change. These results suggest that students grasp the importance of NOS aspects in their exploration of climate change and its scientific explanations.

Water Quality Scientific Explanation NOS Reflection

In this assignment, the students did a whole inquiry process. They started with identifying a river and going out to collect macroinvertebrate data. They formed different graphs from the data and compared it to their groups (4 students), class (6 groups), and the whole course data (six sections each with 6 groups) as it was all stored in the same place. The graphs acted as evidence during the scientific explanation as they had to reason the evidence out exhibiting how and why it supports the claim they made on the state of the quality of the river. In coming up with their scientific explanations, they incorporated the questions for the understanding of the nature of science in the context of the water quality activity as in Appendix D.

In the analysis of the students' responses to questions related to the Nature of Science (NOS) in their water quality assignment, it was evident that they predominantly performed at the "Describe/Define (Moderate)" level. This signifies a moderate level of understanding of NOS concepts within the context of their scientific investigation. Out of the eight sets of responses, approximately 62.5% of their answers fall within this "Describe/Define (Moderate)" category. While the students effectively identified NOS concepts and provided descriptions in their responses, there were occasional inaccuracies and generalities. They identify several NOS concepts relevant to their research, including tentativeness, empiricism, subjectivity, objectivity, invention, discovery, and the influence of culture and society. For example, they effectively highlight the dynamic and persistent nature of scientific knowledge concerning water, recognizing that *"what we know will always be tentative"* and simultaneously acknowledging its durability, grounded in the continual data accumulation. This is exemplified by the understanding that *"water is always changing"* yet remains studyable through data. Notably, the students show a solid grasp of the notion that scientific knowledge is both tentative and durable. They understood the dynamic and evolving nature of scientific understanding, paralleling their observations of changing water conditions. The empirical basis of scientific knowledge, primarily linked to the observation of macroinvertebrates, was a recurring theme in their responses, demonstrating their comprehension of the role of evidence in science. Also, they acknowledged the interplay between subjectivity and objectivity in science, recognizing the influence of creativity and imagination while emphasizing the importance of factual evidence. The students illustrated an awareness of how scientific knowledge can be shaped by societal and cultural factors, yet they comprehend its transcendence beyond these boundaries, as evidenced by their cross-river water quality comparison. Their nuanced perspective on the invention and discovery of scientific knowledge suggested a solid grasp of the dual nature of scientific inquiry. The students convincingly grasp the dual nature of scientific knowledge, perceiving it as a blend of inventive thinking and discovery. Their reflections also provided a nuanced perspective on the scientific method, understanding its utility as a structured framework for inquiry while acknowledging its potential to restrict creativity and adaptability in research. They acknowledged the value of the scientific method as a guiding framework while recognizing its potential to restrict creativity in certain contexts especially because they collected the data by themselves. Finally, their differentiation between observations and inferences underscored their ability to discern fundamental elements of scientific inquiry. Generally, the student's responses reflect a commendable foundation in understanding various NOS aspects as they relate to their water quality assignment, demonstrating promise in their grasp of the Nature of Science and Scientific Inquiry.

Discussion of the Assignments

The students’ responses to the oil spill scenario exhibit a strong alignment with established principles in science education. Their emphasis on empirical evidence and data analysis corresponds with the importance of explicit and reflective teaching approaches (Akerson et al., 2010), underscoring the significance of guiding students in effective data interpretation. Also, the group-based activity in the scenario reflects the concept of a "community of practice" (Akerson et al., 2011), where students collaborate to grasp the nature of science, a valuable pedagogical approach in science education. Their recognition of the role of hypotheses, data analysis, and empirical evidence closely mirrors the objectives of the Views of Nature of Science (VNOS) questionnaire (Lederman et al., 2002), which assesses learners' conceptions of the nature of science. The scenario's focus is on a socio-scientific issue (Sadler, 2011), such as an oil spill, which engages students in critical thinking and problem-solving pertinent to science literacy and the fostering of understanding the nature of science. The students exhibited the ability to apply the nature of science principles that corresponded with the understanding of epistemology and showed how that can inform science education (Matthews & Davies, 1999) and align with broader concepts of the role and character of the nature of science in science education (McComas et al., 1998). The students' approach of observation, inference, and prediction is consistent with principles of inquiry-based learning (Minstrell & van Zee, 2000), fostering active student engagement and exploration in scientific inquiry.

The results from the science and scientific inquiry assignment where students explored and presented authentic examples of contemporary scientific inquiry and identified the aspects of the Nature of Science (NOS) applicable to their chosen topics, align with the broader objective of explicit incorporation of NOS for students' understanding of science. These findings are consistent with the literature on the impact of explicit NOS instruction. The study by Akerson and Donnelly (2009) is particularly relevant as it assesses the understanding of K-2 students regarding NOS, indicating that students at a young age can grasp foundational NOS concepts when explicitly taught. Additionally, the research by Akerson et al. (2000) and Akerson and Hanuscin (2007) emphasizes the influence of explicit NOS instruction, which is consistent with the findings that demonstrate the varying levels of student performance when explicitly identifying and explaining NOS concepts in their research. The distribution of students across different performance levels in the analysis corresponds to the idea that explicit NOS instruction can lead to high, moderate, and low levels of understanding. Bell et al. (2016) emphasizes the outcomes of NOS instruction, particularly among preservice secondary science teachers. The assignment results also parallel the findings of Cook and Buck (2014), which focuses on pre-service elementary teachers' experiences in a community of practice through a place-based inquiry, highlighting the importance of integrating NOS understanding into science teaching. Additionally, the analysis aligns with the work of Capps and Crawford (2013), which investigates inquiry-based instruction and teaching about the NOS. The findings indicate that the integration of explicit NOS concepts can have varied outcomes in terms of students' ability to identify and explain these concepts, emphasizing the need for targeted instructional approaches.

The students were aware of NOS aspects and could apply them to their explanations of climate change which aligned with findings from previous studies in science education. For example, Akerson et al., (2000), in their study focusing on elementary teachers' conceptions of NOS, emphasized the importance of a reflective explicit activity-based approach in enhancing teachers' understanding of NOS. The study demonstrated that by engaging teachers in reflective activities, their conceptions of NOS improved. The current study also highlighted the impact of understanding NOS in the context of explaining natural phenomena, particularly climate change. Akerson and Hanuscin (2007) explored the effectiveness of teaching NOS through inquiry-based approaches. The study showed that inquiry-based instruction positively affected teachers' views of NOS. In the present study, students' reflections revealed a strong understanding of NOS, particularly regarding the empirical evidence, tentativeness, and observation and inference aspects. Bell et al. (2016) delved into preservice secondary science teachers' conceptions of NOS and instructional intentions. The findings highlighted the significance of developing teachers' understanding of NOS to improve their ability to teach science effectively as evidenced in the current study that students' understanding of NOS aspects played a substantial role in their capacity to explain climate change scientifically. Bilican et al. (2015) examined how contextualized learning settings enhance meaningful NOS understanding. The study emphasized the importance of contextualization in fostering students' comprehension of NOS. The current study aligns with these findings, as students' reflections demonstrated that they were able to contextualize NOS aspects within the domain of climate change.

Akerson et al. (2007) investigated the influence of guided inquiry and explicit instruction on teachers' views of NOS. This study emphasized the need for both guided inquiry and explicit instruction to improve teachers' NOS views which aligns with the current study in which students' reflections show that they benefitted from explicit instruction on NOS aspects in the context of their climate change research. Capps and Crawford (2013) examined inquiry-based instruction and teaching about NOS. Their study aimed to understand how effectively NOS was integrated into inquiry-based teaching. In the present study, students' reflections reveal a similar integration of NOS aspects, with a strong emphasis on empirical evidence, tentativeness, and observation and inference. These results affirm the importance of integrating NOS instruction into science education, as it enhances students' scientific literacy and their capacity to make informed decisions about critical issues such as climate change.

This level of understanding the students gained from the water quality assignment aligns with research in science education literature, particularly the work of Lederman and Abd-El-Khalick (1998) and Lederman and Niess (1997), which explores students' conceptions of the Nature of Science. These studies indicate that students often demonstrate a moderate understanding of NOS, acknowledging basic concepts but occasionally struggling with specifics. However, the students' responses also demonstrate potential for growth in their understanding of NOS which aligns with research by Ucar (2011) who suggests that pre-service science teachers' views evolve as they progress through teacher training programs. This process of growth is consistent with the principles of inquiry-based teaching, as emphasized in the literature by Minstrell and van Zee (2000). It emphasizes the importance of engaging students in critical reflection and exploration of NOS concepts within the context of their scientific investigations, as the students in the water quality assignment have done.

The literature, including works by McComas et al. (1998) and Matthews and Davies (1999), underscores the significance of understanding the Nature of Science in science education. It plays a crucial role in fostering scientific literacy, a theme echoed by "National Science Education Standards" (NRC, 1996) and on socio-scientific issues (Sadler, 2011). The alignment of students' understanding with the "Describe/Define (Moderate)" level in this analysis suggests that there is room for further refinement of NOS teaching strategies. Researchers like Holbrook and Rannikmae (2007) emphasize the need for science education to enhance scientific literacy by incorporating the Nature of Science into curriculum and instruction effectively. Bricker and Bell (2008) and Tan et al. (2022) stress the importance of engaging students in inquiry-based practices and enhancing their reasoning abilities. This study aligns with these calls for improved NOS education and pedagogy, as the students' experiences in the water quality assignment offer valuable insights into their conceptual development and the potential for more targeted instruction. There is a need for continued efforts to refine teaching strategies and engage students in inquiry-based practices to enhance their understanding of the Nature of Science.

Inquiry Project Results and Analysis

This part included five inquiry parts each with a prompt that the students had to answer regarding the incorporation of the nature of science.

Inquiry 1

Using the questions as in Appendix E, the students were asked to '*Give a List of the Nature of Science Tenets that could be identified in the located Primary (empirical) and secondary sources*. The results in the Figure 1 were of participants' responses to the above prompt presented as frequencies and percentages.

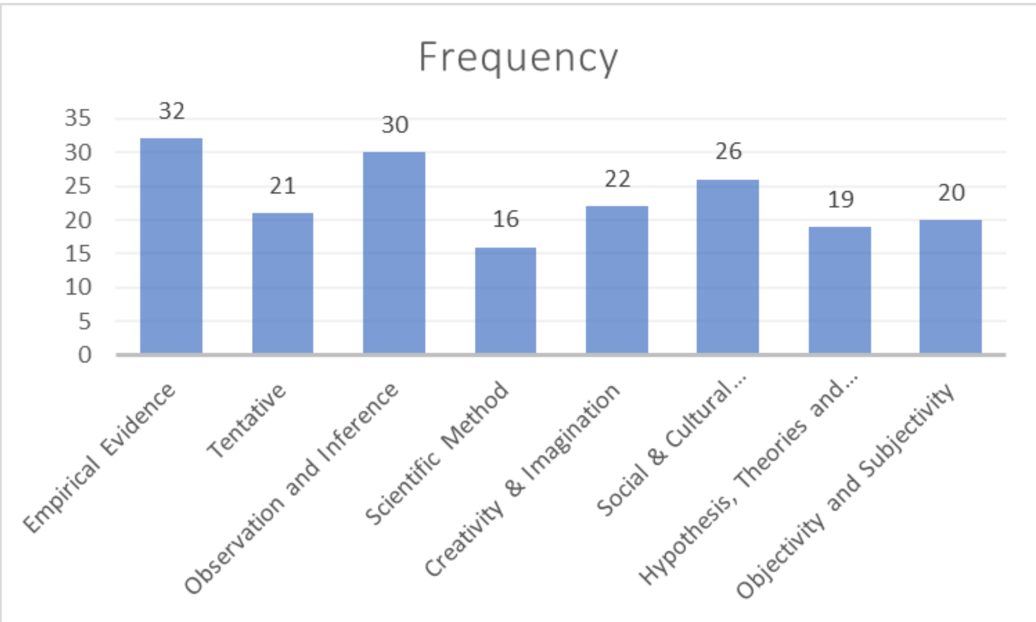

Figure 1. Frequency of the NOS Tenets Identified in the Students' Literature Search for Inquiry Project 1

The data represented the frequency of different Nature of Science (NOS) tenets that were important for understanding the scientific process. Most students (32) recognized the importance of empirical evidence in scientific inquiry, while observation and inference (30) and social and cultural embeddedness (26) were also highly valued. Tentative (21) and creativity and imagination (22) also ranked relatively high, suggesting that PSTs acknowledge the importance of these aspects of the scientific process. However, the lower ranking of the scientific method (16), hypothesis, theories, and laws (19), and objectivity and subjectivity (20) suggested that these concepts may not be as well understood or emphasized in the classroom.

Inquiry 2

In this part of the project, the students read and summarized the three research studies and three secondary sources for the question they identified in part 1 and completed a thorough summary table for each. In so doing, every student analyzed three articles to locate where and how the tenets of the nature of science were highlighted within the studies as shown in Appendix E. Figure 2 gives the frequencies of areas where students located the different tenets of the NOS.

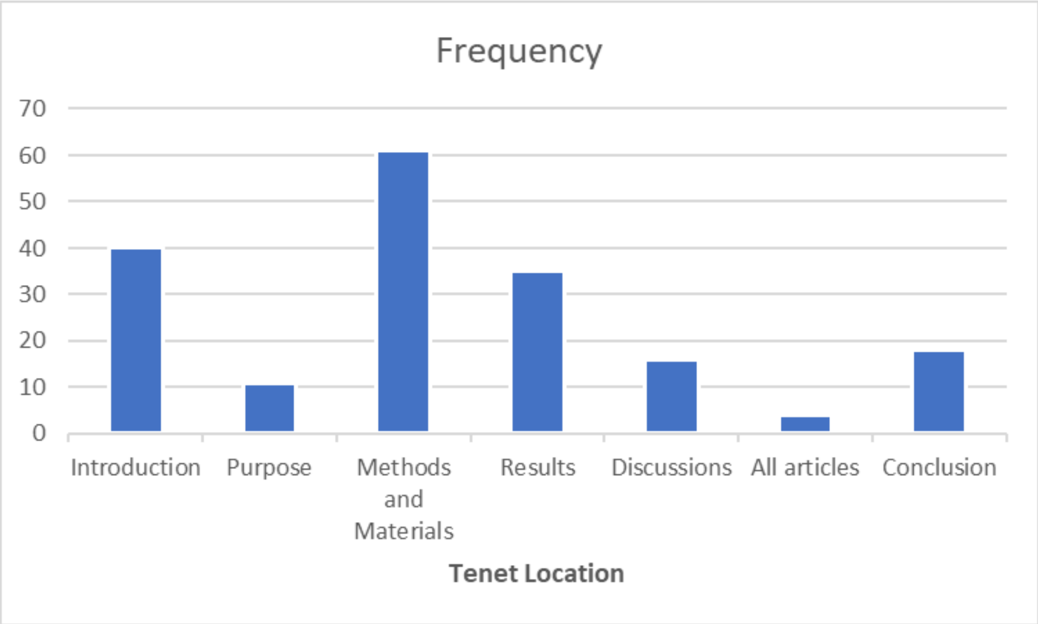

Figure 2. NOS Tenet Location within the Empirical Studies

The data suggests that the NOS tenets were frequently incorporated throughout empirical scientific articles. The Methods and Materials section had the most frequent mention of NOS tenets, indicating its importance for understanding how scientific inquiry is conducted. The Introduction section was the second-most frequent location, where scientists often introduced the NOS tenets to provide a framework for their research question. The Results section was the third-most frequent location, where scientists discussed how their results are consistent with or challenge the NOS tenets. Knowing how NOS tenets are integrated into scientific articles is crucial as it emphasizes the NOS's fundamental role in scientific inquiry.

Inquiry 3

For this part of the inquiry, the students worked with a table (Appendix F) on the task of linking descriptions of Nature of Science (NOS) tenets with their identification in three empirical sources which served to deepen their understanding of NOS, promoting the application of theoretical knowledge to real-world scientific practices.

The students were tasked with identifying the *Empirical Evidence* tenet of the Nature of Science (NOS) in three sources of their choice and explaining its explicit presence in those materials. Analysis reveals a commendable understanding among the students, as many recognized that empirical evidence involves both qualitative and quantitative data. Notably, a majority successfully identified empirical evidence in the form of graphs, charts, and tables displaying research data. For instance, 10 students noted the presence of such visuals in all their chosen sources. Additionally, 24 students acknowledged articles using empirical evidence to substantiate claims, emphasizing its collection through observation and the gathering of qualitative and quantitative data. Some students provided specific examples of empirical evidence, such as surveys, water samples, and experiments, highlighting a nuanced understanding. However, a subset of responses lacked specificity, raising concerns about the depth of comprehension. Despite this, the overall conclusion is that students demonstrated a solid grasp of the empirical evidence tenet of NOS, aligning well with recent literature on the subject. While improvements could be made in terms of specificity and detail in certain responses, the student's ability to identify and articulate the role of empirical evidence in their chosen studies reflects a commendable understanding of this aspect of the Nature of Science.

Students were tasked with identifying the *Observation and Inference* NOS tenet in three empirical and secondary sources, elucidating its explicit presence. Responses varied in content, relevance, and coherence. While some students adeptly illustrated how the tenet was applied in their sources, others struggled to establish a connection. Clear examples were provided, such as making inferences about the relationship between natural resource depletion, renewable energy consumption, and environmental degradation. There was a general understanding of the tenet's relevance to scientific inquiry, but some responses lacked specificity with students either restating observations and inferences multiple times or making vague statements without concrete examples.

In their analysis of the NOS tenet of *Hypotheses, Theories, & Laws*, students showcased an awareness of the significance of these concepts in supporting scientific claims. However, there was a notable gap in their understanding of the distinctions between hypotheses, theories, and laws. Students correctly identified hypotheses as educated guesses used to explain phenomena, present in all articles except some secondary sources. While they were able to recognize research questions or hypotheses, the analysis revealed a tendency among students to associate theories and laws with the discussion and conclusion sections of articles.

Students in the study demonstrated an understanding of the fundamental role of the *scientific method* in the nature of science, as evidenced by their identification of its use in selected articles. The preservice teachers recognized and described the steps of the scientific method observed in their chosen articles, acknowledging the absence of a universal scientific method and the variability in approaches among scientists. However, some responses deviated from the prompt, indicating a lack of understanding of the scientific method among certain participants. Research suggests that students commonly struggle with comprehending and applying the scientific method, leading to incomplete or inaccurate scientific reasoning (Vázquez-Villegas et al., 2023).

The students analyzed how *creativity* as a NOS tenet was evident in their chosen sources. They recognized creativity as an essential component of scientific research, highlighting instances where authors demonstrated imaginative problem-solving and design creation. They noted the creative elements in finding problems to study, collecting, and interpreting data, and designing experiments. However, some students exhibited a limited understanding, potentially viewing creativity as a trait rather than a process. Some students may have misconceptions about creativity as a NOS tenet, viewing it as a trait rather than a process, highlighting the need for more guidance on recognizing and applying creativity in scientific research.

Students analyzed how the NOS tenet of *Objectivity and Subjectivity* was evident in their chosen sources. While some students understood the concept well, others had a limited understanding of the concept. One student argued that Objectivity and Subjectivity meant there was no correct answer, which is not accurate according to the given explanations and definitions. In contrast, another student correctly identified that the empirical articles were peer-reviewed which to them, indicated objectivity. The same student stated that subjectivity was used when looking at other opinions on the topic. In another example, a student observed that scientists were objective by admitting that their data was not fully able to translate into other articles, but subjective in their collection of proper empirical data.

Students demonstrated a good understanding of the *cultural and social embeddedness* as an NOS tenet, recognizing it in background knowledge and demographic information of articles. They also noted its role in making predictions based on what is already known. They identified this tenet in the background knowledge of authors when finding evidence and in the demographic and cultural information presented in the articles. Examples included recognizing social and cultural embeddedness when authors discussed the demographics of an area and observing different cultures being affected by noise pollution in various ways.

The students analyzed how *tentativeness* is evident in the three empirical and secondary sources they chose. They found tentativeness in all the sources as science is constantly changing and new evidence can alter current knowledge. We of the articles used different tenets to find what was happening with pollution, and each article had different conclusions and possibilities about what would happen in the future. They observed tentativeness in the dynamic nature of science, where new evidence can alter current knowledge, and in the different conclusions and possibilities presented in each article about pollution.

Discussions of the Inquiry Projects

A study by Saribas and Akdemir (2020) found that students often struggle to understand the role of *empirical evidence* in scientific inquiry. Some teachers found it challenging to apply the principles of scientific evidence in their work, even when there was a stronger focus on highlighting the specific features that define scientific evidence. However, the preservice teachers in our study demonstrated a good understanding of how empirical evidence is used to support claims in research during scientific inquiry since they were guided in evidence construction as suggested by (Manz & Renga, 2017).

Similarly, a study by Lederman and Lederman (2014) found that students tend to view scientific knowledge as absolute and unchanging. However, the students in this study recognized that empirical evidence is subject to change based on new data or analysis. This shows that the students had a more nuanced understanding of empirical evidence as a dynamic and evolving aspect of scientific inquiry. The study displayed that the students showed a good understanding of the Empirical Evidence tenet of the NOS and how it is used in empirical and secondary sources to support claims and research.

For Inquiry 1 and 2, the students recognized the importance of *observations and inferences*, but the scientific method had the lowest frequency, possibly due to implicit understanding or lack of emphasis. The study revealed a need for additional guidance in linking NOS tenets to empirical and secondary sources. While certain students demonstrated a solid grasp of the Observation and Inference NOS tenet, others require further direction on creating meaningful connections between NOS principles and their chosen materials. The spectrum of responses highlights both strengths and areas for improvement, emphasizing the essential role of explicit guidance in this aspect of scientific inquiry.

Lederman and Niess (1996) and Akerson et al. (2010) align with the findings when they found that explicit instruction on NOS improved understanding, highlighting the need for prioritizing NOS instruction. McComas et al. (1998) showed that explicit instruction improved understanding of observations, inferences, and theory, while Matthews and Davies (1999) found that it helped students understand social and cultural factors in scientific knowledge production. Lederman and Abd-El-Khalick (1998) found significant improvement in understanding the tentative, empirical, and creative nature of science. Some students still separated hypotheses, theories, laws, observations, and inferences. The awareness of NOS fundamental role can enhance students' and researchers' understanding of the intricate and subtle aspects of scientific research. It can also aid science education and communication by emphasizing the significance of teaching and communicating about the NOS framework to improve public comprehension of science.

Drawing from literature (Abd-El-Khalick & Lederman, 2000, Lederman et al., 2002), our findings align with the broader discourse on the necessity for targeted instructional strategies to enhance students' ability to articulate and apply specific NOS tenets within the context of their scientific inquiries. Recent literature supports the idea that understanding observation and inference as an NOS tenet is crucial for scientific inquiry. Hodson and Wong (2014) stress the need for students to engage with the practices of scientists to develop this understanding. Sarıbaş and Akdemir (2020) study reported that while some pre-service teachers improved their understanding of the scientific method and evidence, others still struggled with these concepts. However, Molefe and Aubin (2021) and Yenice and Ceren-Atmaca (2017) identified challenges in linking observation and inference and reported deficiencies and misconceptions about the nature of science and scientific knowledge. These findings highlight the importance of understanding observation and inference as a NOS tenet in promoting scientific literacy and improving scientific inquiry skills.

The responses on *the theories, laws, and hypotheses* indicated a potential misconception among students, with some viewing hypotheses as unproven guesses, theories as proven guesses, and laws as absolute facts.

Clarification is needed, as hypotheses are proposed explanations subject to testing and refinement, theories are well-supported explanations grounded in extensive evidence, and laws are concise statements explaining patterns based on repeated observations (Ashley 2006; Eastwell 2014). The findings underscore the importance of addressing these nuances in scientific concepts to enhance students' comprehension of hypotheses, theories, and laws within the context of scientific inquiry. Multiple studies, including Lederman et al. (2014) and Nehm and Schonfeld (2007), support the assertion that students frequently struggle to distinguish between scientific hypotheses, theories, and laws. Lederman et al. (2014) found that college students harbored misconceptions about scientific theories, viewing them as speculative and untested.

Similarly, Nehm and Schonfeld (2007) discovered that high school students often confused scientific laws and theories, lacking an appreciation for their qualitative distinctions. This aligns with the earlier analysis of student responses, indicating an interchangeable use of these terms and a general misunderstanding of their specific meanings. Contrastingly, Stefanidou and Skordoulis (2017) reported that, following challenges, primary student teachers were able to firmly grasp the concepts of scientific laws, theories, and models. However, literature such as Salmento et al. (2021) and Stefanidou et al. (2018) suggests persistent struggles among students, including graduate students, in comprehending the nature of science, particularly in differentiating between theories and laws. The complexity is exacerbated by inconsistent and inaccurate educational resources (Alger, 2019). Despite these challenges, there is potential for improvement through appropriate instructional sequences (Stefanidou, 2017). The findings underscore the need for explicit instruction and practice to enhance students' understanding of hypotheses, theories, and laws, emphasizing the ongoing importance of targeted science education interventions.

The application of the *scientific method* in scientific inquiry by pre-service teachers is a nuanced process influenced by multiple factors. Studies by Valls-Bautista et al. (2021) and Sarıbaş and Akdemir (2020) indicate that while inquiry-based activities can enhance pre-service teachers' scientific skills, challenges persist in understanding the scientific method and evidence use. This challenge is compounded by oversimplified views of the scientific method (Windschitl & Thompson, 2006), limited understanding of scientific inquiry aspects (Baykara et al., 2018), and difficulties in creating an inquiry-based environment during practicum (Fazio et al., 2010). Binns & Popp (2013) suggest that a coherent approach focusing on core scientific practices and providing opportunities to practice inquiry instruction can help address these challenges. The findings imply that preconceptions and misconceptions about science may have hindered students' understanding of the scientific method, emphasizing the need for explicit instruction (Vosniadou, 2020) to overcome these barriers and promote a more accurate grasp of the scientific method among pre-service teachers.

The students noted that *creativity* was necessary for finding research problems, collecting data, designing experiments, and solving scientific problems. Studies suggest that students may misunderstand creativity as a trait rather than a process in scientific research, leading to misconceptions about its role (Garcês, 2018). Research has also shown that students may have a narrow view of creativity and struggle to recognize its importance in problem-solving and scientific inquiry. These misunderstandings can hinder their academic success. However, teachers' conceptions of creativity in science can also be narrow, focusing on fact-finding and practical activities (Newton

& Newton, 209; Liu & Lin, 2014). To address these issues, Dehaan (2009) argues that it is crucial to integrate explicit strategies for promoting creative problem-solving in science education which can help to bridge the gap between the perception and practice of creativity in science (Schmidt, 2011). Most of the Students' implicit theories of creativity focused on the individual or the product rather than the process which aligns with (Uszyńska-Jarmoc & Kunat, 2019). Therefore, educators must provide students with a clear understanding of what creativity is and how it can be applied in various academic disciplines. For example, Hadzigeorgiou (2012) and Sidek (2020) further suggest that integrating art and science and using pedagogical approaches such as problem-based and model-based learning, can enhance creativity.

When it came to *objectivity and subjectivity*, the examples given by the students showed that while objectivity and subjectivity are both important in scientific research, there needs to be a balance between the two when instructing it, and researchers should strive to maintain objectivity as much as possible. A range of studies have explored preservice teachers' understanding of the nature of science, with a focus on objectivity and subjectivity. For example, Georgiou (2022) found that preservice teachers often hold naive or mixed views about the social embeddedness of science, indicating a lack of understanding of the subjective influences on scientific knowledge. However, Stefanidou and Skordoulis (2017) and Sultan (2021) found that preservice teachers can develop a solid understanding of scientific concepts, including the objectivity of scientific laws and the subjectivity of scientific literacy. Lederman et al. (2002) found that students may struggle with the concept of objectivity and conflate it with neutrality. Examples provided by students in the prompt support these findings, with one student misunderstanding the concept and another correctly identifying peer-reviewed articles as objective while recognizing the use of subjectivity in analyzing other opinions.

The student’s understanding of social and cultural embeddedness aligns with Students' views on the social and cultural embeddedness in science are varied, with some studies indicating a lack of understanding (Cross et al., 2020; Georgiou, 2022; Kurniawan et al., 2022; Akbayrak, 2020). The need for cultural competence in science curricula is emphasized (Cross, 2020), and the influence of religion and culture on student attitudes in science learning is highlighted (Kurniawan et at., 2022). However, the underemphasis on the social context of science in curricula is noted (Akbayrak & Kaya, 2020). The importance of integrating learners' sociocultural experiences in science classrooms is also underscored (Mavuru, 2019). Despite these challenges, the potential of culturally relevant pedagogy in science education is recognized (Ganesan, 2020).

The students understood the tentative nature of scientific knowledge, which is supported by the literature on NOS. Students' understanding of the tentative nature of science is varied, with some recognizing its importance in classroom practice (Stefanidou & Skordoulis, 2018) and others struggling to grasp the concept (Reinisch & Krüger, 2018). This understanding is influenced by their scientific epistemological beliefs (Özgür & Temel, 2021) and can be improved through refutation texts (Flemming et al., 2020). However, traditional lecture formats may not effectively address students' misconceptions about scientific tentativeness (Salame & Dong, 2021). The understanding of the nature of science is also influenced by students' academic backgrounds and majors (Karaman, 2018). With all this, the current literature aligns with the student's understanding that scientific knowledge is tentative and subject to change based on new evidence and perspectives.

Conclusions, Implications, and Recommendations

The purpose of this study was to incorporate explicit and reflective NOS instruction situated in an authentic scientific inquiry context in an elementary preservice classroom. The results show that the explicit instruction of NOS used in this study led to gains in students' understanding of the NOS aspects measured. The results reported are limited to eight targeted NOS aspects, which are appropriately assessed for only the pre-questionnaire. The results showed that the instruction used in this study combined explicit/ reflective NOS instruction in the intense inquiry exposure and ample reflective opportunities in the inquiry projects led to positive learning gains in participants' understanding of the NOS aspects assessed. In the context of incorporating NOS into a scientific inquiry study to help students understand the Nature of Science by the end of the course, instructors may need to place greater emphasis on teaching the myth of scientific method, hypothesis, theories, laws, objectivity, and subjectivity as these were not very sound within the student’s answers. Students may have a more comprehensive understanding of NOS and how it relates to scientific inquiry, ultimately improving their scientific literacy if NOS instruction is incorporated. The study's insights had direct implications for science teacher preparation programs.

The findings provide support for the explicit incorporation of NOS in science education to promote students' understanding of scientific inquiry and the scientific enterprise. This study provides evidence-based strategies for enhancing students' understanding of the nature of science within an Inquiry course. These key dimensions can constitute valuable components of the module or course to train science teachers, provide a framework to interpret the practice of teaching NOS, as well as lay a foundation for probing the conceptions of teaching NOS in other groups of subjects or other contexts (e.g., teaching NOS to in-service teacher).

Given the findings and the contributions of the study to the field of science education, the study impacts science educators, curriculum designers, and researchers who are interested in improving students' understanding of NOS in their classes. The study employs action research as a methodology, showcasing its potential for enhancing instructional methods and promoting innovative teaching practices. The study also identifies specific aspects of NOS that require targeted instruction, such as the scientific method, hypothesis, theories, laws, objectivity, and subjectivity. This guides educators in areas where students may need more emphasis and clarification to develop a well-rounded understanding of NOS. The study's focus on improving students' understanding of NOS contributes to enhancing scientific literacy. There is a need to foster a deeper grasp of the nature of scientific inquiry in which students can be better equipped to critically evaluate scientific claims, communicate their findings effectively, and engage in meaningful scientific discussions.

Action Plan

To enhance students' understanding of the Nature of Science (NOS) framework and promote a collaborative learning environment, several key actions can be taken. First, educators should refine instructional strategies by addressing specific areas of confusion or misconceptions identified in students' responses. Second, integrating authentic scientific practices into the curriculum, such as hands-on experiments and real-world case studies, can provide practical examples of how NOS principles are applied. Additionally, fostering a curiosity-driven environment will encourage students to explore uncertainties and embrace the dynamic nature of scientific knowledge. The implementation of formative assessments and feedback will continuously gauge students' understanding and guide them toward a more accurate comprehension of NOS concepts. Finally, connecting science education to real-world issues will emphasize the relevance of NOS principles in addressing contemporary challenges, showcasing the social and cultural embeddedness of scientific inquiry. Through these actions, educators can create an engaging and effective science education experience aligned with both NOS frameworks and social constructivist principles.

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Appendices.

Appendix A. VNOS-B Questionnaire Items Aligned to Target Aspects of NOS

VNOS–Form B

1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching,* 39(6), 497521.

Appendix B. Focus Discussion: Follow-up Discussion Protocol

The follow-up discussion protocol used in conjunction with the VNOS-B open-ended survey questionnaire included the following questions used by the class discussion as a guide (Related questions have been grouped together.):

VNOS–Form B

1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learner's conceptions of nature of science. *Journal of Research in Science Teaching*, 39(6), 497521.

Appendix C. General Education Curriculum: Natural Scientific Inquiry (NSI) Rubric

Activity	**Learning Out Come**	**(High) Articulate/ explain**	**(Moderate) Describe/define**	**(Low) Identify**	**(No) Limited Evidence**
Assignments	Explain natural phenomena using scientific concepts, theories, and/or principles in terms of NOS aspect identified with in the study.	Identifies the NOS concepts, that apply to the scientific research phenomenon that they are doing. Accurately describes the meaning of the concept in the confines of the study.	Identifies the NOS concepts, that applies to the scientific research that they are doing. Describes the meaning of the concept but may not be accurate.	Identifies the NOS concepts, that applies to the scientific research that they are doing.	Unable to identify any NOS concept in their research.

Source: Appropriated and modified from the VALUE rubrics developed by the Association of American Colleges and Universities (AAC&U). Revised: 4/13/20 (Hart). Accepted by GEOC: 4/23/20 but altered to suit this study.

Appendix D. Assignment Reflection Prompts

N/O	Assignment Given	Prompt to elicit students' understanding of NOS
1	Oil Spill graphing activity	Trace the tenets of the nature of science and explain how they are evident within the current activity.
2	Science and Scientific Inquiry	Identify which aspects of the Nature of Science would apply to your topic of choice through the empirical and secondary sources that you are choosing to use. Discuss how that tenet applies.
3	Climate Change Scientific explanation	Think about climate change and come up with a scientific explanation that includes the claim, evidence, reasoning, and rebuttal for what is going on in the world today. In addition to that, you are required to include a reflection on the nature of science. How is the Nature of science connected to the climate change activity that we have done?
4	Water Quality	*a*) In what sense was scientific knowledge about water tentative? In what

	Scientific explanation NOS Reflection	sense is it durable? b) To what extent was scientific knowledge empirically based (based on or derived from observations of macroinvertebrates)? In what sense is it not always empirically based? c) To what extent are scientists and scientific knowledge subjective? To what extent can they be objective? In what sense is scientific knowledge the product of human inference, imagination, and creativity? In what sense is this not the case? d) To what extent was your scientific knowledge socially and culturally embedded? In what sense does it transcend society and culture? e) In what sense is scientific knowledge invented? In what sense is it discovered? f) How does the notion of a scientific method distort how science works? How does it accurately portray aspects of how science works? g) In what sense are scientific laws and theories different types of knowledge? In what sense are they related? h) How are observations and inferences different? In what sense can they not be differentiated?

Appendix E. Inquiry Projects Reflection Prompts

Assignment Given	Prompt to elicit students' understanding of NOS
Inquiry 1	Give a List of the Nature of Science Tenets that could be identified in the located Primary (empirical) and secondary sources.
Inquiry 2	Examine a research study and pinpoint the sections where the Nature of Science (NOS) tenets are explicitly portrayed. Identify and list these sections, highlighting instances where the authors discuss the nature of scientific knowledge, the role of evidence, and other key NOS components. Be specific in your observations, noting the location within the study where each depiction occurs."
Inquiry 3	Prompt: Following up on the locations that depicted the NOS in inquiry parts 1 & 2, fill in the NOS table below that shows how the NOS is embedded in your study. This was an analysis portion where the student was required to explain how they saw this tenet explicitly evident in the three empirical and secondary sources they chose to use. The students described each of the tenets of the Nature of science and their task was to answer the above question. Below is an analysis of how different students explain the tenets of NOS in the locations they identified in part 2.

Appendix F. Inquiry 3 NOS Description Table

Following up on the areas that depicted the NOS in inquiry parts 1 & 2, fill in the NOS table below that shows how the NOS is embedded in your study.

	Description	Name the NOS Tenet from the description.	How did you see this in the three empirical sources for your study?
1	Scientific knowledge is based on empirical evidence. Empirical refers to both qualitative and quantitative data. While some scientific concepts may be theoretical in that they are derived primarily from logic and reasoning, ultimately all scientific ideas must conform to known observational or experimental data to be considered valid.		
	Empirical data are derived from observation using the five senses. In addition, technological tools can be used to enhance scientists' ability to make observations. An inference is a logical interpretation based on observations and prior knowledge.		
3	In science, a hypothesis is typically used as a proposed explanation or prediction for a research question or problem. Scientific laws describe consistent relationships or patterns in nature. Scientific theories are different from colloquial theories in that scientific theories are well-supported explanations of natural phenomena and are based on large bodies of empirical evidence. Everyday theories are most often based on a few untested personal experiences. Both scientific laws and theories are widely accepted by scientists and can be changed in light of new evidence. Thus, hypotheses, theories and laws are never fully proven.		
4	Contrary to science textbooks, there is no one method for scientific inquiry. Scientists apply many methods to their research and there is no single, correct sequence of scientific activities.		
5	Creativity and imagination are sources of innovation and inspiration in science. Scientists use imagination, evidence, reason, and prior knowledge to generate new scientific ideas.		
6	Scientists are skeptical and apply mechanisms such as peer review and cross-checking new results with existing data to improve the objectivity of scientific knowledge. Nonetheless, personal values and beliefs, intuition, academic training, experiences, and expectations of scientists play a		

	significant role in the development of scientific knowledge. Thus, there is inherently a degree of subjectivity reflected in all scientific observations, inferences, and interpretations.		
7	Science is a human enterprise and is practiced in the context of a larger culture. Science is affected by social fabric, power structures, politics, socioeconomic factors, religion, etc. Scientific knowledge reflects these social and cultural elements.		
8	Scientific knowledge, though reliable and durable, is never absolute or proven. Scientific facts, theories, and laws are subject to change considering new data. Scientific knowledge changes as new evidence are gathered and interpreted. Often this is possible through advances in thinking and technology. Regardless of the tentative nature of science, scientific knowledge is the most reliable knowledge about the natural world and how it works.		