Changes in Preservice Secondary Science Teachers' Views, Beliefs, and their NOS Teaching During a Science Methods Course Guided by RFN

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PRESERVICE SECONDARY SCIENCE TEACHERS' NOS VIEWS AND BELIEFS CHANGES, AND THEIR NOS TEACHING DURING A SCIENCE METHODS COURSE GUIDED BY RFN

by

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ABSTRACT

This multiple-case study investigated the changes in three secondary science preservice teachers' views of the nature of science (NOS), their beliefs about the importance of NOS, as well as how these changes relate to their NOS teaching at the end of a science methods course guided by the reconceptualized family resemblance approach (RFN). RFN is a conceptual framework that visualizes science as a cognitive-epistemic and socioinstitutional system, and its educational applications have recently begun to be explored. Data sources included the pre and post course RFN Questionnaire (Kaya et al., 2019) and individual interviews, as well as each preservice teachers' lesson plan and teaching video from the end of the semester.

Findings showed that there was an overall improvement in preservice teachers' views of NOS and revealed some inconsistencies between the views reflected on the questionnaire compared to those expressed during the interview. One preservice teacher continued to hold misconceptions about scientific theories and laws after the course. Two preservice teachers developed far-reaching beliefs in the importance of teaching NOS that transcend the classroom and were able to implement explicit-reflective NOS instruction at the end of the course. Despite having accurate views and knowledge of effective NOS teaching and professing a belief in the importance of teaching NOS, the third preservice teacher did not enact explicit-reflective NOS instruction at the end of the course.

Contributions to the NOS literature were identified. Recommendations were made for further study and implications for research and science teacher education were discussed.

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FRA	Family Resemblance Approach
NOS	Nature of Science
RFN	Reconceptualized Family Resemblance Approach

CHAPTER ONE: INTRODUCTION

The nature of science (NOS) typically refers to "the epistemology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman, 1992). In other words, NOS represents "what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors" (Clough, 2006, p. 463). Because science is so rich and dynamic and each discipline is varied (Irzik & Nola, 2011), spelling out NOS in a singular way is impractical (Schwartz & Lederman, 2002), and the debate in characterizing science will likely continue at the philosophical level (McComas et al., 1998). While some scholars argue that there is no consensus on the meaning of NOS, disagreements that exist among historians, philosophers, and science educators are not relevant to K-12 instruction (Lederman & Lederman, 2014). Even though the definition of NOS varies, NOS has remained widely accepted and argued for in reformed science standards and documents for over 50 years (AAAS, 1990, 1994; NRC, 1996, 2012).

Besides its placement in national and international reform documents, it is important to teach NOS so that students are prepared to enter society as scientifically literate individuals (Shamos, 1995; Lederman et al., 2013). Researchers Driver, Leach, Millar and Scott investigated and described students aged 9 through 16's NOS understandings, resulting in a seminal book (1996). The researchers expressed why understanding NOS matters from a science curriculum viewpoint that aims to spread scientific literacy. They articulated five main arguments (Thomas & Durant, 1987) positioned in the literature for promoting public understanding of science, and described how understanding NOS is integral for each case. The arguments that drive the need to equip students with a firm understanding of NOS as to promote public understanding of science and increase scientific literacy are as follows: (1) NOS has a utility value, (2) NOS aids in socioscientific decision making, (3) NOS supports people in appreciating and support science as an endeavor, (4) knowing and embodying the moral values of science are valuable traits to society, and (5) NOS can encourage students to learn science while seeing themselves as contributors to science.

Science impacts basically every aspect of 20th century life (McComas et al., 2002). In the modern world where citizens vote toward funding, policy, and legal decisions of scientific consequence, these choices are influenced by personal understanding of the scientific enterprise (Driver et al., 1996). Policymakers and the public are increasingly prone to disregard scientific consensus as mere opinion, due to a lack of understanding how science works (McComas & Clough, 2020). This lack of understanding can be harmful, and even deadly, as seen in the questionable decision making that undermined scientific expertise regarding health and public safety during the Covid-19 pandemic (Verma et al., 2020).

While some preservice teachers "do show an interest in the nature of science, they are not always aware of its value for science education, nor do they possess strategies to incorporate it into instruction" (McComas, 1998, p. 197). Possessing accurate views of NOS is clearly important for many reasons, but far too often, teachers have uninformed views of NOS themselves, do not believe it is important for their students to know, and do not effectively teach NOS (McComas et al., 2020). For decades, lines of research have rested on two basic implicit assumptions: "a teacher's understanding of the nature of science is related to his/her students' conceptions and a teacher's instructional behaviors and decisions are significantly influenced by his/her conceptions of the nature of science" (Lederman, 1992, p. 350). Indeed, preservice and inservice teachers' own views of NOS are understood to have a critical role on students' views of NOS (Akerson et al., 2017). However, research shows that regardless of the instrument used for assessment, experience in teaching years, grade level taught, and science discipline, science teachers do not possess adequate views of NOS (Lederman & Lederman, 2014). This issue may have several root causes, including an absence of philosophy of science and real science research experiences in teacher preparation programs, and the surface-level portrayal of NOS in the textbooks that teachers use for support (McComas, 1996, p. 53).

The most prevalent misconceptions about NOS held by teachers, and consequently by students, include the views that hypotheses become theories which become laws, that there is one linear scientific method, and that scientific knowledge is completely objective and absolute (McComas, 1996). Within preservice teacher education, some views of NOS are more difficult to change than others, including the roles of theories and laws, tentativeness, and sociocultural embeddedness (Cofre et al., 2019). Research reveals that certain views of NOS, including its empirical nature, differentiating between observations and inferences, and the importance of creativity in science, are easier for teachers at all levels to learn (Cofre et al., 2019). Traditionally, scholars have adopted a generalized approach that describes NOS as a list of declarative statements (i.e., science is tentative, science is a human endeavor, etc.) among which there is general agreement (Lederman & Lederman, 2014). While some find this consensus approach to be a pragmatic and effective means to teach NOS (Kampourakis, 2016), critics (Erduran, 2014) have called it undifferentiated and philosophically inadequate (Reinisch & Fricke, 2022), and "blind to the differences among scientific disciplines" (Cofre et al., 2019, p.

207). This may further contribute to shallow understandings of NOS that exist among teachers and students. Irzik & Nola (2011) proposed a family resemblance approach (FRA) that considers scientific disciplines as family members who share some but not all characteristics. Irzik and Nola (2011) contend that this view is more pedagogically useful and is more comprehensive and systematic than alternatives and will lead to a more holistic understanding of NOS. Kaya & Erduran (2016) reconceptualized this approach and proposed the Reconceptualized Family Resemblance Approach to NOS (RFN), expanding the categories to fully portray cognitive-epistemic and social-institutional NOS for utilization in science education. A systematic review of science education literature revealed an increasing number of empirical studies using FRA with preservice teachers, secondary students, and in curriculum analysis (Cheung & Erduran, 2022). The authors suggested that to maximize the potential contribution of FRA in science education, the categories with the social-institutional system dimension must be made explicit as these are both less emphasized in the reviewed studies and are underrepresented and misunderstood aspects of science (Cheung & Erduran, 2022).

Despite successful interventions that lead to more accurate views of NOS among teachers, this is not sufficient to promise that teachers will value it as an important educational goal (McComas et al., 2020). Research shows that in addition to possessing informed views of NOS, teachers must also personally believe in the importance of teaching it (Nouri et al., 2021). There is a persistent culture of school science that prioritizes traditional content knowledge over epistemic knowledge and processes (McComas, 2020). The majority of science teachers believe that their first and most urgent priority is teaching scientific principles (Lee & Witz, 2009). Research finds that, simply “many teachers do not teach NOS because they do not see it as important” (Ward & Haigh, 2017, p. 1251). However, when teachers’ intentions to teach NOS are grounded in a well-developed rationale for teaching NOS, this may enable teachers to overcome potential barriers to teach NOS (Hanuscin, 2013). While much research has been conducted in developing preservice science teachers’ views of NOS (Lederman & Lederman, 2014), little research has been done in developing preservice science teachers’ beliefs about why it is important to teach NOS (Wan & Wong, 2016).

Furthermore, to translate one’s beliefs about the importance of teaching NOS into NOS instruction, it is imperative to have knowledge of how to teach NOS. Teachers must know how to teach NOS because “the most important variables that influence students’ beliefs about the nature of science are those specific instructional behaviors, activities, and decisions implemented within the context of a lesson” (Lederman, 1992, p. 351). Beyond knowledge of activities that can be used to enhance students’ views of NOS, teachers must know how to effectively implement the activities to target misconceptions. According to McComas (1998), teachers’ understanding of NOS and knowledge of appropriate instructional activities are alone insufficient to foster student understanding of NOS, because the actions taken by a teacher are more important. Additionally, many teachers view that NOS will be communicated to students regardless of whether it is done purposefully or accurately through implicit cues during science teaching (McComas et al., 1998). However, empirical research conducted over the past two decades has found that an explicit, reflective approach to NOS instruction is more effective at teaching NOS than is an implicit approach that assumes students will learn about NOS simply by engaging in science (Lederman & Lederman, 2014). To be successful NOS educators, preservice teachers must experience explicit-reflective instruction and practice planning and enacting this type of instruction.

Three main problems are outlined in the previous sections: prevalent and inaccurate NOS views among preservice teachers, a belief that teaching NOS is unimportant, and the false notion that NOS can be effectively taught without explicit attention and reflection around NOS ideas. This research study therefore answers the calls for science education researchers to contribute to the RFN approach by investigating its utility in preservice secondary science teacher education, to develop preservice teachers' beliefs about the importance of teaching NOS, and to explore the enactment of NOS teaching by preservice teachers.

Defining Key Terms

<u>Nature of Science (NOS)</u>: "what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors" (McComas et al., 2002, pg. 4)

<u>Reconceptualized Family Resemblance Approach (RFN)</u>: A conceptualization of NOS as a cognitive-epistemic and social-institutional system.

<u>Teachers' beliefs</u>: "an individual's judgment of the truth or falsity of a proposition" (Pajares, 1992, p. 316).

Purpose Statement

The purpose of this study is to investigate how NOS views and beliefs about the importance of teaching NOS develop among preservice secondary science teachers during a semester-long science methods course guided by RFN, and to explore how preservice teachers' views and beliefs relate to their NOS teaching. Given the context and background of this study, this study aims to:

- employ the most recent conceptual framework of NOS that is of much interest to the science education community and contribute to the scholarship about RFN in the context of secondary science teacher education, and to
- understand how preservice teachers develop their views of NOS, their beliefs about the importance of teaching NOS, and how these relate to their NOS teaching through a science methods course guided by RFN.

Research Questions

In an effort to contribute meaningful insight into understanding the development of preservice secondary science teachers' views of NOS, beliefs of importance of teaching NOS, and NOS teaching, this study seeks to answer the following research questions:

1. What are PSTs' views about NOS, related to each RFN category, before and after a science methods course guided by RFN?
2. In what ways do PSTs' beliefs about the importance of teaching NOS change through a science methods course guided by RFN?
3. How do PSTs' views about NOS and beliefs about the importance of teaching NOS relate to their NOS teaching at the end a science methods course guided by RFN?

CHAPTER TWO: REVIEW OF THE LITERATURE

A central issue in science education is the prevalence of uninformed views about NOS among preservice teachers, lack of belief in the importance of teaching NOS, and the absence of NOS teaching in practice (Nouri et al., 2021). This chapter elaborates on the state of NOS instruction to elicit an understanding of the importance of adequately preparing teachers to teach NOS. Three theoretical and conceptual frameworks will be used to explore each research question and the relevant empirical studies. First, this chapter will describe how Wittgenstein's idea of family resemblance, reconceptualized by Erduran and Dagher (2014) to form the conceptual framework of the reconceptualized family resemblance approach (RFN) guides the investigation of changes in views of NOS through preservice teacher education. Second, Pajare's definition of belief and the literature that supports the need for teachers to develop a belief in the importance of teaching NOS will be described. Third, the explicit-reflective conceptual approach will be characterized as it guides the studies' approach to teaching NOS. Additionally, this literature will generalize existing findings on preservice teacher education for NOS instruction.

Changes in NOS Views through Preservice Teacher Education

Conceptual Framework

The approach to developing understandings of NOS utilized by the present study is guided by Irzik & Nola's (2011) application of Wittgenstein's (1958) family resemblance theory. In the past and current literature, there are two dominant conceptualizations of NOS. Previous research in changing preservice teachers' views of NOS has adopted the first major conceptualization, the consensus approach conceptualization of NOS. This framework lists seven to ten aspects: scientific knowledge is empirical, reliable yet tentative, the outcome of creativity, theory-laden, subjective, and socio-culturally embedded. According to the consensus approach, one must know these aspects in order to be considered informed (Lederman & Lederman, 2014). It is the most assessed approach in research, as evidenced by the dominating use of the V-NOS and its versions to measure NOS views (Abd-El-Khalick, 2014).

While the consensus approach is heavily used, some researchers worry that it might misrepresent individual science disciplines, and that it may be faulty and incomplete "patchwork approaches" (Dagher & Erduran, 2016). Many have critiqued the consensus approach for being limited in its depiction of NOS, leading to the development of the second major conceptualization of NOS, the family resemblance approach. Wittgenstein's philosophical theory of family resemblance rests on the position that while some terms (i.e triangle) can be defined explicitly with necessary and sufficient conditions (closed plane with three straight sides), other terms cannot be defined so straightforwardly. Family resemblance builds upon the premise that members of a family can resemble each other in some respects but not others. When the family resemblance idea is applied to the word 'science', it befits that there is no one single definition of science but rather a cluster of related notions. Irzik & Nola (2011) argue that when it comes to science, there are characteristics that apply to all sciences, but these characteristics alone cannot define as an entire discipline. For example, observation is part of but not unique to science, as is making inferences. Furthermore, within disciplines, the specific nature of observations and inferences varies. Under this assumption, while there are characteristics that all sciences share, they alone cannot sufficiently define science or separate it categorically from other human endeavors. For any two pairs of sciences, they will be similar with respect to some characteristics but dissimilar with respect to others. Therefore, the characteristics alone cannot be used to define science. However, as Irzik & Nola (2011) argue, when approached using the concept of family resemblance, “there are a number of similarities, crisscrosses and overlaps among these scientific disciplines, which give them sufficient unity” (p. 596). Irzik & Nola (2014) suggest conceptualizing science broadly as both a cognitive-epistemic system of thought and practice, and as a social-institutional system. Adopting this perspective, “various aspects of science can be weaved together systematically as a unified enterprise” (Irzik & Nola, 2014, p. 1014). The similarities and differences between sciences can be categorized systematically within the two systems. Irzik & Nola (2014) identified the following categories within science as a cognitive-epistemic system: processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge. Within science as a social-institutional system, identified categories included professional activities, scientific ethos, certification and dissemination of scientific knowledge, and social values. Erduran & Dagher (2014) reconceptualized the family resemblance approach for school science and reframed “processes of inquiry” to “practices” as well as included three additional categories of science as a social-institutional system: social organizations and interactions, political power structures, and financial systems. Table 1 displays the categories in the Reconceptualized Family Resemblance Approach (RFN).

Table 1. Categories of Science within RFN

Science	Category
Cognitive-epistemic System	Practices Aims and Values Methods and Methodological Rules Scientific Knowledge
Socioinstitutional System	Professional Activities Scientific Ethos Social Certification and Dissemination of Scientific Knowledge Social Values Social Organizations and Interactions Political Power Structures Financial Systems

Sources: Irzik & Nola, 2014; Erduran & Dagher, 2014

To illustrate the relationship between science as a cognitive-epistemic system and a social-institutional system and the holistic nature of this relationship, Erduran & Dagher (2014) presented the FRA Wheel (figure 1).

Figure 1: FRA Wheel

Source: Erduran & Dagher, 2014, p. 28

According to Erduran & Dagher (2014), this representation serves as a visual tool to display how the components of both systems are interrelated and impact scientific activity. This is a departure from the consensus view, which focuses on specific propositions that cannot portray the influences between ideas about science in educational context with the same breadth (Erduran & Dagher, 2014). Presenting NOS as broad categories rather than a list of statements allows for different characterizations of disciplines while showing connections among the categories. It is not static and reflects the tentative nature of NOS itself, with a broader scope of NOS that will have greater utility as a tool to make informed decisions about socioscientific issues. The approach to developing secondary science preservice teachers' views of NOS utilized by the present study is guided by Wittgenstein's theory of family resemblance, as described by Irzik & Nola (2011; 2014) and later expanded upon and reconceptualized by Erduran & Dagher (2014). RFN will guide the science methods course design, which has potential to help PSTs' development of their views about NOS and will also be used to analyze the PSTs' changes in NOS views.

Literature Review

Three studies were found to have utilized RFN to study the changes in NOS views of preservice teachers and will be reviewed in this section. Adopting the reconceptualized family approach (Erduran & Dagher, 2014), Erduran & Kaya (2018) conducted an intervention study consisting of 11 3-hours sessions to investigate how visual representations impacts 14 preservice elementary teachers' perceptions of NOS. They specifically focused on PSTs' epistemic insight into the categories of practices and scientific knowledge (mainly, the role of theories, laws, and models). Within the course, each RFN category was covered in two sessions in which PSTs engaged in tasks that asked them to identify examples of the category within a specific domain of science. Within the sessions, researchers selected various topics to allow for PSTs to see how abstract ideas about scientific knowledge and practices are applicable. One example of a visual tool that represents scientific knowledge guided by the family resemblance approach is provided below, which the authors describe as “a meta-tool that highlights the significance of understanding what constitutes scientific knowledge, without which teachers and students would not get a sense of the different forms of knowledge” (p. 1136).

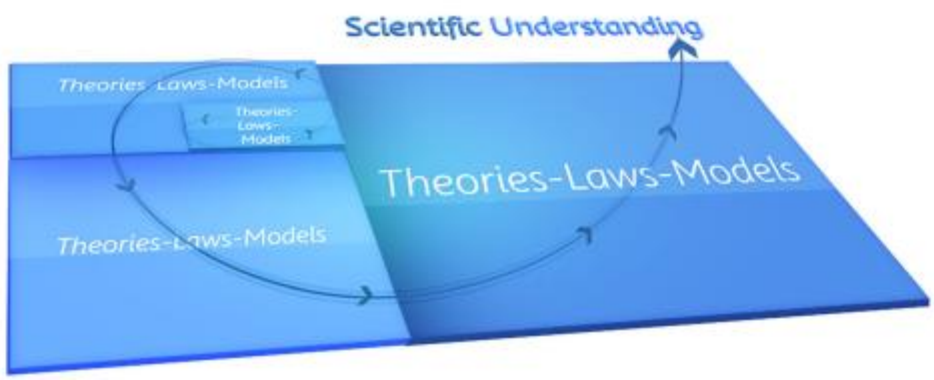

Figure 2: Theories-Laws-Models Meta-Tool

Source: Erduran & Dagher, 2014, p. 115

The primary sources of data used in this study (Erduran & Kaya, 2018) were PSTs’ visual representations and individual interviews. The interview aimed to elicit PSTs’ understanding of NOS in terms of scientific knowledge and practices. Qualitative data analysis was used to offer insight into the participants’ understanding of the target categories of NOS through the drawings overall for all 14 PSTs, and then case study methodology was used to provide an in-depth analysis of how 3 PSTs drawings changed. The 3 cases were supplemented with verbal data from the interviews. All but one PST exhibited a large, positive difference in respect to scientific knowledge. There was more variation in the quality of representations of scientific practices, suggesting that PSTs may have struggled to understand scientific practices, or to visually display their understanding of scientific practices. The researchers noted that a significant outcome was that if PSTs are supported in the use of visual tools, this could help them more deeply understand the cognitive-epistemic aspects of science. This study demonstrated the potential of using an RFN-based intervention to develop PSTs views of NOS, however, did not address the categories of aims and values, scientific methods, or the social-institutional NOS.

In another study, Kaya, Erduran, Aksoz, & Akgun (2019) investigated the impact of a teacher education intervention grounded in the reconceptualized family approach (RFN) on 15 preservice secondary teachers' views of NOS based on RFN. The teacher education intervention included 11 3-hour sessions and used Erduran & Dagher's book (2014a) as a key resource, in which 2 sessions each were allotted for the five main categories within RFN. The theme of domain-specificity (that disciplines have some different features) was incorporated in every session to address both cognitive-epistemic and socioinstitutional systems of NOS. While PSTs produced lesson resources, the enactment of these lesson resources in practice was not part of this study due to limited teaching practice experiences available to PSTs. To assess PSTs' views of NOS based on RFN before and after the intervention, a 5-likert scale instrument consisting of 70 items was developed (RFN Questionnaire). Because the questionnaire includes items based on all RFN categories, "the questionnaire as a whole can be considered to be inclusive of a holistic account of NOS because RFN itself is a holistic account" (Kaya et al., 2019, p. 31). Negative items were used to reduce acquiescence bias in which people tend to agree to statements regardless of their content (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003). The quantitative questionnaire data was supplemented by pre- and post- individual interviews, to elicit PSTs' views of NOS based on RFN in a more comprehensive manner and understand how the intervention may have impacted these views. T-Test results from the RFN Questionnaire showed an overall significant difference in pre- and post- views of NOS based on RFN, suggesting a positive impact of the teacher education intervention. Verbal data from the interview was consistent with these findings. In terms of each category, PSTs' views in all categories except scientific practices were significantly improved after the intervention. The researchers suggest this could be attributed to the fact that PSTs had exposure to scientific practices earlier through other courses, therefore the score for this category was already high for the pre-test.

Cullinane & Erduran (2022) conducted a case study with 4 secondary PSTs to measure the impact of an intervention, in which PSTs attended 7 workshops designed based on RFN. The workshop was designed to support PSTs in developing NOS views as well as knowledge of how to incorporate NOS into instruction. The researchers developed their own instrument, the R-NOS worksheet, to assess PSTs' views of NOS before, after, and several months after participation in the intervention. The worksheet was designed to be qualitative as to capture the rich data that illustrates how PSTs develop their understanding of NOS, but a scoring rubric enables researchers to draw descriptive statistics of the data collected. Results showed that for all PSTs, R-NOS scores increased from pre- to post- intervention. Most markedly, PSTs "held more informed views around the cognitive-epistemic aspects of NOS including scientific methods, and the variety of approaches scientists use, as well as the practices they engage with and aims and values that drive scientists and scientific discovery" (p. 9). Cullinane & Erduran (2022) echoed

Cofre et al.'s (2019) call for the need for empirical research to investigate alternative theoretical frameworks of NOS, including RFN.

The aforementioned studies (Cullinane & Erduran, 2022; Erduran & Kaya, 2018; Kaya et al., 2019) show promise in RFN as a conceptual framework to ground intervention studies that aim to improve PSTs' views of NOS.

Gaps in the Literature

As RFN is a relatively new conceptual framework, it has not yet been used extensively in the NOS literature in developing PSTs' views of NOS, and only three studies were found to have this focus. RFN has been used to design interventions in various contexts such as primary teacher education (Erduran & Kaya, 2018) and undergraduate genetics education (Petersen et al., 2020), with a growing but limited number of studies conducted specifically in preservice secondary teacher education (e.g. Kaya et al., 2019; Cullinane & Erduran, 2022) Additionally, there is no one assessment tool being consistently utilized to measure changes in NOS views in regard to RFN, including both the cognitive-epistemic and socioinstitutional aspects of NOS. This study will address both gaps in the following ways. First, evaluating the impact of an RFN-based intervention in the novel context of a secondary science preservice teacher education course focused on NOS will contribute to the literature that demonstrates how RFN can be transformed for the practical application of developing accurate views of NOS. Secondly, because research utilizing testing instruments from the RFN perspective is currently limited (Cullinane & Erduran, 2022), this study will use the RFN Questionnaire (Kaya et al., 2019) to support the qualitative results and add to this growing body of literature.

Preservice Teachers' Beliefs about the Importance of Teaching NOS

Theoretical Framework

Pajare's theory of teacher beliefs is used to guide exploration of the second research question. Pajare (1992) defines belief as "an individual's judgment of the truth or falsity of a proposition" (p. 316) and asserts that beliefs are the primary indicator of the choices made by individuals during their lifetimes. Across educational literature, findings indicate that teachers' beliefs deeply influence their teaching practices within the classroom (Pajares, 1992; Luft, 1999; Mansour, 2009). Pajare (1992) describes preservice teachers specifically as "insiders in a strange land" (p. 323) because once they begin their teacher preparation program, they already possess well-developed theories and perceptions about the profession. Pajare (1992) identifies how, for preservice teachers, memories of their experiences as students result in inappropriate representations of teaching in their adulthood, and that their perceptions of teaching and teachers are resistant to change even as they grow into trained professionals. Changing beliefs in the face of new information is not an easy task. To measure teacher beliefs, researchers must carefully focus on teachers' beliefs and behaviors, not be content with teachers' own reports of their beliefs, and should use open-ended interviews and obsesrvations to understand the connects and disconnects between teachers' stated beliefs, intentions, and actions (Ashton, 2015).

The process of belief change for preservice teachers can prove to be difficult and threatening, because "most teacher candidates have had positive school experiences, and bring to teacher education an identification with teaching that leads to the perpetuation of conventional practice and reaffirmation of the past (Lottie, 1975; Pajare, 1993, p. 46). Practices within teacher education programs control preservice teachers' beliefs about the nature and purpose of learning

(Pajare, 1993). To develop preservice teachers' beliefs, teacher educators must provide reasonable alternatives (Pajare, 1993). Teacher beliefs can be challenged through emphasizing reflection and belief exploration within the teacher education setting (Mayer & Goldsberry, 1997; Pajare, 1993).

Based on Pajare's theory of teacher beliefs, Driver et al. (1996) explains how science teachers often have well-established notions about how and what science should be taught, including a prioritization of science content over NOS. They suggest that the constraints of time as well as the presentation of curriculum in policy documents and textbooks of science as a body of established knowledge prevents teachers from portraying the epistemology and socioinstitutional aspects of science in a sophisticated manner. Teachers have ideas about science teaching and learning that they were socialized into during their education. Many teachers believe they have a responsibility to focus on science content, and when they do believe teaching NOS is important, it is mainly due to the belief that teaching NOS will support students in science content learning (Mulvey & Bell, 2017; Wan & Wong, 2016). A recent meta-synthesis (Nouri et al., 2021) of the literature examining what competencies are required for teachers to be effective NOS educators indeed found that "teachers who incorporate NOS in science instruction must believe in its importance and be motivated to teach it". In other words, in order to increase commitment in teaching NOS, it is imperative that preservice teachers believe in its importance (Nouri et al., 2021). This idea is consistent with the empirical findings on teacher beliefs. This section will review the literature showing that when science teachers believe that NOS educational outcomes are valuable, they are more likely to teach NOS, guided by Pajare's theory of teacher beliefs.

Like Pajare's (1992) findings, there are several terms used interchangeably in the literature for referring to science teacher's beliefs about the importance of teaching NOS (Ashton, 2015). According to Pajares (1992), beliefs "travel in disguise and often under alias—attitudes, values, judgments, axioms, opinions, ideology, perceptions..." (p. 309). Some studies (i.e. Mulvey & Bell, 2017; Kruse et al., 2017) have referred to the belief in the importance of teaching NOS as "rationales" for teaching NOS, as their rationale is the set of reasons for their particular belief. Other studies (i.e. Herman et al., 2017; Wan & Wong, 2016) have referred to the belief in the importance of teaching NOS as "values" held by teachers for NOS instruction. Regardless of whether beliefs about the importance of teaching NOS are referred to as rationales or values, the existing literature suggests that when teachers deeply believe that teaching NOS is important, they are more likely to enact NOS instruction in their classrooms (Nouri et al., 2021). This is in line with Pajare's synthesis of findings on beliefs, in that "beliefs are instrumental in defining tasks and selecting the cognitive tools with which to interpret, plan, and make decisions regarding such tasks" (p. 325).

Literature Review

In this section, five studies will be reviewed that focused on investigating secondary preservice and inservice teachers' beliefs about the importance of teaching NOS. Due to a lack of studies that focused on developing these beliefs, studies were included if they focused on exploring teachers' reasons for believing that teaching NOS is important with one time of measurement. Lederman (1999) investigated 5 inservice biology teachers and the factors that impeded the relationship between believing in the importance of NOS and classroom practice and found that the reasons provided by teachers for teaching NOS impacted their tendency to teach NOS. Data sources included semi-structured and informal teacher interviews, an open-ended questionnaire, classroom observations, lesson plans, instructional materials, and student interviews. Findings showed that teachers typically did not intentionally plan to teach NOS and, when they did address NOS, they provided only affective reasons, such as it being fun, and bringing science confidence and enjoyment to students. Lederman (1999) called for a concerted effort in science teacher education to focus on advancing a deeper internalization of the idea that NOS is a crucial instructional objective that needs to be considered while planning for every type of classroom learning experience. This study did not investigate how teachers' beliefs about the importance of teaching NOS changed over time.

Mulvey & Bell (2017) explored 70 preservice secondary science teachers' rationales for including NOS in their instruction. The intervention experienced by participants was a program which included two secondary science methods courses that both had an explicit emphasis on NOS. NOS lessons were taught through modeled activities and included first eliciting students' ideas, followed by an explicit and reflective discussion. Additionally, NOS lessons were taught along a continuum from decontextualized to highly contextualized. Post-instruction interviews were analyzed to identify participants' plans and rationale to teach NOS. All participants indicated that they intended to teach NOS, with the most common rationale being that NOS supports teaching what science is and/or teaching science content. Other rationales brought up in interviews included that NOS supports students in doing science, in developing problem-solving skills, in gaining an interest in science and a desire to be a scientist, in improving appreciation for science, and science literacy. The synergistic relationship between the PSTs plans to teach NOS and their rationales for teaching NOS support the role that teacher beliefs play in their teaching practices. Mulvey & Bell (2017) did not measure preservice teachers' rationales for including NOS in instruction prior to the intervention.

Herman et al. (2017) found that the reasons provided for teaching NOS were ultimately related to the degree at which 13 secondary science teachers taught NOS in their individual classrooms. All secondary science teachers had experienced the same teacher education program and had completed a NOS course that promoted research-based NOS instruction, and currently taught in schools where there was either no NOS curriculum, or NOS was not encouraged to be taught. Classroom observations and interviews were conducted. Teachers were not aware of the NOS-focus of the study, so it is reasonable to assume their NOS teaching practices were a reflection of their normal practices. Preservice teachers' NOS teaching was characterized according to their level of NOS implementation as low, medium, or high (Herman et al., 2013). Classroom observations and instructional artifacts were analyzed using the Nature of Science Class Observation Protocol (NOS-COP) instrument which helps classify NOS teaching using well-established criteria including accuracy, explicitness, and contextualization level. Interviews were analyzed using a semi-inductive approach (Miles & Huberman, 1994) to develop coding categories which were then organized across six themes including the type of utility value for NOS teaching and the general importance for NOS teaching. Researchers found that all but one teacher expressed the importance of NOS teaching and that NOS should be a curricular priority and a substantial focus of science instruction. However, a difference was found in the rating for type of utility value for NOS teaching expressed by teachers in different NOS implementation levels. All high and medium NOS implementers expressed high utility value because these preservice teachers clearly described far-reaching outcomes for teaching NOS that included and extended beyond the immediate value of NOS teaching and learning in the classroom. Their reasons for teaching NOS seemed genuine and well-considered. Of the teachers who implemented a low amount of NOS, none of them expressed clear and compelling reasons why they should teach NOS, instead providing general statements about how NOS is relevant and related to everyday life. Researchers concluded that teachers who do dedicate instructional time and focus on NOS value rationales that transcend learning science content and understanding NOS as a goal in and of itself. Those that do teach NOS highlight the value of NOS for citizenship and in socio-scientific decision making, which transcends the concerns of schooling, including success in the course and on exams. Herman et al. (2017) called for research exploring the complexity of teachers' NOS understanding, how deeply they value teaching NOS and its utility, and their general and NOS-specific pedagogy as they are impacted by a myriad of contextual factors.

Kruse et al. (2017) explored the impact of a NOS course on preservice secondary science teachers' NOS rationales. Six participants were first exposed to NOS in a science methods course prior to taking the NOS course, while six other participants did not take the science methods course prior and were receiving their first exposure to NOS from the NOS course. In the methods course, NOS was taught in an explicit-reflective manner by being introduced through black-box activities and developed with contextualized activities. Students also engaged with historical short stories and reflected on pedagogical strategies to teach NOS. In the NOS course, students engaged in discussions surrounding the overlap and variation between scientific disciplines in terms of values, assumptions, and purposes. One of four formal assessment tasks included a rationale paper identifying aspects of NOS important for scientific literacy. Findings revealed that participants held varying rationales for why NOS should be taught, including that it can increase students' interest, critical thinking abilities, confidence in science, and content knowledge. Other rationales identified by participants included that understanding NOS can increase accessibility of science, decrease the difficulty of science, confront misconceptions, and foster scientific literacy. Preservice teachers for whom the NOS course was their second exposure to tended to have rationales that transcended improved science content learning when compared to students who were not exposed to NOS prior to the course. Researchers concluded that NOS rationales become more multifaceted with repeated and extended exposure, and that addressing NOS rationales should become a consistent feature of teacher education programs that consider NOS important.

Wan & Wong (2016) investigated how 15 inservice secondary science teachers perceived the value of teaching NOS. They recruited teachers in Hong Kong who had already expressed intention to teach NOS and had previously participated in 1-2 projects on NOS. Semi-structured interviews were conducted in which teachers were asked to describe their NOS teaching practices and were asked the question, "What do you think are the values of teaching NOS in school science lessons?" (p. 1097). An explorative approach (Stake, 1995) was adopted to analyze interview transcripts, and initial codes generated from reading the transcripts represented specific values of teaching NOS. Later, these codes were organized into one of two categories depending on if the value was pertinent to science learning or beyond science learning. Researchers found that the values pertinent to science learning included facilitating the study of science content, increasing interest, supporting engagement in scientific inquiry, meeting the needs of exams, and that NOS is fundamental to science learning. Beyond learning science, teachers discussed that teaching NOS can develop students' thinking abilities, cultivate scientific ethics, and support decision making on socioscientific issues. It was concluded that teachers suggested relatively fewer reasons for teaching NOS that were beyond science learning. Wan & Wang (2016) called for future studies with teachers to investigate how views of teaching NOS are related to pedagogical content knowledge, self-efficacy for teaching NOS, and how these influence NOS teaching in the classroom .

Gaps in the Literature

While many studies find that belief in the importance of teaching NOS is a factor that impedes the translation of accurate NOS views to practice, only one study was found to explicitly seek to develop preservice teachers' beliefs about the importance of teaching NOS (Kruse et al., 2017). Teachers' belief in the importance of teaching NOS is not a main focus in many studies, but is rather found during analysis to be a factor that impedes the translation of research-aligned NOS views and pedagogy to practice (e.g. Herman et al., 2017; Lederman, 1999). There is a limited number of studies that focus on developing *preservice secondary* science teachers' rationales for teaching NOS. While there has been much research on NOS views, there has been less of a research focus on the beliefs of preservice teachers about why they should teach NOS. However, it is clear from the studies reviewed above that valuing the teaching of NOS can be a significant predictor if and how teachers will plan for and enact NOS instruction. In addition to the lack of teachers' understanding of NOS (Abd-El-Khalick et al. 1998), the intention, self-efficacy, and pedagogical content knowledge of teaching NOS needs to be a focus of science teacher education (Faikhamta, 2013; Hanuscin et al., 2011; Lederman, 1999; Schwartz & Lederman, 2002). Additional research is needed in how to "inculcate among teachers a deep sense of responsibility to accurately and effectively teach about the NOS" (Clough, 2018, p. 4).

NOS Instruction by Preservice Teachers

Conceptual Framework

The explicit-reflective approach to NOS instruction is used to guide the exploration of the third research question. This approach to NOS teaching is necessary for the transfer of NOS understandings from teacher to student. The term "explicit" is used to emphasize the idea that NOS understandings are cognitive outcomes of instruction and must be purposely targeted and planned for, similar to when teaching abstract scientific principles (Abd-El-Khalick & Akerson, 2004). Explicit approaches should be adopted to teach about NOS in the same manner they are utilized to support students' developing their own understandings of complex and abstract science concepts. The second term "reflective" in the descriptor "explicit-reflective" is used to highlight specific instructional moves that allow students opportunities to analyze their activities from a NOS perspective, making connections between what they are doing and what scientists do, and how this is related to scientific epistemology. An explicit-reflective approach considers student metacognition of certain cognitive-epistemic and socioinstitutional aspects of NOS in relation to their classroom tasks, and student reflection on these activities from a NOS framework. This study is guided by the conceptual framework of the explicit-reflective approach in both designing the intervention and exploring the third research question.

Teachers with accurate NOS conceptions are prone to downplay the importance of NOS instruction and fail to enact explicit NOS instruction (Duschl & Wright 1989; Abd-El-Khalick et al. 1998; Bell et al. 2000). This is because they believe that if they plan science instruction such as labs that mirror NOS, students will gain an understanding of NOS implicitly. A large amount of research suggests that this is not the case (Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002; Lederman, 1992). According to Clough (2006), years of learning science and experiencing science in and out of school repeatedly misrepresent NOS, but explicitly and implicitly. This simplistic and inaccurate manner in which NOS is communicated leads students to possess deeply held misconceptions that are resistent to change due to implicit, accurate NOS instruction. Clough states that "the expansive, yet inaccurate frameworks students possess regarding the characteristics of science and how it works act as filters that obscure the more faithful implicit NOS messages in authentic inquiry experiences" (p. 465).

Two important components of effective NOS instruction guided by the explicit-reflective conceptual framework are NOS questioning and the use of a context continuum (Clough, 2006). Student-centered questioning guides students to accurate views of NOS (Clough, 2020). Some types of NOS questions (divergent or convergent) are more appropriate for some educational outcomes than others (Kruse et al., 2020, Voss et al., 2021). Divergent NOS questions are more open-ended and can elicit students' current thinking about NOS at the beginning of a lesson, or at the end to assess student learning about certain NOS aspects (Kruse et al., 2022; Voss et al., 2022). Convergent questions are more useful for guiding students to respond with a specific, accurate position about NOS, or to challenge students to further explain accurate, but oversimplified views of NOS (Voss et al., 2022). Additionally, preservice teachers must consider the role of context when planning for NOS instruction. Clough (2006) developed a context continuum that ranges from decontextualized activities (i.e. black box) to highly contextualized (i.e. socioscientific issues). Different degrees of contextualization are better suited for certain situations, so preservice teachers should understand how to teach NOS at multiple levels of contextualization (Cullinane & Erduran, 2022).

Literature Review

In this section, representative studies that were guided by the explicit-reflective conceptual approach to NOS instruction and investigated the development among preservice teachers of either their instructional planning for NOS teaching (Abd-El-Khalick, 2005; Voss et al., 2023) or enactment of NOS teaching (Lotter et al., 2009; Mesci et al., 2020) will be reviewed. Abd-El-Khalick (2005) studied the impact of a two-science methods course sequence on 56 preservice secondary science teachers' NOS instructional planning, in which 10 participants were simultaneously also enrolled in a philosophy of science course. During the first science methods course, 15 generic activities (Lederman & Abd-El-Khalick) and certain assigned readings were incorporated to give PSTs opportunities to analyze and reflect on their own NOS views, as well as to explicitly introduce PSTs to intentional aspects of NOS using an explicit-reflective approach. Students also wrote two NOS-specific reflection papers on the readings to help them discuss NOS ideas and compare them to their own, such as one about the myths of science (McComas, 1996). In the second methods course, participants planned four detailed lesson plans using a variety of instructional approaches and targeting topics and objectives of their own choice. Lastly, they wrote a reflection paper about how the discussed NOS ideas may impact their future teaching practices. Students who were also enrolled in the philosophy of science course explored original, seminal pieces from the philosophy of science that influenced how science in the science education community is thought about, and wrote four extended reflection papers discussing these ideas, comparing them to their own, assessed changed in their ideas, and identified ways they were related to pre-college science, if any. V-NOS C (Abd-El-Khalick et al.) was used as a pre and post assessment, supplemented by semi-structured interviews with 25% of the participants. The NOS-specific reflection papers and lesson plans were analyzed. The translation of participants' NOS views into planned instruction related to NOS was minimal, and lacked any explicit or reflective components to address NOS aspects. A substantially greater portion of the participants in the experimental group translated their NOS understandings into explicitly planned instructional sequences and also used language that was consistent with accurate conceptions of NOS. Although students who took the philosophy of science course were self-selected and had been sensitized to NOS aspects in their first science methods course, the author concluded that coursework in the philosophy of science can support science teachers in their NOS instruction. Abd-El-Khalick (2005) focused only on NOS instructional planning, and preservice teachers did not actually enact any NOS instruction.

Lotter et al. (2009) investigated the impact of repeated teaching and reflection on preservice secondary science teachers' teaching of NOS from their first project-based unit enactment to their second. Data sources included the VOSI, interviews, and written reflections. Within the course, preservice teachers observed effective NOS instruction and were directed to implement similar instruction in their units. The researchers identified that key features of this progression were the participants' opportunity to directly observe and reflect on the influence of their instructional decisions on high school students' learning and engagement. The most important aspect in developing preservice teachers' teaching skills were the guided reflections after their teaching episodes. By writing reflections on their individual teaching, preservice teachers analyzed the strengths and the “missed opportunities”, which led preservice teachers to view these as opportunities for growth rather than failures. The preservice teachers’ viewing of their own teaching recordings while developing their electronic portfolios also supported their growth. This study provides evidence that implementing several, low-risk teaching experiences that are related to the methods course goals, and highly scaffolding these experiences with instructor and teacher support and self-reflection, is important for the growth of preservice teachers as they learn to teach NOS. Researchers concluded that early teaching experiences during teacher education programs need to help students revise their perceptions of teaching and apply the approaches learned in methods courses.

Mesci et al. (2020) investigated the development of 34 preservice secondary science teachers’ NOS (referred to in their study as NOSI, or nature of scientific inquiry) related teaching practices. Participants were enrolled in a semester-long science methods course in which targeted aspects of NOS were introduced using the explicit-reflective approach in both contextualized and decontextualized ways during the first 6 weeks of the course. Following this period, instructors taught how to prepare and enact a science lesson using the 5E instructional model (Bybee et al., 2006), teaching a model lesson as an example, in which NOS aspects were purposefully integrated. Participants working in partners were asked to prepare two 5E lesson plans that included at least one NOS aspect taught explicitly and reflectively, contextualized in the content area of their interest. Instructors gave feedback on the lesson plans, preservice teachers made revisions according to the feedback, and then enacted the lesson plan for practice in the classroom. A class discussion followed each lesson in which instructors and peers provided informative feedback. This process repeated for a second 5E lesson plan. Participants used a modified 5E lesson plan template in which NOS was embedded. Findings showed that participants who did not have informed views about NOS had difficulty integrating NOS aspects into their lesson plan, and after the first lesson plan, almost no participants effectively integrated NOS, experiencing issues such as "inconsistency between the selected inquiry level and lesson, the lack of selected appropriate evaluation activities, or the failure to integrate the NOS aspects in to science topic appropriately" (p. 59). Researchers identified that preservice teachers' lack of NOS understanding, lack of experience, and belief in the prioritization of content knowledge over NOS may have contributed to this failed first attempt. Preservice teachers showed a progressive development as they planned and enacted their second lesson plan, however, some continued to have problems. Influencing factors were identified from the data analysis and included subject matter knowledge, the lesson plan process, motivation, practice, and personal characteristics like confidence and being open to criticism. Researchers concluded that the process of preparing the lesson plans including observing their peers and their reflective observations significantly impacted the application of their lesson and recommended that "pre-service science teachers should make more than one lesson plan and practice, mentors should give feedback to the lesson plans as much as possible before the application, and give the opportunity to evaluate and criticize" (p. 64).

Voss, Kent-Schneider, Kruse, and Daemicke (2023) conducted a study in which the FRA "guided instruction to help preservice secondary teachers establish more nuanced conceptions of NOS and more deeply examine ideas related to social institutional NOS." (p.7). The intervention took place within a NOS course that had the goals of (1) understanding NOS concepts, (2) understanding NOS pedagogy, and (3) implementing NOS instruction, with 14 participants who were preservice secondary science teachers. Data was collected to measure changes in NOS instructional views throughout the semester through the use of interviews and a Content Representation (CoRE) document, in which the preservice teacher identified big ideas within topics and described how they would teach them. CoREs were modified to address NOS teaching across the FRA Wheel (Erduran & Dagher, 2014). Researchers found that at the end of the semester, preservice teachers had shifted their instructional views from an implicit to an explicit-reflective approach and were more likely to use specific NOS questions. It was found that preservice teachers more commonly used less contextualized instruction and more concrete for the inner ring of the FRA Wheel when compared to the middle and outer rings. The study highlights the need for explicit, reflective discussions related to NOS teaching after preservice teachers have learned NOS content. Their findings also aligned with prior research that shows preservice teachers address social-cultural aspects of science less frequently. This study's focus is limited to the development of preservice teachers' instructional views and does not address the enactment of these views.

Gaps in the Literature

There is a gap in the number of studies that explore in what ways preservice teachers enact explicit-reflective instruction, specifically aligned with an FRA approach. It is clear that a complex interaction of factors impacts the teaching of NOS, and more information is needed about how to support the development of effective and research-based NOS teaching practices. While some research has investigated the integration of isolated NOS aspects into lesson plans, fewer studies have investigated how the reconceptualized family resemblance approach can be used to support preservice teachers in planning and enacting explicit-reflective NOS instruction.

CHAPTER THREE: METHODOLOGY

Context and Participants

This study was conducted at a large southeastern public university in the United States. Two participants were enrolled in the four-year secondary science education bachelor's degree program within the college of education at the university with a focus on biology, while one participant was an environmental studies major, enrolled in the science education program as a minor. The science methods course was offered as an elective that would count toward the required number of elective course hours for both programs. The focus of the course is to provide a knowledge base on the nature of science (NOS) and the major historical developments of science and their implications on science teaching and learning. This course was selected for this study because the learning objectives involve both developing accurate views of NOS and an understanding of how to teach NOS. The course lasts for one semester, as are most NOS interventions (Cofre et al., 2019), and was taught by the author of the study. Class meetings occurred once weekly for 2 hours and 50 minutes over the course of 15 weeks. Research participants were recruited in class during the first meeting. Participation was limited due to the small size of the secondary science preservice teacher program, and the status of the course as an elective and not a program requirement. Four preservice teachers were enrolled in the course, and 100% consented to participate**.** Purposeful sampling was used for this study (Patton, 1990). According to Patton, the purpose of purposeful sampling is "to select information-rich cases whose study will illuminate the questions under study" (p. 169). Three out of the four cases were selected because they met the criterion of consistently attending class meetings throughout the semester and were more information rich and worthy of in-depth study**.** Each of the three participants constitutes a case in the study.

Because the researcher is the instructor of the NOS course, care was taken to ensure that participants didn't feel obligated to participate in the study or that their participation had any bearing on their grade. This was explicitly stated while recruiting participants. The privacy of participants during all interviews was maintained through using a waiting room and password protected meeting on Zoom. All data is being kept securely by the researcher for the specified time required by the IRB. Full IRB approval was received before beginning the study. Pseudonyms are used for the study.

Table 2. Participants' Information

Preservice teacher	Gender	Race	Program	Level within program
Ben	Male	White	Secondary education, biology concentration	Junior
Valentina	Female	Latina	Environmental studies major with science education minor	Senior
Michael	Male	White	Secondary education, biology concentration	Senior

Science Methods Course

Overview

The science methods course consisted of coursework and class activities during the semester-long course. There was one introductory session, one session about RFN, two sessions each that focused on the five major categories of RFN, then two sessions focused on NOS lessons and one session summarizing the course. The main course text required by preservice teachers was Erduran & Dagher's (2014) book, Reconceptualizing the Nature of Science for

Science Education, which explains the theory of RFN as well as each category and their educational applications. For some weeks, there were supplemental readings in addition to the course text. After completing the readings each week, participants were asked explicit-reflective questions about what they have learned and how it relates to NOS in an online discussion post.

Discussion Posts

Throughout the semester, preservice teachers were assigned 8 discussion posts total. Each discussion post consisted of required readings and a set of 2-4 extended response questions. Preservice teachers were required to respond to one peer after posting. In the class after which each discussion post was due, the instructor would lead the class in a discussion about each of the questions and the responses, highlighting and emphasizing certain responses that were especially thoughtful or accurate in answering the prompt. The assigned readings and corresponding discussion post questions are in Appendix B.

In-Class Activities

During the class sessions, preservice teachers engaged in a variety of activities including discussions, card sorts, video reflections, stations, and worked through several example instructional tasks related to each RFN category. All in-class activities are described in Appendix C.

Assignments

Nonhistorical science drama roleplay. Preservice teachers were required to complete four major assignments throughout the semester. The first assignment was a non-historical science drama roleplay, which is recommended for teaching socioscientific issues (McComas, 2020). This assignment was situated in instruction around the aims and values of science, both in terms of the epistemic-cognitive system (i.e., objectivity, novelty, accuracy) and the sociоinstitutional system (i.e., honesty, addressing human needs, equality of intellectual authority) (Erduran & Dagher, 2014). The practice of utilizing contemporary cases to teach NOS is “directly relevant to the contemporary SSIs [socioscientific issues] that students will address outside the classroom, where contentious scientific claims mingle with discourse on values” (Allchin et al., 2014). In the first of two sessions covering aims and values and after being introduced to aims and values of science, preservice teachers read and discussed the types, benefits, and limitations of roleplay in science teaching and learning as well as how to utilize roleplay in the science classroom (McSharry & Jones, 2000) and explored an example of a role-play activity in which preservice elementary teachers acted out senate hearings around the theme of global climate change (Harwood et al., 2002), after which they modeled the creation of their own role-play activities. The selected socioscientific issue had to be current, elicit an emotional response in students, have multiple perspectives, and be focused and specific (McSharry & Jones, 2000). Preservice teachers were required to produce a presentation that detailed what type of roleplay the activity was (debate, science play, charades, radio/tv commentary, game, analogy, etc.), the socioscientific issue chosen and multiple perspectives of that issue as it would be presented to students, a general timeline of the activity, guiding questions for students, and a reflection on whether the preservice teacher would implement this activity and why, and how it may help students understand the aims and values of science. Preservice teachers created and presented their roleplay ideas individually in the second session that focused on aims and values of science.

Interview with a nonscientist. The second major assignment required preservice teachers to conduct an interview with a person who is not typically viewed as a scientist to see if there are aspects of that person's lived experiences that could be considered science oriented. Preservice teachers were required to make claims involving at least 3 of the 8 science practices (NGSS Lead States, 2013) that their interviewee may or may not engage in through their work or daily activities, supporting their claims with specific quotes from the interviewee and their own interpretation of the quotes. One purpose of the assignment was to require preservice teachers to think critically about scientific practices and expand their thinking on what may constitute as "doing science", since there is a myth that having students doing hands-on activities qualifies as students engaging in scientific practices (Huff, 2016). Additionally, many people see science as merely the accumulation of facts about the natural world (Driver et al., 1996). The problem with focusing on science as a collection of knowledge is that it fails to give learners "a sense of the relations between different forms of scientific knowledge; how scientific knowledge grows; and what criteria, standards and heuristics drive growth of scientific knowledge" (Erduran & Dagher, 2014, p. 67). Lastly, identifying science-oriented aspects of nonscientists' lives can help challenge damaging stereotypes of scientists, the most common of which "evokes a smart, hard-working, eccentric, workaholic man" (Tintori, 2017, p. 4). This assignment was situated in the context of learning about the FRA categories scientific practices and scientific methods, as types of scientific methods can be explored for the purpose of supporting better understanding of scientific practices (Erduran & Dagher, 2014).

Curriculum Material Production on the History of a Scientific Discovery. The third assignment required preservice teachers to create a curriculum material about a historical account of a scientific discovery. The history of science has long been advocated and used as an approach to teach NOS (McComas, 2020). The history of science can be used to communicate much about the socioinstitutional NOS (Erduran & Dagher, 2014) and when used carefully, can “tell the tale of how science works, what its rules and traditions are, and how knowledge is established in the sciences” (McComas, 2020, p. 527). This assignment was situated in instruction about scientific knowledge and the epistemic dimensions of theories, laws, and models, understanding which can provide students with “a richer understanding of why particular scientific knowledge is considered valid, how such knowledge is justified in the first place, and how it can be applied within and across science disciplines” (Erduran & Dagher, 2014, p. 132). Alongside learning about the history of science, students must be explicitly directed to NOS ideas and reflect upon them (Abd-el-Khalick & Lederman, 2000). Therefore, preservice teachers were required to embed reflective NOS questions throughout their story that explicitly targeted NOS ideas. In class, preservice teachers learned about and discussed the rationales for including history of science in science teaching (McComas, 2020) and read examples of historical cases with embedded NOS questions (Clough & Olson, 2004; storiesbehindthescience.org). Preservice teachers also learned about NOS question types (general NOS, specific NOS, and specific NOS with a preamble) and their effect on student responses (Kruse et al., 2022).

NOS Lesson. For their final assignment, preservice teachers were required to create a lesson plan that integrated NOS in science content teaching (Clough, 2006), and were required to teach the lesson to the class during the last session. Teaching within a teacher education course provides a safe context to practice teaching NOS without added constraints and removes the factor of voluntarily addressing NOS since including NOS is an explicit requirement (Kim et al., 2005). The instructor modeled two lessons in the weeks prior and provided students with the example lesson plans, one on temperature and chemical changes, and the second on historical models of the solar system. Part of the NOS lesson rubric specified that preservice teachers would be scored on the extent that the lesson structure and artifacts have clear opportunities for accurately and explicitly addressing NOS, based on what has been covered throughout the semester about NOS teaching. The lesson needed to be 35-45 minutes in length, have both specified content and NOS learning goals, and follow a shortened 5E lesson structure (Bybee, 2006) of "engage, explore, explain, and evaluate".

Research Design

A multiple case study approach (Yin, 2003) is used to explore three research questions in this study. A case study is "a specific instance to illustrate more general principles" (Cohen et al., 2007, p. 253). A multiple case study is an appropriate approach to answer the research questions in this study because it will provide a rich description of how each preservice teachers' views of NOS, beliefs about the importance of teaching it, and NOS teaching developed through the course (Cullinane & Erduran, 2022). A case study implementation has been long established in educational research (Yin, 1994; 2003). More specifically and according to Yin (2009), a case study is an empirical investigation into a contemporary phenomenon within its real-life context, particularly when the boundaries between phenomenon and context may be blurred. Yin (2009) states that a case study is most appropriate in the situation where a researcher wants to "understand a real-life phenomenon in depth, but such understanding encompassed important contextual conditions - because they were highly pertinent to your phenomena of study" (p. 18). In seeking to understand the phenomena of developing NOS views, beliefs about its importance to teach, and actual teaching of NOS, contextual conditions have a major impact and must be covered. In seeking to understand the phenomena of developing NOS views, beliefs about its importance to teach, and actual teaching of NOS, contextual conditions have a major impact and must be covered. In this study, each preservice teacher constitutes a case. The three cases are Ben, Valentina, and Michael. This study exhibited four key characteristics of case studies (Punch, 2005): a bounded system (the semester long methods course), a case (each preservice science teacher developing ideas about NOS and NOS teaching), holistic nature (studying every category of NOS view and belief about why and how to teach NOS for each participant), and multiple sources of data (interviews, RFN questionnaire, lesson plans, video recordings of lessons).

Data Sources

Individual Pre and Post Interviews

At the beginning and end of the course, the researcher conducted a 25-minute interview with each preservice teacher to understand the preservice teachers' views about NOS related to each RFN category, beliefs about the importance of teaching NOS, and ideas about how to teach NOS. The interview protocol is in Appendix A. The interviews were transcribed using the help of built-in Zoom transcription software.

RFN Questionnaire

The RFN questionnaire (Kaya et al., 2019) consists of 70 items that reflect the 5 RFN categories of aims and values, scientific practices, scientific methods, scientific knowledge, and social-institutional aspects. Additionally, 16 items reflect the educational applications of RFN.

Each RFN category includes both positive and negative items to minimize acquiescence bias. Content validity was established using expert review when Kaya et al. (2019) employed the questionnaire in a study that investigated the outcomes of a teacher education intervention on 15 PSTs. Following the review of two experts in science education, any repetitive or unneeded items were eliminated to ensure remaining items' appropriateness in terms of the context. Kaya and coauthors conducted a preliminary test of reliability as well: "In order to calculate the reliability, the questionnaire was administered to 222 pre-service science teachers from two public universities. The Cronbach alpha was calculated as 0.8" (Kaya et al., 2019, p. 32). Kaya et al. (2019) also compared verbal data from interviews with questionnaire results and found consistency among them. Azninda & Sunarti (2021) used a combination of the RFN Questionnaire and interviews to investigate the NOS views of 25 science and non-science teachers, and also found that the RFN Questionnaire scores were complemented by and consistent with the analysis from the interviews. In another study, Akgun & Kaya. (2020) employed the questionnaire with a total of 15 science and nonscience majoring university students, also finding that the qualitative and quantitative results aligned.

Table 3. RFN Questionnaire Item Distribution

Category	Example	Question Items
Aims and values	Scientific facts are not affected by bias and individual subjective prejudices of scientists (negative item).	7
Scientific practices	All branches of science use observations (positive item).	13

Scientific methods	All hypothesis testing is manipulative (negative item).	9
Scientific knowledge	Scientific knowledge does not change (negative item).	9
Social-Institutional aspects	Policies of governments affect the growth of scientific knowledge (positive item).	16
Educational applications	Students should understand that scientists need to have social values such as honesty (positive item).	16

Source: Kaya et al., 2019

PSTs completed the RFN Questionnaire on Canvas during the first week of class, and again during the last week of class. The PSTs scores from the RFN questionnaire were calculated by coding their selection of the options of ‘totally agree’, ‘agree’, ‘not sure’, ‘disagree’, and ‘totally disagree’ as 5, 4, 3, 2, and 1 (Kaya et al., 2019). Recoding is common for the interpretation of Likert scale questionnaire data. The negative items were reverse-scored so each response was coded in the same direction.

Lesson Plans

PSTs were required to plan and teach a lesson that includes NOS within the context of a chosen disciplinary core idea in science. The lesson plans that preservice teachers created as their final assignment were collected to be analyzed. These were submitted to Canvas.

NOS Teaching Videos

Preservice teachers were video recorded while enacting their lesson plan in the final class session. The video recordings were transcribed using the help of built-in Zoom transcription software and used as a data source. Each lesson was approximately 40 minutes. The researcher took observational notes during the lessons and the lessons were video recorded. Preservice teachers watched their own lesson recording and reflected on their NOS teaching in a discussion post. Data sources for this study include the video recording and lesson plan, which were reviewed and coded for themes that emerged related to NOS instruction, using the RFN categories as a priori codes.

Data Analysis

Research Question 1

Both the RFN Questionnaire (Kaya et al., 2019) and pre- and post-course interviews were used to understand the differences in preservice teachers' pre and post views of NOS, related to each RFN category. The researcher compared these data sources for consistency in terms of changes in views of NOS related to each RFN category. Initial and final scores for each RFN category and the educational applications were calculated, as well as the changes in each category for each preservice teacher. When analyzing the interview transcripts for changes in preservice teachers' views of NOS, deductive analysis was utilized, using the RFN categories as a priori codes, followed by a thematic analysis.

Research Question 2

The individual pre and post interviews were used to explore preservice teachers' development of beliefs about the importance of teaching NOS. Driver et al.'s (1996) arguments for why understanding NOS matters were used as a priori codes in analysis and in categorizing the reasons that preservice teachers believed teaching NOS is important. These arguments are described in Table 4. Transcripts of the interviews were reviewed and coded for themes that emerged relating to each PSTs' beliefs about teaching NOS.

Table 4. Arguments for Why Understanding NOS Matters

Argument	Description
Utilitarian	To make practical use of scientific knowledge, people must understand the grounds for having confidence in scientific knowledge (by understanding how that knowledge came to be) and in sources of scientific knowledge (such as experts)
Democratic	Socioscientific decision-making relies not only on understanding the basic science content relating to the issue, but in understanding that science is tentative yet negotiated and agreed upon, rather than certain
Cultural	To appreciate and therefore support the aims of the scientific enterprise, people must understand and share the aims and values of science and its societal benefits
Moral	Learning about and embodying the institutional norms of science, such as organized skepticism and freedom of thought, is of general value to society as a whole
Science Learning	Understanding that science is theory-laden and dynamic helps students to see themselves as contributors to science, and not become demotivated or affixed to the view that science depends solely on memorization

Source: Driver et al., 1996

Research Question 3

The pre and post course interviews, RFN Questionnaire, lesson plans, and NOS teaching video transcripts were analyzed to explore how views and beliefs about NOS teaching were related to how preservice teachers taught NOS at the end of a science methods course guided by RFN. The RFN categories were used as a priori codes in analysis to uncover which RFN categories were taught by each preservice teacher. To understand the interaction between preservice teachers' NOS teaching, views of NOS, and ideas about teaching NOS at the end of the course, the results from the teaching were compared to the post course interview and post course questionnaire data for each RFN category. These were analyzed for potential alignment and inconsistencies.

Cross Case Analysis

After all data analyses had been conducted to create the three case profiles, gathering the data regarding changes in views of NOS, changes in beliefs about the importance of NOS, and exploring how these relate to the teaching of NOS separately for each participant, a cross case analysis was performed to examine the similarities and differences within each research question of all the preservice teachers. These cases and analyses will follow in the next chapter.

CHAPTER FOUR: FINDINGS

In this chapter, each case will first be explored individually to address the three major research questions for each preservice teacher. First, changes in each preservice teachers' NOS views related to RFN will be described using both the RFN Questionnaire data (Kaya et al., 2019) and verbal data from pre and post course interviews. Second, changes in each preservice teachers' beliefs about the importance of teaching NOS will be compared and discussed using verbal data from pre and post course interviews. Finally, using the pre and post course interviews, RFN Questionnaire, lesson plans, and lesson recordings, each preservice teachers' NOS instruction will be characterized related to their NOS views and beliefs about the importance of teaching NOS.

Ben

Ben was a white male in his early 20s. He was a preservice biology teacher in his junior year of the secondary education degree program, had not yet completed his first internship and had no prior teacher education coursework in NOS, or experience teaching NOS. He was very interested in science and watched online videos in his free time about current science, emerging technology, and fascinating cases in science history. Ben wanted to teach high school biology and was receptive to learning about NOS and how to teach NOS.

Ben's Views of NOS

It was clear that Ben had some foundational background knowledge of NOS coming into the course, as he exhibited some but not all of the common misconceptions about NOS. His pre-course overall score of the RFN Questionnaire (Kaya et al., 2019) indicated that he had a moderate understanding of NOS based on RFN (Akgun & Kaya, 2020), but to different degrees when considering each RFN category. This was mostly consistent with the verbal interview data in which he expressed his initial views. After the course, Ben’s views had become more accurate and developed related to all RFN categories.

Aims and Values. Ben had accurate views of the aims and values of NOS prior to the course, both according to the RFN Questionnaire, scoring 30 out of 35 maximum points, and according to his pre-course interview. The quote below is Ben’s response to the question, “what are the aims of science?”

> Ben: It's a great question. Perhaps, to somewhat recursively, expand scientific knowledge, right, just to gain a greater understanding of I mean, I guess, any field right like, whether that's fundamental physical laws of the universe to biology, to how to synthesize certain compounds. Although they obviously, science does not need to be in necessarily in those specific categories or in strict categories. So, the goal of science is to expand scientific knowledge.
>
> Researcher: So, for scientists to successfully accomplish these goals, what values would a scientist need to have?
>
> Ben: Hmm, well, I guess communicate, being able to have the virtue to be able to communicate with other people, I guess, and maybe the virtue of trying to be patient of trying to do other things. If stuff doesn't work. Values. Yeah, honesty, maybe.

Initially, Ben described the cognitive-epistemic goal of expanding scientific knowledge as an aim of science. Ben’s response also highlights his pre-course understanding that novelty and honesty are values of science. While his RFN Questionnaire score did not change in this category when assessed at the end of the course, his post-course interview responses indicated that Ben had a slightly more sophisticated understanding of the aims and values of science at the end of the semester.

> I mean once again, it's a very hard question to actually answer, just because it really depends on what type of science you're doing. But you know, generally aims of science would have to be trying to add on to scientific knowledge. An aim could be you know, trying to solve a problem of some sorts. I mean the values of science could be trying to say as neutral or as unbiased as possible.

After the course, Ben repeated that “trying to add on to scientific knowledge” is an aim of science, but also included a social aim of science, in that science tries to solve problems. He also stated that one value of science could be “trying to stay as neutral or as unbiased as possible”, newly identifying both the scientific aims of objectivity and being free from inductive bias.

Scientific Practices. Ben’s understanding of scientific practices improved when comparing his views in this category from the beginning to the end of the course. Before the course, Ben identified that the practices of scientists were dependent on their discipline.

> I assume in physics you're going to be using, you have to be good, really good at a certain type of math. But then you might be a biologist, and you really need to know statistics. I assume you need statistics in physics as well, but you get the point, right? Where, what you need to be good at really depends on your field, because math is a part of the acronym in STEM. Math is probably one of the stereotypical skills you need to know how to do, once again going back on general observation skills, or critical thinking, creativity perhaps, being able to communicate with other scientists. Stuff like that.

This quote highlights that Ben's conception of the main types of things that scientists do was heavily focused on the practice of math and computational thinking, but he was also aware that observations had an important role in science as well as communicating information "to other scientists". After the course, Ben elaborated on scientific practices, especially communication.

> But what are the exact day to days? I mean, I'll go with the one that I can think of at the current moment, and that's you know how, sometimes a scientist's day to day not only involves talking to other scientists, but, you know, talking to once again non-scientists, but the exact, whether that be through trying to communicate your findings to the public, in like a radio interview, or trying to get a senator to understand something, and 'please give me money' or it's usually not as high as a senator, but 'please give me money'. And then the other day to day is just, you know, doing whatever they're supposed to be observing. Generally, if we want to go with scientists.
>
> Researcher: So, they're making observations. They're communicating. What types of things might they do in between?
>
> Ben: In between, alright, it's, I mean, obviously planning also has to come up into play, because you can't make an observation. Well, you can make an observation without a plan, but if you want to make a more useful observation, you're supposed to be planning. Let's see. Communicating. I know there's ones I'm forgetting. But they're not coming up at the moment.

After the course, Ben explained that scientists need to communicate for different purposes, such as to educate the public or to advocate for funding. He also talked about observations again, but now discussed planning (types of investigations) so that scientists knew what types of observations to make.

Scientific Methods. Ben had the lowest score on the category of scientific methods relative to the other categories of NOS represented on the RFN Questionnaire. Ben's score on the RFN Questionnaire in this category experienced the largest numerical increase, and his pre and post interview responses show an improvement in his understanding of scientific methods. In his pre-course interview response, Ben described the scientific method as "the process of experimentation".

> Well, when I think of the scientific method, I think of the like 7 or odd steps that I can't exactly think of right now, you know, like, observe, hypothesize, problem is, I can't even remember the exact steps right now. But you know generally the process of experimentation, and tricky thing is that not all science involves experimentation like it, like I always forget which one is the like with the one with like star signs, which one's the at... astronomy like that one purely is almost an observational thing, because you can't perform experiments on the universe, you just kind of have to see what the stars are doing.

While Ben does refer to the scientific as the set of seven or so traditional steps, he goes on to say that some science does not involve experimentation, such as astronomy. This shows that Ben is knowledgeable that there is more than one method when it comes to science, but on the pre-course RFN questionnaire, Ben 'agreed' with the inaccurate statement that "There is a universal scientific method that all scientists use all over the world." It is possible that Ben thought the 'experiment' step of the scientific method could be substituted for other types of investigation, but the other steps needed to remain the same. Before the course, Ben also ‘agreed’ with the statement “All scientific disciplines such as physics, biology and chemistry use the same scientific method”, which conflicts with his interview statements but might be due to him not understanding that astronomy is a subdiscipline of physics. After the course, Ben selected ‘strongly disagree’ for both example statements about scientific methods, demonstrating an improved understanding that aligned with the interview data. In his post-course interview, Ben acknowledged the limitations of the lockstep scientific method,

> Ben: Well, we want to go with the scientific method. It's the oh, you think of something. You get hypotheses, you test it, etc., etc. But you know the better version of the scientific method is that everything is sometimes you're going to be talking to people. Sometimes you're going to be experimenting. Sometimes you're going to be publishing those results, but you know…The scientific method is more just, I'll use the phrase again, the day of the operations of being a scientist, right? And the exact procedures in that day to day…I mean the stereotypical example that we've been going with is astronomy, right? Because astronomy is almost purely observational. You can't exactly follow experimentation, which is what the scientific, the lockstep scientific method heavily implies.

Ben again rephrased the commonly taught steps of the scientific method, but then acknowledged that there is a better version that is not so limited. Ben again brought up astronomy as a counterexample to the ‘universal’ scientific method, explaining that in astronomy, scientists cannot follow the typical scientific method.

Scientific Knowledge. Before the course, Ben had a strong understanding in some aspects of scientific knowledge, being that scientific knowledge changes over time and that models are a form of scientific knowledge that can be used to represent, explain, and predict phenomena, and demonstrated this understanding in both his pre-course and post-course questionnaire responses and interview statements. However, prior to the course, Ben's ideas about scientific theories and laws were mostly inaccurate and were inconsistent when comparing his questionnaire responses to interview data.

> Scientific law, being general explanations that are kind of just put out there, but there's no real explanation for it. So… like Newton's law of gravity, right? That's a law, because it says okay, things drop down, right? Versus maybe like Einstein's [theory] of relativity, where, Einstein essentially says, hey, there's this ball in this blanket, and because there's this ball in this blanket, the things will go to the ball, and depending on how heavy it is or how large it is, things will be more attracted to it. And stuff like Einstein's theories versus like Newton’s laws, there’s generally lots more evidence to support it than any evidence the law would have.
>
> Researcher: So, you're saying a theory has more evidence than a law?
>
> Ben: Correct.

At the beginning of the course, while Ben said that scientific theories were supported by “lots more evidence” compared to scientific laws, he ‘agreed’ with the statement “Laws are more verifiable scientific knowledge than theories” in the questionnaire. After the course, Ben provided a much more accurate description of the roles of and relationship between theories and laws.

> "If we want to go for an example, Newton did laws for gravity, and Einstein did theories for gravity and tried to explain it more…Newton's law of gravity attempted to model in a sense gravity…Because you know there is, you know, he formulated equations, etc., etc...by definition no [a theory cannot become a law], the theory can change, or there could be a whole entire new theory once you gain more evidence over time. But you can't subtract evidence. You can say this evidence is now wrong…. in a sense [a law can change], well, in the sense of you know, we find more situations where that law isn't necessarily relevant. Going back to Newton, where we have to add that, like extra variable G for gravitational constant.... Sometimes you'll modify the law. Sometimes you create a new law entirely.

This quote illustrates that after the course, Ben seems to understand that as opposed to laws, the role of theories is to explain. He also recognizes that there is not a hierarchical relationship between the two forms of knowledge, because by definition a theory cannot become a law. He also understood that both theories and laws can be revised and was able to provide an example. This is in better alignment with his post-course questionnaire response of 'strongly disagree' for the statement "Laws are more verifiable scientific knowledge than theories."

Socioinstitutional NOS. Ben had a strong understanding of the socioinstitutional NOS at the beginning of the course. Of the seven subcategories in the socioinstitutional system of NOS category (professional activities, scientific ethos, social certification, social values, social organizations and interactions, political power structures, and financial aspects of science), Ben mentioned all but two (social organizations and interactions, and political power structures) in his pre-course interview. During his first interview, Ben discussed "the physicist who tried to gather research on like a new element, but just made everything up... so I guess just being honest when you publish.” This quote demonstrates that Ben understands how ethical conduct is important to science. Ben made many references to the act of social certification and dissemination in science, for example, saying that communication is important in science because “You publish papers so that other scientists are going to replicate your work.” Ben talked about the need for social values such as honesty in science, as well as the financial aspects of science, stating that “society decides what it wants to fund, and sometimes it doesn't fund all the possible science stuff that can be done.”

In his post course interview, Ben discussed all seven subcategories within the socioinstitutional NOS. In terms of professional activities, Ben elaborated on his previous ideas, saying that “someone who is doing it [science] professionally is assumed to be more interested in publishing where someone who's traditionally a nonscientist isn't going to publish or spend as many resources publishing”. Publishing is one of the professional activities of scientists that contributes to the norms of scientific communities. Ben brought up the Tuskegee study to illustrate the importance of acting in good ethical faith while conducting science, providing an example of scientific ethos. Ben also described the interplay between social certification and dissemination, political power structures, and funding systems.

> Sometimes a scientist’s day to day not only involves talking to other scientists, but, you know, talking to once again nonscientists, but the exact, whether that be through trying to communicate your findings to the public in like a radio interview, or trying to get a senator to understand something, and ‘please give me money’ or it's not as high up as a

senator, but ‘please give me money’. And then the other day to day is just, you know, doing whatever they're supposed to be observing.

Ben’s description of scientists talking to other scientists is an example of the social certification and dissemination subcategory, as scientists must communicate their findings to other scientists to put their investigations to test through the scrutiny and validation of the scientific community. Ben’s mentioning of a scientist who needs to communicate their findings to a senator illustrates the relationship between science and the government who supports it. Lastly, Ben’s understanding that science is mediated by economic forces is also visible in this quote, as the scientist is begging the senator for money to be able to continue the scientific work. While the interview data suggested an improvement in Ben’s already strong understanding of the socioinstitutional NOS, Ben’s score for the socioinstitutional aspects category within the RFN questionnaire decreased by 2 after the course. In learning that science is a social institutional system, and that science cannot be separated from the scientists engaging in it, Ben may have selected responses that indicated an understanding that personal identities may lead to bias. For example, Ben changed his view from ‘not sure’ to ‘agree’ for the statement “The gender of scientists influences how they do science.”

Ben’s Beliefs about the Importance of Teaching NOS

Prior to the course, Ben expressed a utilitarian argument for why understanding NOS matters during his pre-course interview.

> “I'd also argue that you know, knowing science in general is useful, just because pretty much everything else that we said, how science affects technology, how society, then it affects science, which will then affect society. Basic skills like, do I need to go to my

> doctor, if X, Y, and Z are happening, or is this a normal biological process? Let's see, similar stuff on medication in a certain sense of knowing that antibiotics will not help your cold virus and stuff like that. And…while you can rote memorize those things, it's always going to be more useful for understanding if you know the basic nature of science principles.

This quote illustrates that Ben found the connectedness between science and society as a reason that it would be useful to teach NOS. Ben also believed that an understanding of NOS would be useful for students in personal decisions, such as their medical health, emphasizing the utilitarian argument for teaching NOS in that “people would feel more 'at home' with the products of science if they had a better understanding of the ideas involved” (Driver et al., 1996, p. 16).

At the end of the course, Ben’s rationale for teaching NOS was more deeply developed. Ben restated the utilitarian argument (“thinking critically, and having scientific thinking, is a good skill for life generally”), but shifted to more of a democratic and moral rationale for why it is important for students to learn about NOS.

> Hmm. Well, partly because you know, being able to have the society have some trust in science at the very least, is important because the alternative to not trusting science is just lull, which isn't exactly the best practice to put in place, and you know you also want students to think critically, because you know, outside of the stereotypical thinking critically, having scientific thinking is a good skill for life generally. And also like I want to go back to this Tuskegee. Not all scientists do science well, so you know, having, you know. For the States is the wrong term for it. But you know, being able to be somewhat

> of a watchdog, assuming you were not just immediately falling into the wrong rabbit holes. That's important for society.

He described that in the interest of scientific progress, it is necessary to have a society that has trust in science. Such trust will only be gained if society understands how scientific knowledge is built and validated. Ben also argued that, in reference to Tuskegee, not all scientists “do science well”, so it is important for citizens to “be somewhat of a watchdog” and monitor science to ensure it is upholding and embodying the institutional norms, instead of “immediately falling into the wrong rabbit holes”. When discussing his plans to teach NOS, Ben also added that this would support students in their assessments, however he called that the “cynical” reason, saying, “Nature of science is a huge portion of EOCs [end of course assessments], if you want to really go that route, so it's important to reinforce that, although it's definitely important to reinforce that for other reasons other than the cynical one.” End-of-course assessments refers to the statewide assessments for science where Ben lives.

Ben’s NOS Teaching

At the end of the course, Ben demonstrated informed NOS views based on RFN overall. The most significant changes occurred in his views of scientific methods, scientific knowledge, and scientific practices since Ben already had a strong understanding of the aims and values of science and the socioinstitutional NOS at the beginning of the course. In terms of beliefs about the importance of teaching NOS, Ben at the beginning of the course believed it was important to teach NOS because NOS is “useful”. At the end of the course, his beliefs about the importance of teaching NOS were more far-reaching, and Ben stated both moral and democratic reasons for why it is important that society understands NOS.

At the end of the semester, Ben wrote and taught a lesson to the class. The requirements for the lesson were that it integrated NOS in science content teaching, in accurate, explicit, and reflective ways. Ben wrote his lesson plan for the context of a high school biology course during a chemistry unit. The science content idea that Ben targeted was the unique properties of water that contribute to Earth's suitability as an environment for life: cohesive behavior, ability to moderate temperature, expansion upon freezing, and versatility as a solvent. Ben included an ambitious and unrealistic number of NOS ideas in his lesson plan, considering that this was a single, maximum 45-minute lesson. In his lesson plan, Ben identified several ideas about NOS that he wanted his students to learn aspects of the cognitive-epistemic system of NOS (what characterizes scientific methods, how similar investigations result in the same outcome, how inferences are drawn from observation in science, and the function of models in science) and of the socio-institutional system of NOS (weighing costs and benefits for solving specific societal problems). He also identified four science practices (NGSS Lead States, 2013) that would be a focus of the lesson, which included developing and using models, analyzing and interpreting data, constructing explanations and designing solutions, and obtaining, evaluating, and communicating information. Ben explicitly addressed both RFN categories of scientific knowledge and scientific practices in his lesson, two areas in which he had misconceptions about prior to the course but his views had significantly improved through the course. Ben implicitly addressed the socioinstitutional NOS, which he had a moderate understanding of before the course, but was expanded to include an awareness of other aspects of the socioinstitutional NOS.

Ben first incorporated the RFN category of scientific knowledge into his lesson when he introduced the lesson.

> Today we are going to be working with models. Specifically, we're going to be modeling properties of water. The properties of water you're going to be modeling today are its cohesive behavior, its ability to moderate temperatures, its tendency to expand upon freezing, and its versatility as a solvent, although we're more modeling cohesive behavior and solids.

This instruction explicitly addresses one form of scientific knowledge, models, and how they can be used as tools to represent phenomena, as well as the scientific practice of using models.

Ben further incorporated the RFN category of scientific practices into this lesson when, after the introduction, he asked students (his peer preservice teachers and myself) how many drops of water they thought could fit on a penny before allowing them to measure for themselves. He then guided the class through four station activities, each focused on a different property of water. A handout for one of his station activities, which followed having the class read about solubility and water as a universal solvent, is below as an example.

Try dissolving some potential solutes in water and see if they successfully dissolve. If the solute does not dissolve in the water, what type of mixture was created? Feel free to use the popsicle stick to stir.

Substance	Did it dissolve into our solute (water)? If not, what does the mixture look like?
Salt	
Sugar	
Coffee	
Oil	

1 – What can you infer from this demonstration?

____

2 – Explain

____

Figure 3: Ben's Station Activity Handout

Ben embedded the question set "What can you infer from this demonstration? Explain" in two different station activity handouts, to be answered after students had made observations about the phenomena. According to Erduran & Dagher (2014), "When embedded in scientific theories and interlinked to other epistemic practices such as modeling, observation becomes a scientific practice" (p. 73). At the end of the lesson, students were instructed to complete an exit ticket. Ben included one question (question 4) that required students to explicitly reflect on the category of scientific practices. In his exit slip, he included four questions.

1. In your own words, explain Cohesion and Adhesion:
2. What are examples of Solutes and Solvents?
3. What's a property of water you're interested in learning more about?
4. What scientific practices do you think you practiced today? Why?

The fourth question can be classified as a divergent NOS question (Voss et al., 2021) as it will "allow students freedom to respond with a variety of viewpoints" (p. 1279).This question type "might be useful to teachers when they are looking to survey the landscape of student ideas about a specific NOS idea" (p. 1286).

The third category of NOS that Ben included in his instruction was the socioinstitutional NOS, specifically the subcategory of social values. As part of his lesson covering water's expanding when frozen, Ben shows a video about the scientific cause of potholes and the economic and public safety impact of potholes. The video he selected shows how science can be used to solve a societal problem, thereby teaching about the social value of science. According to Erduran and Dagher (2014), "Respecting the environment, social utility and freedom are considered social values that are embodied by science…Increased attention to the social utility of scientific research is necessary for garnering public support. Respect for the environment is critical for human survival" (p. 142). This is related to Ben's decision to utilize this video for his lesson and ask specific questions afterwards. After the video, he says, "The authors of this video did come up with some solutions to try to fix potholes. Are there any ways, besides these, that you think could fix potholes?... You're allowed to think outside the box for this one". After the students share some ideas, Ben says, "One of the things I was thinking of, was reducing reliance on vehicles so that you're not having... cars continually agitating the pothole and making more cracks inside of it". While Ben implicitly made connections to social issues, this instruction was not explicit, as Ben did not explicitly state how this relates to the scientific aim of addressing human needs.

At the beginning of the course, Ben was asked how he might teach NOS to his future students. Ben responded, "Yeah, I would not know other than like experiments in which the nature of science is ingrained, but specifically teaching nature of science, I would not know." Although NOS teaching must be explicit and reflective to be effective, Ben explained that he would teach NOS implicitly such as through experiments, however, these experiences often lead students to interpret NOS in ways that are not intended (Driver et al., 1996).

When Ben was asked in his post interview how he would teach NOS, he described many ways that he would do so. One way is by emphasizing certain ideas, such as by saying "Hey, not everything is an experiment." Ben went into detail about how he would teach NOS, referring to the course instruction.

> I'm gonna reference the first document that I'm not remembering correctly with the 4 sliders of, oh, how much you want to teach explicitly how much you want to teach implicitly... Yeah. The continuum, so probably just make sure that I'm not necessarily teaching nature of science in one way, is probably going to be the best approach....One way it [NOS instruction] could look [explicitly] like it's just... you know, 'scientists come from different backgrounds. What backgrounds can scientists come from? Explain.' That's the literal approach to teaching explicitly. But you know...I mean the Mendel thing where you know we're talking about a scientist and their life and sprinkle in various bits of the [NOS] standards in there, or the engineering practices, you know, have those types of questions, or simply just make sure you're clearing these misconceptions, as in you know what is a theory, what is a law.

Ben referred to the NOS teaching continuum (Clough, 2006) that shows how NOS instruction can be thought of as a scale in terms of contextualized vs decontextualized and implicit vs explicit and said he would "just make sure that I'm not necessarily teaching nature of science in one way, is probably going to be the best approach". By saying he will avoid "one way" of teaching NOS, Ben is highlighting the strategy of using a mix of implicit and explicit NOS instruction. and embedding explicit and reflective NOS questions in his lessons. Ben wrote his curriculum material using the history of science to teach about a scientific discovery on Gregor Mendel, and included personal facts about his life, such as that he came from a low socioeconomic background. When talking here about explicit NOS instruction, he's recalling one of the explicit-reflective NOS questions that was embedded into the story he wrote for the assignment. Ben's ideas about how to teach NOS were represented in the lesson that he taught, as the lesson did include both implicit and explicit NOS instruction, as well as an explicit-reflective NOS question.

Valentina

Valentina was a female Latina in her early 20s. She was an environmental studies major, earning a minor in science education. She was very passionate about environmental justice and advocating for equal opportunities for underrepresented students. She had recent experience working at a science camp, and when asked, didn't report teaching NOS at the camp. At the beginning of the course, she acknowledged that there were things she didn't know about NOS but was eager to learn more.

Valentina's Views of NOS

Valentina's views of NOS had room for growth at the beginning of the semester. Her pre-course overall score on the RFN Questionnaire (Kaya et al., 2019) indicated that she had a moderate understanding of NOS based on RFN (Akgun & Kaya, 2020), earning about 70% of the maximum points in each RFN category, which was aligned with the verbal interview data from her pre-course interview. After the course, Valentina's views of NOS were high, and she was able to more accurately and specifically articulate ideas related to all RFN categories. This finding aligns with the RFN Questionnaire data, as Valentina's scores improved in every category.

Aims and Values. Before the course, Valentina had a better understanding of aims and values when compared to the other RFN categories, stating both cognitive-epistemic and social values of science. She stated that a goal of science was "to make discoveries to gain knowledge around the world around us." She described the values of science as "good ethics, like good at collaborating, valuing other people's opinions, flexibility with other disciplines." Valuing other people's opinions' addresses the social value of decentralizing power, which Valentina had an awareness of before the course. After the course, she was able to identify more aims and values of science.

> Trust, communication...authenticity, not having bias ...I'm trying to think of…the short story we did. How like I incorporated some aims and values, just justice, and like for a society so like creating, I guess, like equal opportunities for everyone...communication and trust, and just making sure your work is like accurate, and being able to share your data or discoveries with the public and not, you know, hiding anything.

This quote illustrates Valentina's new understanding of the aims and values of objectivity, accuracy, honesty, and furthers her stance on the value of decentralizing power.

Scientific Practices. Before the course, Valentina had an understanding that scientific practices differ when it comes to different disciplines.

> I think you're [scientists are] doing, let's see, experimentation, that's usually what people think right, I think, like people think like scientists and lab coats. But there's also like social sciences. So, I feel like also like working with people doing surveys, and just I feel like it depends on the kind of science you're doing. But I think yeah, I think everyone's just trying to find some answers to a specific problem in whatever kind of discipline they're doing.

In terms of scientific practices, Valentina's understanding was limited to identifying experimentation, surveys, and finding answers to problems. After the course, she referred specifically to the 8 science practices outlined in the NGSS when asked about scientific practices.

> I know you said there's 8 practices...There's like asking questions, analyzing data like you're using mathematics, communicating with other scientists, constructing experiments and explanations, that's a couple. Oh, investigations is one, so planning and carrying out investigations...and then engaging with others, and too with, so to like, talk about evidence and stuff. Yeah, those are some practices of science and engineering.

Valentina conceptualized the practices of science in a more detailed way after the course, identifying parts of 7 out of the 8 science practices identified by the NGSS. The practice she did not discuss was 'developing and using models', although she did talk about models in other parts of her interview. The RFN questionnaire also suggested improvement of Valentina's understanding of scientific practices, as there was a positive change in her score for this subcategory.

Scientific Methods. Valentina’s pre-course interview and RFN questionnaire data for the category of scientific methods indicated inaccurate views of this idea. In the questionnaire, Valentina ‘agreed’ with the statement “There is a universal scientific method that all scientists use all over the world.” In her interview, she described the scientific method as the “process of doing experimentation”. She did state that “it doesn't have to be chronological”, but it was just the process of doing an experiment and “finding something out, how you would look into something that you are trying to get the answer for”. After the course, Valentina did not mention experimentation as part of the scientific method and addressed that the scientific method is not universal.

> You know, someone says scientific method. It's more of like everyone thinks like the universal like. Oh, like, observing a phenomenon, ask a question about it, creating data or analyzing data, creating models and conclusions. And you know it's like these like certain steps. But I think we learned that the scientific method is not a linear set of a specific linear set of steps. In fact, it could, depending on disciplines, it could be very different, or the sciences. So, I think we just learned that it's just not universal. It's just, for example, scientists and what they're doing.

This response illustrates that Valentina is both aware of the misconception regarding the scientific method (“what everyone thinks”) and the accurate conception (depending on the discipline, it could be very different). This aligns with her RFN questionnaire score, which increased after the course. For example, after the course Valentina selected ‘strongly disagree’ for the statement “There is a universal scientific method that all scientists use all over the world.”

Scientific Knowledge. Prior to the course, Valentina knew that science is tentative, and that scientific progress occurs when ideas are evaluated and revised, selecting ‘totally disagree’ for the statement “Scientific knowledge does not change” and explaining this in her pre-course interview. However, she held misconceptions about the relationship between theories and laws in science, and strongly agreed with the statement “Laws are more verifiable scientific knowledge than theories.” Her pre-course interview statements aligned with this view.

> I know law is more confirmed around the science community with a lot more evidence, and it's almost like...It is accepted, as you know, like universally true, whereas a theory is...I know it's supported by lots of evidence, but it's not as high up as a law.

This quote illustrates that Valentina believed laws were more “high up” and evidence-based than theories. Valentina’s understanding of laws and theories improved during the course, as shown by her positive change for this category in the RFN questionnaire, and her post-course interview statements.

> Theory is the why and laws are the what, and I know that you said that, like theories are often I think backed up by hypothesis or hypotheses, and then, like laws, are more like a lot of like formulas, and…things like that. But the most important thing is that that neither one is more reliable than the other, neither is more accurate, like a theory doesn’t become a law.

After the course, Valentina accurately articulated basic distinctions between theories and laws, which is that theories explain phenomena whereas laws describe them (the ‘why’ and the ‘what’), and that theories develop from hypotheses and laws can be formulas. She corrected her previous beliefs regarding hierarchy between the two terms, explaining that neither are more accurate or reliable and a theory does not become a law. In the RFN questionnaire, Valentina changed her pre-course response from ‘agree’ to ‘strongly disagree’ for the statement “Laws are theories that are confirmed.”

Socioinstitutional NOS. Valentina had a basic understanding of the socioinstitutional NOS at the beginning of the course. Of the seven subcategories in the socioinstitutional system of NOS category, Valentina recognized four in her pre-course interview.

> If you're going to be experimenting with the world around you, a lot of that's like living stuff, and I feel like you need to have good ethics, with how you treat everything and how you treat your fellow scientists, community and everything and the people that you're experimenting on.

This quote illustrates that Valentina was aware of the importance of scientific ethos. Also in her pre-course interview, Valentina identified a professional activity of scientists, peer review, saying that peer review is “very important”. Social certification and dissemination were illustrated in her statement that scientists are involved in “sharing the knowledge so it could be confirmed, or ‘oh, this wasn't true!’” Valentina identified the social value of addressing human needs within science, saying that “science works, together with society, to be able to improve”. Valentina did not discuss aspects of financial systems, political power structures, or social organizations and interactions within science during her pre-course interview. After the course, Valentina did include these systems in her responses, first by mentioning the “economic side” of science. Valentina also referred to the interactions between Rosalind Franklin and Watson and Crick.

> She [Rosalind Franklin] was maybe treated differently because of the time period, and like how like women were seen as like, maybe not as reliable, or they had to like, prove themselves more than like their male counterparts, so that, like hindered her a lot, and had to make her, maybe be more. not secretive, but more protective of her work.

This quote illustrates how Valentina understood that institutional structures and dynamics shape the interaction among scientists working in and across organizations, and the interplay of science with the politics of government, including gender.

Valentina's Beliefs about the Importance of Teaching NOS

During her pre-course interview, Valentina expressed only one type of argument for why understanding NOS matters, which was the science learning argument.

> I would want everyone… all the kids to come out feeling like a scientist, to feel like they learned something, to feel that they can do it…I want them to understand that science is not just like oh, knowing the definition of this big fancy science word, there's a lot more to science and each one of them could do it if they wanted to.

Valentina believed NOS aids in science learning, and had mainly affective reasons for wanting to teach NOS. After the course, Valentina expressed a deeper belief in the importance of teaching NOS during his post-course interview.

> I think it's important because I think I like, I can even say, from my own experience, like when I was younger, like I didn't pick myself as like someone who would grow up to have a STEM major. So, because of how I felt like it was very limited, for, I don't know just like I'm like a first generation. English is my second language, I'm female…So sometimes it was, it feels like extra barriers for different kinds of students, and it could be

> very intimidating, so I think it's very nice to…humanize science a little bit by talking about the scientists and understanding the process a little bit more and just kind of understand science as a whole, as like a whole concept, and just understand it better. And then maybe, if we understand science better, and we allow our students to, maybe they could learn to love science and feel like they can do it too.

After the course, Valentina elaborated on the science learning argument mentioned initially and described that as a first-generation immigrant and English learner, she never saw herself as someone who would grow up to have a STEM major because of a lack of representation and the presence of extra barriers for herself and students like her. Valentina also provided a second argument for why teaching NOS is important during her post-course interview.

> Science is like in everything. And there's like, for example, the practices of science are like in every kind of career so, and every kind of, even if you don't have a career, a stay-at-home mom, you're using a practice of science. So I think that it's very important. Theres also different aspects of science, like the economic side, the societal side, and these are all things that are very important even when they leave the classroom so I think that if they can understand that, then they can have a better mindset and idea of how the world works.”

This demonstrates that Valentina had developed a utilitarian argument for teaching NOS, believing that scientific practices are useful in every career and for students’ lives beyond the classroom.

Valentina's NOS Teaching

At the end of the course, Valentina demonstrated informed NOS views based on RFN overall. She had significant improvements in her views across all RFN categories, both according to her post-course interview statements and her post-course RFN Questionnaire responses. In terms of beliefs about the importance of teaching NOS, Valentina at the beginning of the course believed it was important to teach NOS because understanding NOS can help students feel like they can be successful at learning science and being a scientist. At the end of the course, her beliefs about the importance of teaching NOS were deepened in how NOS can support science learning in the classroom, but she also believed there is utility in understanding NOS for students beyond learning science. Valentina struggled to implement NOS in her lesson at the end of the semester, planning to address NOS, but mostly implicitly rather than through an explicit-reflective approach. There was no explicit-reflective NOS instruction during the enactment of Valentina's lesson.

Valentina's lesson targeted the content of pollination, plant structure and function, as well as the interdependence between bees and humans, and was designed for a 7th grade life science class. In her lesson plan, Valentina specified that students would be engaging in the scientific practices of developing and using models and asking questions and defining problems. She also included as part of her procedure to "emphasize the importance of pollination for the environment and human life", illustrating a social value of science.

Valentina integrated the RFN category of scientific practices into her lesson. She started her lesson by asking students what they already know about the word "pollination", then after introducing pollination and showing a video about pollination, she instructed students to work as a group to complete a matching worksheet in which students labeled the parts and function of each part of an angiosperm using a word bank. According to Erduran & Dagher (2014), “The scientific practices involve the collection of data for particular purposes, for instance modeling of phenomena” (p. 71). In this sense, Valentina was engaging students in developing a model to represent an angiosperm and the form and function of its parts. After having the students complete the matching worksheet, Valentina referenced the social-institutional NOS, specifically the social values subcategory.

> Let me establish why we’re learning about the anatomy, because it's very important for what happens after a pollinator lands… let's talk about why we ... learn pollination in the first place. Without pollination, there would be basically no plant diversity in the world because there’s two types of pollination: there’s self-pollination...and cross pollination… So, without these things, there would be, if you remember the Bee movie, if you have seen the Bee movie, then you remember what happened when they removed all the bees. All the flowers and the plants started doing really poorly because without bees there would be no diversity at all.

Valentina uses the example of bees as a way to help recontextualize science learning to promote civic engagement (Erduran & Dagher, 2014). Her teaching of this category falls toward the implicit end of the NOS teaching continuum (Clough, 2006) as she does not ask students to reflect on what this means about how science and society interact.

At the end of the course, when asked how she would teach NOS, Valentina lists many strategies, including concept maps, discussions prior to a lesson, using models, using roleplay to teach more about the “societal side of science”, and bringing in scientists from underrepresented groups such as people of color and women. Strategies that she listed such as concept maps and discussions are supports for teaching science or teaching in general, and are not specific to NOS. The other strategies can be used to teach NOS if they are done so explicitly and reflectively, which is not something that Valentina describes. Valentina did engage students in modeling when she taught her lesson, but did not utilize any of other approaches that she brought up in her post interview as ways she would teach NOS.

Michael

Michael was a white male in his early 20s. Michael was a senior in the secondary science education degree, biology track, and wanted to teach high school biology when he graduated. Michael was very mature and enjoyed having deep conversations about NOS. Michael had previous volunteer experience teaching science and said that he loved seeing students get excited about science. He was very thorough in every discussion post and assignment within the course. Simultaneously, he was enrolled in another science methods course.

Michael's Views of NOS

Michael's views of NOS based on RFN at the beginning of the course were advanced. His overall NOS understanding as represented by the RFN Questionnaire was high, which was consistent with his interview data. While he did begin with a strong understanding of NOS, his views improved for each category through the course according to the interview data, which was not always consistent with the change in each category's score as reflected on the RFN questionnaire. Michael did continue to hold some misconceptions pertaining to the category of scientific knowledge at the end of the course.

Aims and Values of Science. In his pre-course interview, Michael articulated a cognitive-epistemic aim of science as expanding knowledge, and an aim of science to address human needs, saying, “We use our knowledge about the world to make a better place to solve problems, like engineering problems, and then designing a solution for it.” He also mentioned the social value of honesty, “because if you flub some numbers just to make your hypothesis correct, then that's a null and void experiment, and you're just lying to people.” Both his post-course responses and positive change in post-course RFN Questionnaire demonstrated an improvement of views in this category. When asked about the aims and values of science after the course, Michael said, “ethics of you know, intellectual equality, honesty, empirical data, empirical adequacy, accuracy… like knowing science history as opposed to you know, obscuring it. That’s more of a value [than an aim].”

After the course, Michael elaborated on the role of ethics in science, this time also highlighting the cognitive-epistemic values of objectivity, empirical adequacy, and accuracy, and the social values of honesty and addressing human needs. Additionally, Michael discussed the social value of decentralization of power, stating ‘intellectual equality’ as part of his response. Lastly, Michael described that knowing science history is a value in and of itself, indirectly referring to how in some social organizations, science is treated as opinion.

Scientific Practices. At the beginning of the course, Michael was able to describe some scientific practices when asked during his interview.

> The experiment conducting and recording... What I assume scientists do is they enter a sort of scientific journal discourse, and they'll go and read other people's research on research that they know something about. and they will either corroborate their findings or go, huh! That's interesting, and maybe start their own research in their own

> experiment. And then they'll publish something and be like, so, because of this person's experiment, and it builds on itself, and it's knowledge is like building a brick house, and you know you could think of finding every bit of knowledge is putting a brick on, but every person finding and validating information that's putting the mortar on each brick and getting it to stick there and solidify.

Michael’s response especially highlights the scientific practice of obtaining, communicating, and evaluating information. This quote also shows that he conceptualized experimentation as a main scientific practice. After the course, Michael’s interview responses showed an expanded understanding in this category, but this finding is inconsistent with the RFN Questionnaire, which indicated a decrease in Michael’s understanding. Michael was able in his post course interview to articulate more scientific practices than in his first interview.

> They observe, they ask questions, they seek to answer questions about the world that either they form, or other people ask. They seek to solve problems, all that good stuff, you know, all those lovely practices of science making and using- or designing and using models, analyzing and interpreting data is the easy one, but it's the …obtaining, evaluating and communicating evidence is the last one. Uh, mathematical and empirical calculation, calculations and stuff, that activity.

This response highlights five different science practices (asking questions and defining problems, analyzing and interpreting data, developing and using models, using math and computational thinking, and again, obtaining, evaluating and communicating information), as outlined by the NGSS. Michael’s small decrease in the RFN Questionnaire score for this category was partly due to him changing his pre-course response of “disagree” to, post-course, “agree” with the statement “Different branches of science like physics, biology and chemistry have the same practices.” It is possible that in learning about the NGSS' science and engineering practices, Michael interpreted this statement to mean that all scientific disciplines use variations of these same practices. It is also possible that the wording of the statement was ambiguous, as while some practices are common among scientific disciplines, they differ in their enactment.

Scientific Methods. Michael had misconceptions about scientific methods at the beginning of the course, as revealed by both RFN Questionnaire data and his pre-course interview. Prior to the course, Michael 'agreed' with the statement "There is a universal scientific method that all scientists use all over the world." However, Michael stated in his interview that there may be "other ways" to do science.

> Well, from a strictly formulaic perspective of what was taught in school, the scientific method was, build your hypothesis so it's ask a question, design an experiment, conduct an experiment, record observations, and then make a conclusion. That's the direct academic scientific method. But I prefer to think of it less in that sort of box and more, you ask a question, of course, because if that's what it is you ask a question, how does that work? And then you try to figure out a way to test that issue. So, create an experiment. Then you obviously have to conduct that experiment. And yeah, and as far as recording observations, if it's just like for your own knowledge, and you're just doing a little experiment like you're not publishing a work on how much water comes out of my sink every day that that's just silliness. You're not gonna publish that, but it's just a little bit of everything in the scientific method.

This quote highlights Michael's pre-course understanding that the formulaic perspective is the "direct academic scientific method", and that this method necessarily involves an experiment. Where he says may differ is how the observations are recorded, and whether they are for personal use or for publication. Michael went on to say there could be “messier ways to go about it [science]”, such as in chemistry one could simply ask what happens between two chemicals and mix them. However, Michael believed that the step-by-step scientific method was “universally agreed upon to be the way that is easiest for people to understand and to conduct the research.”

Michael’s post-course interview and RFN questionnaire results, which increased the most out of all subcategories, showed a positive change in his understanding of scientific methods.

> There is no “the” scientific method except for the one that's taught about in schools, unfortunately…what I mean by unfortunately, is that in schools it's commonly taught. Or I don't know if it's still taught that way now, but hopefully not …not every experiment needs a hypothesis. Not every field of science conducts itself to an experiment, like psychology, for example….There is no one concrete frame of the scientific method.

After the course, Michael explicitly described that the statement he had previously agreed with, and said in his interview, was false (i.e., that there is one universal scientific method). He also described that scientific methods differ by discipline and expressed his displeasure in how “the scientific method” is commonly taught in schools.

Scientific Knowledge. At the beginning of the course, both the RFN questionnaire and the pre-course interview revealed that Michael understood how scientific knowledge changes over time, and understood the role of scientific models, but held misconceptions about scientific theories and scientific laws. Michael ‘agreed’ with the statement “Laws are more verifiable scientific knowledge than theories”, which aligns with what he said in his interview, that “theories are less reinforced laws because they don't always work all the time, but they mostly work a lot of the time.” After the course, Michael’s score for this subcategory in the RFN

Questionnaire improved, but his post-course interview description of theories and laws still reflected a misconception.

> Theories essentially seek to provide explanations that are backed up with evidence or hypotheses that have been tested and tested, such as climate change. And then we have laws which are more empirically-based that seek to, ‘this is how it works, because this’ and it's not necessarily seeking to say why it happens, just what happens, I throw the ball this way, it goes that far because I threw it this hard.... Most of the time [laws are more empirically-based than theories].You can make a, well because a lot of scientific laws in physics are mathematical formulas. So that's what I meant.

This quote illustrates Michael’s understanding that a distinction between theories and laws is that theories provide explanations, whereas laws provide descriptions of what happens. However, his response suggests that he incorrectly believes theories are supported by less evidence (are less empirically-based) than laws. This is inconsistent with his post-course questionnaire selections of ‘disagree’ for the statement “Laws are more verifiable scientific knowledge than theories” and ‘totally disagree’ for the statement “Laws are theories that are confirmed”.

Socioinstitutional NOS. Michael had a very strong understanding of the socioinstitutional NOS coming into the course, earning 76 out of 80 possible points on this subcategory in the RFN questionnaire, and mentioning, in his pre-course interview, almost all the subcategories in the socioinstitutional system of NOS, only leaving out scientific ethos. For example, Michael discussed the professional activities of scientists and the social certification of science in his pre-course interview.

> It's incredibly important that we have repetition, and we're able to replicate the data. And why, even if someone comes out with a published work that says, ‘this is my findings’,

> there needs to be a redo by other people, either using the same circumstances or different circumstances just to make sure everything's okay.

Michael referred to the public sharing and dissemination of results with which scientists begin to certify and validate their findings, which illustrates that the socioinstitutional NOS consists of both the professional activities of scientists (publishing) and social certification and dissemination. Michael identified a social value of science in that one of its aims is “fixing anything or making things easier with science”. This addresses the social value of addressing human needs. Michael was also aware that science operates within social organizations and political power structures.

> There is the community, the science community that's its own little subsection of society. But also, science impacts society in very direct ways, sometimes like with what happened at the end of World War 2. That was a very big impact on society.

In saying that scientists are their own subsection of society, Michael is illustrating the idea that scientists work in institutions (i.e., universities, research centers) that are socially organized. Referring to how scientists developed the atomic bomb during World War II points to the political heritage of science. Michael discussed that “in order for science to get done, it needs the proper funding and time”, indicating the financial aspect of the socioinstitutional NOS.

Michael reiterated these socioinstitutional aspects of NOS during his post-course interview.

> Michael: Well, given that science is a medium which is meant to be shared with not only other scientists, but also just the general populace, it's how the general populace reacts to it. For example, the people that can use that knowledge can either choose to do something

> about it or not do something about it, or you have, you know the popular opinion, how they change around science, or how their beliefs are, you know, will change how they interpret that data because they will look at a study going, there is a definitive study showing you that vaccines do not in fact, cause autism. And yet they will go, 'Okay, but I don't believe you.' So.

After the course, Michael described how science is meant to be shared with the public, but the public's beliefs and perceptions can act as a barrier to the proper dissemination of science. Also in his post-course interview, Michael discussed the role of scientific ethos.

> A trusted scientist will have been peer reviewed multiple times, have lots of credited sources. and of course, the statistical data and research methods are accurate and ethical, and of course they don't use wording that is intentionally made to throw you off. You know, the 9 and 10 dentists agree with this toothpaste. Where they get that from, they didn't do one. I took a statistics class, so I think statistical data is very important, especially when examining scientific studies, because there are scientific studies. And then there are scientific studies that are just someone standing outside a parking lot with a clipboard."

This illustrates Michael's understanding of the ethical norms that scientists are expected to embody, including being honest and not deceitful. While this indicates an improvement in understanding of the socioinstitutional NOS, Michaels' score for the socioinstitutional aspects category within the RFN questionnaire decreased by 2 when taking it again at the end of the course, meaning the two forms of data are inconsistent. In learning that science is a social institutional system, and that science cannot be separated from the scientists engaging in it, Michael may have selected responses that indicated an understanding that personal identities may lead to bias. For example, regarding the statement, “Race and ethnicity of scientists have nothing to do with science”, Michael went from totally agreeing before the course to disagreement after the course.

Changes in Beliefs about the Importance of Teaching NOS

Michael’s belief in the importance of teaching NOS at the beginning of the course was in part related to how NOS understanding supports science learning, explaining that teaching NOS is “how you create scientists and people that think”. Michael described how NOS can support students in becoming excited about science, recalling “I have had volunteer experiences where…seeing kids get excited about science is awesome, it really is…And so I guess, seeing that, like that glimmer in their eye that they're starting to get it.” Prior to the course, Michael also brought up a democratic argument for why teaching NOS is important. He stated students should learn “especially how society right now affects science and climate change and all that, because I definitely learned about that in high school, so why can't they?” He recalled a guest speaker coming into his high school to teach about the extent of climate change and melted polar ice caps and said, “that's just sad that it's been this many years, and nothing's really like changed or adapted”.

After the course, Michael’s beliefs in the importance of teaching NOS were more fully developed and he more types of arguments for teaching NOS that transcended science learning in the classroom. Michael did restate the science learning argument, saying in his post-course interview that he hoped teaching NOS would help students when it was time for their end of course exams: “Hopefully when eoc’s [end-of-course assessments] come up, and they know the content as well, they'll be able to figure stuff out on their own without necessarily having to memorize everything." NOS standards are assessed on the statewide science exams where the study takes place. However, Michael also newly described a moral argument for why teaching NOS is important, saying that he especially wants to teach about values of science such as honesty, empirical adequacy, and accuracy, "for their own benefit as free thinkers". In his post-course interview, Michael also elaborated on his previously stated democratic argument for teaching NOS.

> If they're not too interested in the content, I can at least teach them well, in society, because that's somewhere you're going regardless of what field you're going into, you're gonna have to deal with people that are giving you the right information, people that are giving you the information as best they know it, and people that are giving you information that's coming from nowhere in particular. and I want them to be able to catch the difference… like make decisions on their own, because… I don't want to teach them how I feel about a thing, I want to present to them the topic, the scientific knowledge, and have them come to their own conclusions.

Michael further articulated the argument that NOS will support students in making practical decisions and choices that involve scientific knowledge. According to Driver et al., (1996), in making these decisions that involve epistemological issues, people must decide whether a piece of knowledge is applicable to the case at hand, and they must then "form a judgement about the reliability and the possible limitations of the knowledge they possess" (p. 16).

NOS Teaching

Michael held highly accurate views of NOS based on RFN both before and after the course, apart from the scientific knowledge category. Michael's deep-rooted misconception regarding a hierarchical nature between theories and laws did not change through the course. However, Michael was informed of the nature of scientific models, and of how scientific knowledge changes over time. The pre-course RFN questionnaire and pre-course interview responses indicated that Michael was especially informed of the socioinstitutional NOS. In terms of beliefs about the importance of teaching NOS, Michael at the beginning of the course believed it was important to teach NOS because teaching NOS can help with creating scientists, critical thinking skills, it can get students excited about learning science, and found it important to increase student's awareness of the relationship between science and society, in the context of climate change taking place. At the end of the course, his beliefs about the importance of teaching NOS were more multi-faceted. After the course, Michael's reasons for teaching NOS focused on how to prepare students to interact with science in society when making decisions on science-related issues, and that embodying the aims and values of science was important morally. When Michael taught his lesson at the end of the semester, he included a significant amount of NOS both in planning and in enactment.

Michael's lesson revolved around the socio-institutional NOS, specifically addressing the subcategories of financial systems, social values, and social organizations. The content ideas that were targeted were the effects of oil spills and the consequences of biodiversity loss, and the lesson was planned for a high school biology class. Michael explicitly planned to teach NOS, as illustrated by two of his stated learning goals below:

1. Explore the relative costs associated with cleaning up an oil spill, describe the impact of cost on decision-making to clean up oil spills, and explore and evaluate alternative oil spill cleaning strategies and their merits based on costs and benefits.
2. Students will be able to describe and evaluate the pros and cons of real-life decisions related to the environment.

Michael's lesson began with asking students what they knew about British Petroleum (BP) and showed a video showcasing the 2010 BP leak in the Gulf of Mexico. Then, students were asked how they think this could impact marine life.

Michael incorporated the RFN category of scientific practices in his lesson. He provided students with a short article about oil spills and their effects on the coastal environment (Dell'amorein, 2010), as well as 6 figures, three data tables, and charts from a scientific article about the benefits and limitations of different solutions to oil spills (Al-Majed et al., 2012). Using these resources, students were asked to complete the table on their handout (figure 4) and answer three guiding questions: "(1) What evidence have you found that demonstrates the consequences of an oil spill on Marine Life in general?, (2) What are the solutions provided to address these issues?, and (3) If so, does the data you collected support their ideas? Explain." This engaged students directly in analyzing and interpreting data, a science practice (NRC, 2011).

Environmental Impacts	Cleanup Methods	Associated Costs	Limitations of Method

Figure 4:Table from Michael's Handout

Michael also incorporated the socioinstitutional subcategory social values in his lesson. Throughout the lesson, students were learning about and considering the environmental impacts of oil spills. After students had completed their tables, they were asked to share their results while Michael summarized pros and cons of different solutions on the whiteboard. This prompted one of the students to ask, "who is paying for all this cleanup?", and Michael replied, "that's the funny part, is it the government or the companies? BP is a company that didn't step up, and the government had to step in at a certain point, but the question remained, did they do a good enough job?" Michael's response emphasizes both the environmental and economic costs at play in the situation, and the need to act against environmental wrongdoing.

At the end of Michael's lesson, he instructed each student to complete a 5 question exit ticket, consisting of one true/false question, three multiple choice questions, and, in his words as seen in the lesson plan, "one free-response question inquiring about the nature of science and the role data has in society relative to environmental concerns".

> Free Response: In the real world, scientists have to gather data, conduct experiments, and construct arguments for or against certain methods about societal responses to environmental problems. When considering which strategies to utilize, what factors can affect the decision-making process that government officials or independent companies have regarding Oil Spills? Minimum 10 Word Response.

This NOS question can be classified as divergent, as no particular perspective is specified within the question. Divergent NOS questions tend to yield highly descriptive results (Voss et al., 2021) and have potential to reveal misconceptions.

Cross-Case Analysis

There were similarities and differences in the cases of Ben, Valentina, and Michael. This section will compare and contrast the preservice teachers' changes in NOS views, changes in beliefs about the importance of teaching NOS, and NOS teaching. These will be addressed in terms of three major areas: (1) changes in views about NOS, (2) expansion of beliefs about the importance of teaching NOS, (3) RFN categories in NOS teaching.

Changes in Views about NOS

When considering the change in subscores representing each category of RFN, the majority of NOS views related to each category were improved at the end of the course for Ben, Valentina, and Michael.

Table 5. Preservice Teachers' Changes in NOS Views According to the RFN Questionnaire

RFN Category	Ben			Valentina			Michael				
	Pre-Course	Post-Course	Change	Pre-Course	Post-Course	Change	Pre-Course	Post-Course	Change	Number of Items	Maximum Score
Aims and Values	30	30	0	22	27	+5	26	27	+1	7	35
Scientific Practices	51	52	+1	47	50	+3	54	48	-6	13	65
Scientific Methods	28	39	+11	29	33	+4	33	39	+6	9	45
Scientific Knowledge	32	39	+7	33	36	+3	36	39	+3	9	45
Social-institutional aspects	60	58	-2	59	63	+4	76	74	-2	16	80
Educational applications	62	68	+6	61	65	+4	70	73	+3	16	80

Table 5 displays the changes in each preservice teachers' NOS views related to each RFN category, and a 6th category, educational applications, which measures how preservice teachers considered the teaching aspects of RFN. All three preservice teachers' scores in the categories of scientific practices, scientific methods, and educational applications increased during the course. Both Michael and Ben scored lower in the socioinstitutional aspects category after the course. Michael's score also decreased in the scientific practices category after the course. There was no change between Ben's pre- and post-course score in the aims and values category. Unlike Ben and Michael, Valentina's scores increased in every category.

Expansion of Beliefs about the Importance of Teaching NOS

At the beginning of the course, Ben, Valentina, and Michael all believed teaching NOS was important, for reasons that overlapped in some areas and were unique in others. The three preservice teachers were more strongly convinced about the importance of teaching NOS at the end of the course and provided deeper rationales in their post-course interviews, but these rationales seemed to take different positions about why it is important to teach NOS.

Through the course, Ben developed a democratic argument for teaching NOS that was deeply rooted in the need for citizens to make sense of socioscientific issues and participate in the decision-making process at the end of the semester. He mentioned both climate change and the Covid-19 vaccine in his post-interview, stating that the interaction between society and science is complex and dependent on "how much society trusts science". Ben described that the ability to recognize what is science and what is not science or what is pseudoscience affects the public trust for science, and that there is a dangerous "snowball" effect in which society continues to develop a deeper distrust in science. Ben stated that he wanted his students to be able to differentiate between what is and what is not science, and to develop critical thinking skills in what he called the “correct” way, which was not them saying that “I don't trust the mainstream. I'm going to go to the fringe theory”.

Like Ben, Michael also developed a strong democratic argument for teaching NOS, believing that it was essential for students to develop the understandings needed to evaluate credentials of a knowledge provider, and of the knowledge provided. He wanted students to be able to “come to their own conclusions” when it came to making decisions on their own about what to do with scientific information. When asked what he wanted his students to know about NOS, Michael replied that he really wanted to “hammer in the whole honesty aspect”, and that scientists embody values such as honesty and accuracy. Michael wanted to teach his students that "[scientists] have been peer reviewed multiple times, have lots of credited sources, and of course the statistical data and research methods are accurate and ethical” so that students would develop the grounds to have confidence in scientific knowledge. Like Ben, Michael described the public distrust in science, saying that “people that can use that [scientific] knowledge can either choose to do something about it or not do something about it”. Michael described how popular opinions and beliefs of society can change how data is interpreted, i.e., "they will look at a study...a definitive study showing you that vaccines do not in fact, cause autism, and yet they will go, ‘okay, but I don't believe you.’” This statement emphasizes Michael’s belief that teaching NOS is important to develop a public understanding of science. Valentina did not make this same argument.

Valentina also developed a stronger belief in the importance of teaching NOS, but her argument remained mainly utilitarian, in that NOS was important because understanding NOS is necessary for practical reasons, i.e., “if people are to make sense of the science and manage the technological objects and processes they encounter in everyday life." (Driver et al., 1996, p. 16). Valentina fervently believed that learning NOS would benefit students on a personal level, saying "maybe, if we understand science better, and we allow our students to, maybe they could learn to love science and feel like they can do it". This is different than Ben and Michael, whose reasons were more tied to benefiting society as a whole. Valentina really wanted students to understand that science is not just a "hard thing that only specific people can do" and believed that teaching NOS would help communicate that. She described for herself that there were many obstacles in pursuing a STEM major and believed that if she would "humanize science a little bit by talking about the scientists and understanding the process", this would help eliminate barriers for her students. After the course, Valentina listed many reasons for teaching NOS that would help students, such as that learning the "economic side" of science would help the outside of the classroom, and that engaging in a roleplay about economic injustice would help them understand abstract concepts more deeply. Valentina was focused on ensuring that students saw themselves represented in scientists and said that she wanted to bring in guest scientists from around the community with diverse backgrounds similar to her students. Her passion for wanting students to love and feel capable of doing science was the dominant reason for her belief in the importance of teaching NOS, unlike Ben and Michael.

RFN Categories in NOS Teaching

The lessons taught by Ben, Valentina, and Michael at the end of the course shared certain aspects of RFN by targeting aspects within the scientific practices and socioinstitutional NOS categories of RFN. However, they varied in how explicitly and reflectively these aspects were taught.

All three preservice teachers taught aspects within the socio-institutional NOS, specifically the social values subcategory. Ben and Valentina both primarily touched on social values by directly explaining to the class how the content is related to the aim of addressing human needs. The social values of science were a focal point of Michael's lesson. He emphasized, as he stated in his lesson plan, "the economic costs of solutions, weighed against the environmental cost of inaction." He did so explicitly and reflectively by embedding contextualized NOS questions into his lesson.

All three preservice teachers included scientific practices in their lesson. In Ben's lesson, he implemented station activities that engaged students in carrying out investigations, using models, analyzing and interpreting data, constructing explanations, and designing solutions. The activities themselves were implicit means of teaching about scientific practices, but Ben also included explicit-reflective instruction on this category through the assessment question he wrote that had students explain what scientific practices they practiced during the lesson, and why. Michael's lesson involved students analyzing and interpreting data, engaging in arguments from evidence, and obtaining, evaluating, and communicating information. Language associated with these practices were explicitly stated in class and on student handouts during Michael's lesson, but students did not reflect on how these practices are the major activities of scientists and how their engagement in them is similar or different to how science is done.

While all preservice teachers integrated the RFN categories of scientific practices and the social values in their lessons, there was variation in how explicitly and reflectively these aspects were addressed. Both Ben and Michael included explicit-reflective NOS questions in their lesson materials. Valentina's lesson included the most implicit and least reflective instruction of scientific practices, as she instructed students to develop a physical model of an angiosperm but did not refer to this as a model or discuss the role of models such as that in science. Michael and Valentina did embed scientific practices in their lessons but did not require students to explicitly reflect on the practices like Ben did. In terms of explicitly addressing the socioinstitutional NOS during their lessons, Michael did so through his assessment questions. Ben showed a video and then posed a question to the class that caused students to reflect on how the aim of addressing human needs related to his content. Valentina provided an explanation of how society is dependent on pollination but did not pose any reflective questions to the class.

In the following chapter, themes across the findings and their implications will be discussed.

CHAPTER FIVE: DISCUSSION AND CONCLUSION

The purpose of this multiple case study was to explore the ways in which secondary preservice science teachers' views of NOS based on RFN and beliefs about the importance of teaching NOS change through a science methods course guided by RFN, and how these views and beliefs relate to their NOS teaching at the end of the course. In this chapter, themes across the findings will be discussed and the findings will be connected to the literature, highlighting specific contributions this study makes to existing gaps in NOS teacher education. The implications of this study as well as its limitations will be presented. Finally, this chapter will make recommendations for future research.

Discussion

Changes in preservice teachers' views of NOS

Improved Views of NOS. Overall, Ben's, Valentina's, and Michael's views about NOS based on RFN improved from before to after the science methods course guided by RFN. After the course, they were able to describe a more sophisticated understanding of aims and values, scientific methods, scientific practices, scientific knowledge, and the socioinstitutional NOS. For example, in her post-course interview, Valentina referenced the historical short story she created for the course assignment, which was about environmental activists, including Hazel Johnson and Rachel Carson, in describing how creating equal opportunities are values of science and important to social justice. While prior to the course all preservice teachers believed there was one universal scientific method, after the course they demonstrated knowledge of a diversity of scientific methods both in the RFN questionnaire and in the post-course interviews, selecting 'totally disagree' or 'disagree' for the statement "There is a universal scientific method that all scientists use all over the world." All preservice teachers were able to describe more scientific practices at the end of the course compared to in the beginning. For example, while Ben identified using mathematics and communication with other scientists as scientific practices in his pre-course interview, he elaborated in his post-course interview to include other practices such as planning investigations, recording observations, and communicating with different types of audiences. Additionally, all preservice teachers' scores on the scientific knowledge category of the RFN questionnaire increased from before to after the course. A more sophisticated understanding of the final category, socioinstitutional NOS, was displayed in preservice teachers' post-course interview results. For example, Ben and Valentina both discussed political power systems within science only in their post-course interview and not in their pre-course interview. The finding that NOS views based on RFN were overall improved is consistent with Cullinane & Erduran (2022), who found that an RFN workshop improved preservice secondary science teachers views of NOS. The finding also echoes Kaya et al. (2019), who found that an RFN based intervention significantly improved preservice secondary science teachers views of NOS in the RFN categories of aims and values, scientific methods, scientific practices, and the socioinstitutional NOS.

After the course, Ben, Michael, and Valentina had an improved understanding of scientific practices as evidenced by their post-course interviews, in which they each described several of the scientific practices outlined by the NGSS. For example, before the course, Michael described scientific practices as "what I assume scientists do is they enter a sort of scientific journal discourse, and they'll go and read other people's research on research that they know something about, and they will either corroborate their findings or go, huh! That's interesting, and maybe start their own research in their own experiment, and then they'll publish something." In his post-course interview, Michael identified the scientific practices of asking questions and defining problems, analyzing and interpreting data, developing and using models, using math and computational thinking, and again, obtaining, evaluating and communicating information. The present finding that preservice teachers' understanding of scientific practices increased is inconsistent with Kaya et al.'s (2019) findings, as in their study, preservice teachers' understanding of scientific practices stayed the same. It can be noted that in Kaya et al. (2019), preservice teachers had already been exposed to scientific practices in a previous course and thus had informed views in this category at the start of the course. The present study's finding that understanding of scientific practices improved among preservice teachers is also inconsistent with Erduran & Kaya (2018), who found that preservice teachers struggled to understand scientific practices after an RFN workshop incorporating visual tools, such as the Benzene Ring Heuristic. This might be because the course for the present study may have taken a different approach to conceptualizing the scientific practices category, because while the Benzene Ring Heuristic was introduced like in Erduran & Kaya (2018), the primary teaching of scientific practices was within the context of the NGSS (NGSS Lead States, 2013), due to this being a dominant force shaping curriculum and practice in the United States. It is possible that the scientific practices of the NGSS are easier for preservice teachers to understand than the more philosophical conceptualization of scientific practices presented by Erduran & Dagher (2014). Future research may investigate how these conceptualizations impact preservice teachers' understanding of this category.

Views Resistant to Change. Ben, Michael, and Valentina held misconceptions about the roles of and relationship between theories and laws, but Ben and Valentina expressed accurate views at the end of the course. For example, in her pre-course interview, Valentina said that theories are “supported by lots of evidence, but it's not as high up as a law”. Then, in her post-course interview, Valentina explained of scientific theories and laws, “the most important thing is that that neither one is more reliable or accurate than the other.” However, Michael’s understanding about the lack of a hierarchical relationship between theories and laws within the scientific knowledge category did not improve during the course. The idea that theories are less empirically supported than laws is a widespread belief (McComas, 2020). According to Michael’s post course interview, Michael still incorrectly believed laws were more “empirically based” than theories. This did not align with his post-course questionnaire response of ‘disagree’ to the statement “Laws are more verifiable scientific knowledge than theories.” The difficulty found in changing Michael’s views of this aspect aligns with Mesci & Schwartz (2017), who found that the theories and laws aspect of NOS is harder to change than other aspects.

Inconsistencies Between Questionnaire and Interview Results. Although there were some decreases for the specific category score revealed in the questionnaire data for Ben and Michael’s cases, interview data showed positive increases for the preservice teachers’ views of those categories. For example, Both Ben and Michael’s score on the socioinstitutional aspects of NOS decreased by 2 at the end of the course according to the RFN Questionnaire. That result was inconsistent with Ben and Michael’s interview responses, which indicated a more sophisticated understanding of the socioinstitutional NOS, making connections to all subcategories in that category. The finding that the interview and RFN Questionnaire results did not align is unlike Kaya et al. (2019), as in their study, researchers found consistency between interviews and RFN Questionnaire data. The present study echoes the findings of Azninda & Sunarti (2021), who identified a potential gap between quantitative and qualitative NOS views using the RFN Questionnaire and interviews, stating in their study that “Despite getting high scores in the Socio-Institutional Aspect category, teachers have not been able to provide good explanations and examples.” The present study showed the opposite, in that their scores on the socioinstitutional aspect category decreased, while interview responses contained highly informed explanations and examples. It is possible that the RFN Questionnaire was reductive in terms of presenting preservice teachers’ views of NOS, which can be explored more in-depth using a case study.

Development of beliefs about the importance of teaching NOS

Science Learning and Utilitarian Arguments Pre-Course. At the beginning of the course, preservice teachers identified reasons to support their belief in why teaching NOS is important, and these beliefs fell under either the science learning or utilitarian argument, or both. The pre-course interview responses revealed that preservice teachers did believe it was important to teach NOS, because it can get students excited about science (i.e., the science learning argument) and that understanding NOS is practical (i.e., the utilitarian argument). For example, Ben said in his pre-course interview, “it's always going to be more useful for understanding if you know the basic nature of science principles.” This initial reasoning that learning NOS would be useful for students in their lives was not particularly guided. Prior to the course, both Valentina’s and Michael’s reasons for teaching NOS was that it would support students in science learning, and these reasons were primarily affective in nature, as both preservice teachers believed that NOS would help students feel excited and motivated to learn science. These findings echo Bell et al. (2016), who found that the most common rationale for teaching NOS reported by preservice teachers was that it improves science content understanding. These findings also align with Wan & Wong (2016), who found that teachers were more sensitive to different values of NOS instruction that were relevant to learning science within the classroom.

Beliefs Deepened During the Course. Over the course of the semester, Ben, Valentina, and Michael developed deeper beliefs in the arguments they had initially stated for why it is important to teach NOS. For example, Valentina was able to list more persuasive reasons as justification for her belief that teaching NOS would support students in learning science. In her pre-course interview, Valentina stated, “I want them [students] to understand that science is not just like oh, knowing the definition of this big fancy science word, there's a lot more to science and each one of them could do it if they wanted to.” In her post-course interview, Valentina described specifically that the act of humanizing science by teaching about NOS, talking about science as a process, and showing that people from all types of backgrounds are scientists, can help students understand science as a whole concept and be more confident in learning science. In the study by Kruse et al. (2017), researchers also found that the preservice teacher who believed teaching NOS would help all students view science as accessible, particularly groups underrepresented in the sciences, also expressed this rationale again at the end of a methods course. It is possible that this argument is especially relevant and motivating to some preservice teachers when considering why it is important to teach NOS.

Beliefs Expanded During the Course. All three preservice teachers were able to further elaborate on why it is important to teach NOS, describing new types of arguments that were not stated initially. At the end of the course, Ben developed a democratic argument for teaching

NOS, and Michael developed a moral argument for teaching NOS. For example, in his post-course interview, Ben explained "being able to have the society have some trust in science at the very least, is important because the alternative to not trusting science is just lull." This quote illustrates his development from believing NOS is important for students in the classroom, to believing NOS is important for society. Additionally, all preservice teachers communicated an intention to teach NOS at the end of the course. This positive finding aligns with the findings of Kruse et al., (2017), who found that preservice teachers' NOS rationales become more multifaceted and transcend classroom learning with extended exposure to NOS and NOS pedagogy ideas. Like Mulvey & Bell (2017) and Bell et al., (2016), the preservice teachers in the present study expressed multiple rationales that moved beyond affective reasons to teach NOS, such as cultivating scientific ethos in students (Wan & Wong, 2016).

Differences in Changes of Beliefs. While both Ben and Michael developed arguments that moved beyond the immediate value that NOS has for teaching and learning in the science classroom, Valentina's main reason for teaching NOS at the end of the course remained that it would support students in science learning. For example, in her post-course interview, she stated, "I feel like understanding the nature of science would help settle some anxieties and help kids feel like they could do it." Similarly, Mulvey & Bell (2017) found all but one participant planned to teach NOS for reasons beyond student engagement and enjoyment.

NOS Teaching After a NOS Methods Course Guided by RFN

NOS in End of Course Lessons. Whereas Ben, Valentina, and Michael did not have well-developed ideas about how to teach NOS prior to the course, mostly believing that NOS could be taught implicitly, by the end of the course, all preservice teachers planned a lesson that addressed NOS in the context of a disciplinary idea. For example, Ben chose to integrate the scientific practices category of RFN in his lesson properties of water, Michael chose to integrate the socioinstitutional NOS into a lesson on the environmental consequences of oil spills, and Valentina chose to integrate the socioinstitutional NOS into a lesson on pollination. Unlike Abd-El-Khalick (2005), where the translation of participant preservice teachers' acquired NOS understandings following NOS instruction into instructional planning related to NOS was minimal, Ben, Valentina, and Michael planned for NOS instruction. This can likely be attributed to the fact that NOS was explicitly stated as a requirement for the assignment in which preservice teachers created and taught a lesson plan. All preservice teachers incorporated aspects of the scientific practices and the socio-institutional NOS in their teaching. Ben and Michael, and to a lesser extent Valentina, did not seem to have difficulty teaching the social aspects of science. For example, Michael included an explicit-reflective question in his lesson materials for students to consider how costs and benefits impact decision making when it comes to cleaning up oil spills. The finding that the preservice teachers integrated the socioinstitutional NOS in their lessons is different from Voss et al. (2023) and Cullinane & Erduran (2022), who found that preservice teachers had difficulty teaching the socioinstitutional NOS. Georgiou (2022) speculated that preservice teachers' instruction of the socio-institutional NOS might be underdeveloped compared to the cognitive-epistemic categories of NOS because preservice teachers tend to have a limited understanding of the social aspects of science (Georgiou, 2022). This study might be different because the preservice teachers did have sophisticated understanding of socioinstitutional NOS at the end of the course. However, this study's findings did align partly to Voss et al. (2023), because when planning for socioinstitutional NOS, preservice teachers tended to take a topic approach whereas the inner ring (i.e., scientific practices) was more embedded, as seen in Ben and Valentina's implicit inclusion of modeling within their lessons.

Explicit-Reflective NOS Teaching. Two preservice teachers, Ben and Michael, both included explicit and reflective NOS questions in their lessons. For example, Ben included the question, "What scientific practices do you think you practiced today? Why?" Like Abd-El-Khalick (2005), when Ben and Michael's lesson plans included objectives targeting science process skills, such as designing experiments and testing hypotheses, these preservice teachers included questions or explicit statements that alerted students to the NOS-related ideas. The findings of the present study echo those of Voss et al. (2023), who found that preservice teachers tended toward an implicit approach to NOS instruction and shifted to an explicit-reflective approach at the end of a methods course guided by RFN. Additionally, in alignment with Lotter et al.'s findings (2009), both Michael and Ben were successful at incorporating NOS ideas regarding observation verses inference, and the importance of detailed data collection processes in science. During their post-course interviews, Ben and Michael both described how they would teach NOS explicitly and reflectively. For example, Michael said in his post-course interview when asked what type of discussion questions he would use with his students, "Well, they need to be explicit if they're nature of science questions, which I want to have at least one in every assignment." Ben explained that he would use a mix of explicit and implicit NOS instruction, and when asked how the explicit teaching may look, he replied, "I guess one way it could look like it's just…you know, scientists come from different backgrounds. What backgrounds can scientists come from? Explain." This is an example of an explicit-reflective NOS question he wrote for the historical short story course assignment. These positive changes in the preservice teachers' beliefs and practice of NOS teaching brings further support to Lotter et al. (2009) claim that explicit modeling of NOS teaching and practice creating instructional materials are important to gradually build capabilities to teach NOS. Additionally, Lotter et al. (2009) also found that coursework within a science methods course, combined with practicing teaching NOS during the course, helped move preservice secondary science teachers toward effective, explicit-reflective NOS teaching. Like Voss et al. (2023), in the present study, the preservice teachers mostly described and utilized activities that they had experienced themselves in the methods course.

Differences in NOS Planning and Instruction. Despite all preservice teachers having accurate views of NOS and beliefs in the importance of teaching NOS, there were differences in how much NOS instruction they enacted in their lesson. While Ben and Michael addressed NOS explicitly and reflectively, Valentina's NOS teaching was more implicit. Like Lotter et al. (2009) who found that the teachers' enactment of NOS teaching was still a work in progress, with some groups reverting to PowerPoint notes to cover most of the content standard, Valentina relied heavily on videos and a worksheet to cover her chosen content standard at the expense of including NOS. This echoes other findings (Abd-El-Khalick, 2005; Cullinane & Erduran, 2022), that indicate not all participants were able to transition to teaching NOS explicitly. Unlike Ben and Michael, Valentina did not discuss teaching NOS explicitly or reflectively when asked how she would teach NOS. Instead, she described implicit approaches such as having students act out NOS. For example, in her post-course interview, Valentina said, "So maybe kind of putting this idea of like environmental injustice, kind of like the abstract concept a little bit, and then, like putting it into that activity, and like having them by acting it out." This echoes the findings of Herman et al. (2017), who found that the level at which preservice teachers understand effective NOS pedagogy is associated with their level of effective NOS instruction. In Kruse et al. (2017), of the participants who were enrolled for the first time in a course covering NOS like those in the present study, the preservice teachers were all able to describe more accurate NOS views after the course, but only some preservice teachers gained an understanding in the effectiveness of the explicit-reflective framework for teaching NOS. Echoing the findings of Herman et al. (2017), Michael and Ben, who implemented NOS at a higher level, expressed a greater utility value for NOS education, and a stronger understanding of explicit-reflective NOS instruction, compared to Valentina. This might be attributed to Michael and Ben having beliefs for the importance of NOS teaching that relate to specific far-reaching outcomes beyond the classroom, such as a public that trusts science. This brings further support to Herman et al.'s claim that valuing NOS in a general sense does not automatically translate into implementing NOS instruction and improving NOS teaching. While Valentina valued NOS instruction and had accurate views of NOS at the end of the semester, this was not especially reflected in either her planning for or enactment of NOS instruction.

Limitations

Some limitations in this study are to be acknowledged. Although a multiple case study is a time intensive methodology and contributes rich insight into the phenomena under investigation, this study examined three preservice teachers in one science methods course, and thus has limited transferability to theoretical propositions and other preservice teacher populations. A second limitation concerns the fact that this data did not investigate the relationship between the course design and preservice teacher outcomes. Such an investigation could have provided valuable insights regarding how aspects of the course supported preservice teachers' NOS views, beliefs in the importance of NOS, and NOS teaching. Additionally, even though the researcher was careful to interpret the results from the perspective of a researcher, they were also the sole instructor of the course.

Because there was no measure of teaching at the beginning of the semester, it was not possible to relate the change in teaching to the change in views or beliefs about the importance of NOS. This information would have been useful to see if and how changes in these three areas develop synergistically. Preservice teachers taught their lessons to their peers as it was not possible to observe preservice teachers teaching secondary students. A more authentic context to practice NOS instruction could influence the approaches preservice teachers take to teaching NOS. Lastly, it is unknown whether and for how long preservice teachers will maintain the views, beliefs, and NOS teaching demonstrated at the end of the semester without following up.

Conclusion and Implications

This study provides promising evidence that it is possible to improve preservice teachers' views about NOS, deepen and expand their beliefs about the importance of teaching NOS, and prepare them to teach NOS explicitly and reflectively during a science methods course guided by RFN. The preservice teachers in this study displayed more accurate and holistic understanding in each RFN category after the course. They gained a higher justification for why they believe it is important to teach NOS. At the end of the course, they created a lesson plan that included NOS, and in two cases, taught NOS explicitly and reflectively.

This study contributes to the field as other studies who have investigated how preservice teachers develop their NOS views guided by RFN did not investigate how preservice teachers' views of NOS were related to their NOS teaching (Kaya et al., 2019; Cullinane & Erduran, 2022; Erduran & Kaya, 2018). Understanding how NOS views based on RFN and NOS teaching interact provides meaningful information about the factors that influence NOS instruction. Additionally, this study contributes to an emerging line of research investigating preservice and inservice teachers' beliefs in the importance of teaching NOS, how beliefs in the importance of teaching NOS can change during a science methods course, and how these beliefs may relate to what preservice teachers choose and choose not to teach about NOS. This study helps to address a gap in the literature because while many studies (Voss et al., 2023; Erduran & Kaya, 2018, Cullinane & Erduran, 2022, Abd-El-Khalick, 2005) offer glimpses into preservice teachers' NOS teaching through their stated pedagogical views or written lesson plans, there is a need to observe the enactment of NOS teaching. This is important because intentions to teach NOS do not necessarily translate into effective NOS instruction (Lederman, 1999).

Implications for Research

This study contributes to the emerging literature that uses RFN as a conceptual framework to guide preservice and inservice teacher courses, workshops, and professional developments. Further research is needed to evaluate the usefulness of this NOS conceptualization in teacher education. Future research should also explore how preservice teachers develop accurate views of scientific practices and if a difference in conceptualization of scientific practices impacts the changes in preservice teachers' views of this category. Future research should investigate how preservice teachers' explicit-reflective NOS teaching develops during a methods course by measuring it before and after the course.

Implications for Science Teacher Education

This study also provides further empirical support for the need to explicitly include opportunities for preservice teachers to develop the accurate views, rationales for teaching, and effective pedagogy for NOS, if they will be expected to teach NOS once entering the classroom. Courses with these learning outcomes should be required elements of a secondary science teacher education programs, rather than offered as elective coursework. Even though some NOS views were more resistant to change, and one preservice teacher did not teach NOS explicitly and reflectively, these difficulties can inform future methods course design to support preservice teachers in these areas. More opportunities to plan for and enact explicit-reflective instruction should be embedded into teacher education coursework. For example, assignments such as the curriculum material production based on a discovery from the history of science, which required preservice teachers to embed explicit-reflective NOS questions. Because preservice teachers often refer to the NOS activities and teaching strategies, they experience themselves in their methods course, preservice teachers may need more opportunities to develop their own NOS instructional material types during their teacher education courses. Addressing NOS ideas explicitly and reflectively should be made a clear requirement of science teacher lesson plans written as coursework, since this increases the possibility, but does not guarantee, that the lesson will include NOS.

APPENDIX A: IRB APPROVAL LETTER

UNIVERSITY OF CENTRAL FLORIDA

Institutional Review Board
FWA00000351
IRB00001138, IRB00012110
Office of Research
12201 Research Parkway
Orlando, FL 32826-3246

EXEMPTION DETERMINATION

January 10, 2023

Dear Kelsey Beeghly:

On 1/10/2023, the IRB determined the following submission to be human subjects research that is exempt from regulation:

Type of Review:	Initial Study, Initial Study
Title:	Development of Preservice Secondary Science Teachers' Views, Beliefs, and Teaching of NOS During a Science Methods Course Based on RFN
Investigator:	Kelsey Beeghly
IRB ID:	STUDY00005014
Funding:	None
Grant ID:	None
Documents Reviewed:	• Beeghly HRP-251- FORM - Faculty Advisor Form_SU GAO.pdf, Category: Faculty Research Approval; • Interview Protocol, Category: Interview / Focus Questions; • List of Variables, Category: Other; • RFN Questionnaire, Category: Survey / Questionnaire; • SCE4933 Course Calendar, Category: Other; • Scenario Based Questions, Category: Test Instruments; • Study 5014 Consent, Category: Consent Form; • Study 5014 Protocol, Category: IRB Protocol

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made, and there are questions about whether these changes affect the exempt status of the human research, please submit a modification request to the IRB. Guidance on submitting Modifications and Administrative Check-in are detailed in the Investigator Manual (HRP-103), which can be found by navigating to the IRB Library within the IRB system. When you have completed your research, please submit a Study Closure request so that IRB records will be accurate.

APPENDIX B: INTERVIEW PROTOCOL

Purpose: Explore preservice secondary science teachers' views of NOS, beliefs about the importance of teaching NOS, and their ideas about how to teach NOS.

Interview goals	**Possible questions and probes**	**Notes**
Overview/ Explanations	• Thank you for meeting with me today • The purpose is to understand more about how you see NOS, and what you know about teaching NOS, so I can make decisions about how to structure our class.	Purpose and nature of interview
1. Establish Rapport	***Tell me, what does "the nature of science" mean to you?*** • What do you mean by "_______"	Establishing friendly tone and conversation Probe misconceptions

RFN Categories	• Aims and values
	  ○ "What are the aims of science?"
	  ○ "For scientists to do this…What values does a scientist need to have?"
	• You've probably heard the phrase "scientific method". What does this mean to you? …. Are there other ways to do science or is this the only way?
	• Science practices
	  ○ What main types of things do scientists do?
	• What is scientific knowledge based on?
	  ○ What is the difference between scientific theories and scientific laws?
	  ○ Did you ever use or create a model in science class? Can you give me an example of a scientific model? What is a scientific model?
	  ○ How does scientific knowledge grow? Does it ever change?
	• "Is science affected by society? How?"
	• "Is society affected by science? How?"
		Probe to see what views are on each category

2a. Grand Tour	***What do you want your future students to understand about the nature of science?*** • How much do you think students should be expected to know about the nature of science? • Do you think it's important for students to know that? Why or why not?	Overview of their beliefs about teaching NOS
2b. Follow one of	***Tell me more about that reason / strategy...***	Explore an idea

the ideas mentioned in the grand tour		mentioned in previous answer
4. Wider lens	***Have any events or experiences impacted your ideas about why it is (or isn't) important to teach NOS?*** • What does teaching NOS look like in your future classroom?	If uncertain, ask what contributes to that uncertainty
3. Looking for ways to characterize experience	***What experience do you have in teaching NOS ideas?*** • Tell me about your NOS teaching experience (such as during internship) • Was it relatively difficult or easy to teach NOS? Did students understand? • How confident are you in teaching NOS?	Focusing in on experience and confidence level
9. Concluding invitation	***Is there anything you would like to add?***	Wait for a few seconds after asking
10. Parting	***Thank you so much for talking with me***	Let appreciation be known

APPENDIX C: COURSE READINGS AND DISCUSSION POST QUESTIONS

Assigned Readings	Discussion Post Questions
McComas & Clough, 2020 (pp. 3-10)	1. What does the expression “nature of science” mean? 2. How do we know what the nature of science is, and how do we decide what to teach about the nature of science?
Continuum: Selecting Inquiry-Based Experiences to Promote a Deeper Understanding of the Nature of Science (Banner, 2008) Erduran & Dagher (2014) chapter 2, sections 2.1 and 2.4	1. What does effective NOS teaching look like? (Be sure to note the 4 key features from the article). 2. Summarize what you learned about the Family Resemblance Approach (FRA) model and its educational applications.
Erduran & Dagher (2014) chapter 3	1. What are the aims and values of science? 2. Do you think scientific aims and values can be promoted in science lessons? If yes, how? 3. Where in the (state) NOS standards can you see evidence of aims and values? 4. Do you think it is important for students to learn about the aims and values of science? Why or why not?
Erduran & Dagher (2014) chapter 4 Appendix F (NGSS)	1. "The primacy of “science-as-knowledge” has been challenged since the 1970s with increasing attention devoted to “science-as-practice” (Erduran & Dagher, 2014, p. 68). In your personal experience as a student in K-12 and now undergraduate science education, which ideal (if any) has been the curricular emphasis? Did it differ as you progressed through school/different teachers? 2. What are scientific practices, generally? 3. What are the 8 science practices outlined in the Next Generation Science Standards? 4. Why is it important for students to both learn about and engage in science practices? Quote and/or reference the rationales stated throughout chapter 4 and Appendix F in your response.
Erduran & Dagher (2014) chapter 5	1. Referring to chapter 5, what are the limitations of the lock-step "scientific method"? 2. Also referring to chapter 5, what are the varieties of scientific methods that scientists use to collect data, and that can be explored in school science?

	3. Where in the (state) NOS standards can you see evidence of scientific methods? 4. Why is it important for students to learn about the diversity of scientific methods?
Erduran & Dagher (2014) chapter 6	1. Referring to chapter 6, what functions and roles do theories, laws, and models play in the development of scientific knowledge? 2. What are the disciplinary variations in theories, models, and laws in science? 3. Where in the (state) NOS standards can you see evidence of scientific knowledge? 4. Based on your own opinion and what you read in the text, what example features of scientific knowledge are important to promote in science teaching and learning, and why?
Erduran & Dagher (2014) chapter 7	1. Chapter 7 includes two reasons for the inclusion of the social dimension of science in science education, and two assumptions behind advocating the teaching and learning of science as a social-institutional system - in your own words, what are these reasons and assumptions? 2. For each social category, write one sentence to represent what is meant/embodied by that category, from a classroom perspective: (1) Professional Activities, (2) Scientific Ethos, (3) Social Certification and Dissemination, (4) Social Values of Science, (5) Social Organizations and Interactions, (6) Political Power Structures, (7) Financial Systems. 3. According to the text, "Components of science as a social institutional system are essential in understanding science and thus should be made more visible in the science curriculum". After reading the chapter, what initial ideas do you have on how to include these components while teaching in your subject area?
	1. After watching your teaching video, write one thing you notice about your teaching that you think you did well and one thing you notice that you think you could improve upon. Be specific. 2. Provide at least two timestamps and explain how in those moments, you were teaching some aspect of the nature of science. Use quotes of yourself in your response. 3. Reflecting on the semester, how do you feel about teaching the nature of science to your future students (excited, apathetic, motivated, scared, annoyed, etc.) and what assignments/experiences from the semester contributed the most to this overall feeling? (you can be honest!)

APPENDIX D: IN CLASS ACTIVITIES

Aims and Values. In the first class session covering the aims and values of science, preservice teachers were asked to use sticky notes to write down as many aims and values as they could and post them on a board at the front of the room. Next, the class list was compared to the one in the book (Erduran & Dagher, 2014), discussing similarities and differences.

As Erduran & Dagher explain, "while one of the values in science upholds the ideal of neutrality, strict adherence to scientific methods does not eliminate all bias because other values are at play at different phases of inquiry" (Wilholt, 2009 in Erduran & Dagher, 2014, p. 44). Therefore, to further understand the complex role of bias, preservice teachers watched a brief video in which Astrophysicist Neil deGrasse Tyson, speaking at the University at Buffalo, answers a student's question about the role bias plays in science. Preservice teachers then discussed in response to a prompt that asked how it can be made clear that personal beliefs and public opinions are not the factors that decide the validity of scientific discovery. Next, preservice teachers identified which of the educational applications of aims and values from Erduran & Dagher (2014, p. 52) were highlighted in the video. Preservice teachers then completed the Bengal Tiger activity (Erduran & Kaya, 2020) which includes explicit-reflective questions to guide students toward the scientific aims of equality, objectivity, and addressing human needs. Preservice teachers reflected on how this activity could be used or adapted to use with their future students and what may be the benefits or limitations of such an activity.

In the second session on aims and values, the class explored an example in the history of science that illustrates the significance of aims and values of science. The specific case study used was the history of lead use, shown through the video "The Man Who Accidentally Killed The Most People In History" (Muller, 2022), during which students took notes on any instances of scientific aims and values. After the video, preservice teachers discussed what aims and values Kettering failed to uphold, what the consequences were, and how the outcome for society may have been different if Kettering had upheld the aims and values of science. Preservice teachers also discussed in what ways Clair Patterson did uphold the aims and values of science, and the positive results of doing so. At the end of the session, the following quote was shared as a final note on aims and values of science: “If someone doesn’t value evidence, what evidence are you going to provide that proves they should value evidence. If someone doesn’t value logic, what logical argument would you invoke to prove he should value logic?” (Erduran & Dagher, 2014, p. 57).

Scientific Practices. In the first session on scientific practices, preservice teachers engaged in a science practices circus activity (California Academy of Sciences, 2016) to introduce them to the science practices of the NGSS. In this activity, preservice teachers visited hands-on stations with sample activities and tried to identify the main practice highlighted in each one. Before the stations, preservice teachers were asked as a group to take two minutes and write down as many verbs they could think of that describe what scientists do. Next, they were instructed to categorize those verbs under the 8 science practices. After the stations, the class discussed which practices they had engaged in and reflected on how the experience impacted their understanding of scientific practices. Next, preservice teachers completed an activity called States of Football, adapted by the researcher from the States of Rugby activity (Erduran & Kaya, 2022).

States of Football: Modeling the structure of matter!

Matter is anything which occupies space and has mass. Matter may exist as a solid, liquid, or gas. These are known as the states of matter. The properties of each state of matter are described in the following football example.

A HUDDLE • The players are fused together tightly • Players are fused into a definite shape • The huddle shape is difficult to compress into a smaller shape • The huddle shape has a definite volume • Since players have restricted movement, they have limited energy as moving particles 	**A BALL SNAP** • When the ball is "snapped", players move together • Players move together but have no definite shape • When the ball is "snapped", players move together as one line to give the shape with a definite volume • Players are free to move together which gives them some energy as moving particles 	**AN INTERCEPTION** • Players are free to run in any direction to any area on the field • Players' random movement gives no definite shape • When the players run close together, their shape can be compressed • The random movement of players means that they do not have a definite volume • Players are free to move in all directions which gives them lots of energy as moving particles 
TASK: Classification Match the State of Football to the state of matter: A huddle Gas A ball snap Liquid An interception Solid	**Task: Modeling** Models are used to represent science concepts but all models have limitations. 1. Can you identify the strengths of this model? 2. Can you identify the limitations of this model? 3. Develop your own model to represent the three states of matter. (Answer on back)	Remember the word **model** has a different meaning in the science class. Here we mean the representation of an idea, an object, or even a process that is used to describe and explain phenomena that cannot be experienced directly. Explain how the "states of football" is a **model** for a scientific concept.

Figure 5: States of Football Activity

After reading and completing the tasks, preservice teachers shared their responses and discussed which scientific practice(s) were being developed through the task, and how models like this might help students make sense of scientific concepts.

For the second session on scientific practices, instead of meeting for class, preservice teachers attended the local county middle and high school science fair and served as judges, interviewing students about their projects and assisting in making decisions about which students would advance to the next round. When the class next met, preservice teachers discussed which practices students were engaging in and how, which practices they noticed students struggle in or engage in improperly, and how teachers can provide scaffolding or supports for students to engage in science practices more authentically.

Scientific Methods. In the first session on scientific methods, preservice teachers engaged in an argumentation task in which they were placed in two groups and had five minutes to develop an argument for the claim that was assigned to them, being either "All science disciplines use the same stepwise methods. There is one universal scientific method." or "All science disciplines do not use the same stepwise methods. Each discipline uses a different method." After both groups shared their arguments, preservice teachers read a case study about Luis Alvarez (UC Berkeley, 2007) that was written to highlight that the process of science is non-linear, unpredictable, and ongoing. Afterwards, preservice teachers were shown a flowchart (figure 6) meant to emphasize the non-linear nature of scientific methods and were asked to relate what they read in the story to the flowchart and why or why not the pathway of all scientists might be the different or the same.

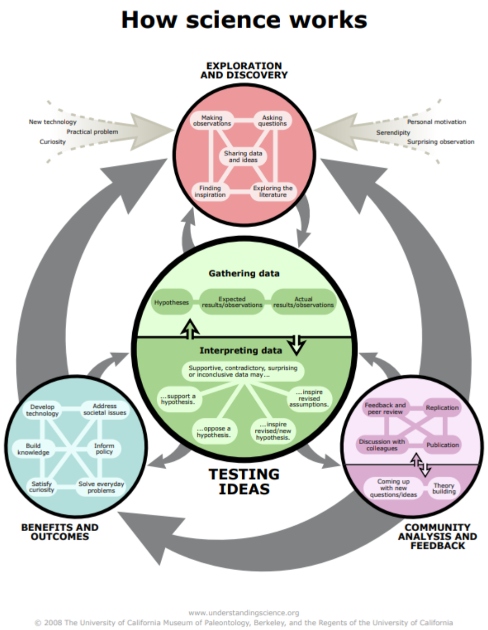

Figure 6: How Science Works Flowchart

Source: UC Berkeley, 2008

The class was shown a video showcasing another case of diversity in scientific methods (Ocean Leadership, 2014), using an example from an expedition to sea of the International Ocean Discovery Program. Next, preservice teachers were asked "How does the flowchart and what you saw in the video differ from the Scientific Method that we tend to see in most textbooks?".

Preservice teachers then completed an instructional task called the scientific methods activity (from Erduran and Kaya, 2019, p. 92) and reflected on what they think this task is intended to highlight in terms of scientific methods, and how they could incorporate tasks like this into teaching any specific science topic in their content area. Next, preservice teachers explored Brandon's Matrix and other visual representations of the diversity of scientific methods (Erduran & Dagher, 2014, p. 101). Preservice teachers were shown the NGSS progression of the

NOS understanding that ”scientific investigations use a variety of methods” from K-2 up to high school. Lastly, the class revisited one of the claims earlier, that “All science disciplines use the same stepwise methods. There is one universal scientific method.” and discussed how it was false and why it is so persistently made.

In the second session on scientific methods, preservice teachers practiced classifying different types of investigations (descriptive, comparative, and experimental). They took notes on how investigation types can differ (i.e., in purpose, whether they have a hypothesis, if they have independent or dependent variables, if they have a control group). Then preservice teachers engaged in a Kahoot and a card sort that had them practice choosing a type of methodology based on the scientific question being asked. Lastly, preservice teachers completed an example instructional activity created by the instructor using a plant growing virtual simulation that allowed them to control variables and make measurements, designed to help students understand the principles of experimental design. Preservice teachers reflected on the benefits and limitations of using this activity with students, and why it is important for students to understand experimental design.

Scientific Knowledge. In the beginning of the first session on scientific knowledge, preservice teachers were asked to what extent they agree or disagree with the statement, “If a hypothesis is supported it becomes a theory, and if a theory is proven it becomes a law.” Next, preservice teachers were shown a Ted Ed YouTube video comparing scientific theories and scientific laws (TED-Ed, 2015), and asked to revisit the statement from earlier to rate their extent again. Preservice teachers completed a card sort in which they classified statements that either applied to theories, laws, or both. After the card sort, the instructor led the class in creating a three column T chart on the board (theory, law, both) to compare and contrast theories and laws based on the characteristics they had sorted. Then, preservice teachers corrected 6 common misconceptions about scientific theories and laws by being shown the statement on the board and individually writing the corrected statement on their white boards.

The next part of class focused on scientific models, with students reflecting on what type of models they remember engaging with or developing in science class, what are different types of scientific models (i.e., physical, conceptual, mathematical). There was a discussion on the ways in which scientific models vary by discipline, while maintaining a common purpose of representation. Preservice teachers were introduced to T-L-M as forms of scientific knowledge, using the meta-tool developed by Erduran & Dagher (2014).

The class then completed the theories-laws-models and paradigm shift task (from Erduran & Kaya, 2019, pp. 94–95), in which they observed and compared theories, laws and models in biology, chemistry, and physics, before brainstorming more theories, laws and models, and categorizing them. Lastly, preservice teachers reflected on how theories, laws, and models have very specific meanings and functions within science.

Socioinstitutional NOS. The first session on the socioinstitutional NOS began with preservice teachers reading the introduction of a study in which the discovery of the structure of DNA was used to illustrate cultural aspects of science (Dai & Rudge, 2018, p. 1). Preservice teachers were then asked to reflect on where they may have heard the names of the scientists associated with the discovery of DNA structure (James Watson, Francis Crick, Maurice Wilkins, and Rosalind Franklin), and what they know about them. Preservice teachers were introduced to the flowchart below.

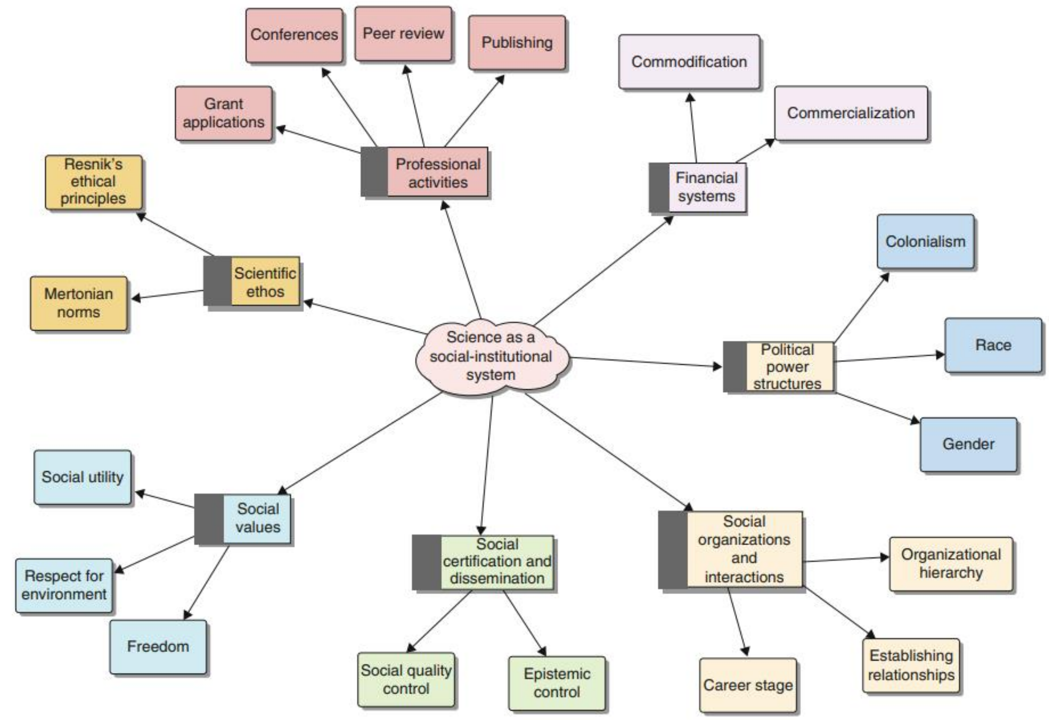

Figure 7: Science as a social-institutional system and its categories

Source: Erduran & Dagher, 2014, p.

Then, while watching the documentary The Secret of Photo 51, they took notes on examples from the flowchart that related to instances of the case. After watching and sharing what they noted with their classmates, preservice teachers reflected on questions (see Dai & Rudge, 2018) to explore the episode from an ethical perspective.

In the second session on the socioinstitutional NOS, preservice teachers read the rest of the study (Dai & Rudge, 2018) looking at an accompanying modeling DNA activity, the learning objectives, assessment, and conclusion. They also discussed the application of other FRA categories to the context of DNA discovery. For a second instructional example, preservice teachers read the short story “Tea for Two” (Ampatzidis & Ergazaki, 2021), which is a historical narrative about Charles Darwin and Joseph Dalton Hooker written to illustrate the socio-cultural embeddedness of science, specifically “that scientific research is influenced by the beliefs, values, and expectations of the society” (p. 48). Lastly, preservice teachers reflected on the explicit-reflective NOS questions written by Ampatzidis & Ergazaki (2021) to accompany a reading of the narrative (see Ampatzidis & Ergazaki, 2021).

REFERENCES

American Association for the Advancement of Science. (1990). *Science for all Americans*. Oxford University Press.

American Association for the Advancement of Science. (1994). *Benchmarks for science literacy*. Oxford University Press.

Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers’ views and instructional planning. *International Journal of Science education*, *27*(1), 15-42.

Abd-El-Khalick, F. (2014). The evolving landscape related to assessment of nature of science. In *Handbook of Research on Science Education, Volume II* (pp. 635-664). Routledge.

Abd-El-Khalick, F., & Lederman, N. G. (2000). Improving science teachers' conceptions of nature of science: A critical review of the literature. *International journal of science education*, *22*(7), 665-701.

Akerson, V. L., Abd-El-Khalick, F., & Lederman, N. G. (2000). Influence of a reflective explicit activity-based approach on elementary teachers' conceptions of nature of science. *Journal of Research in Science Teaching, 37*(4), 295-317.

Akerson, V. L., Buzzelli, C. A., & Donnelly, L. A. (2010). On the nature of teaching nature of science: Preservice early childhood teachers' instruction in preschool and elementary settings. *Journal of Research in Science Teaching*, *47*(2), 213-233.

Akerson, V. L., Pongsanon, K., Park Rogers, M. A., Carter, I., & Galindo, E. (2017). Exploring the use of lesson study to develop elementary preservice teachers' pedagogical content knowledge for teaching nature of science. *International Journal of Science and Mathematics Education*, *15*(2), 293-312.

Akgun, S., & Kaya, E. (2020). How do university students perceive the nature of science?. *Science & Education*, *29*(2), 299-330.

Ashton, P. T. (2014). Historical overview and theoretical perspectives of research on teachers' beliefs. In H. Fives & M.G. Gill (Eds.), *International handbook of research on teachers' beliefs* (pp. 31-47). Routledge.

Azninda, H., & Sunarti, T. (2021, February). Teachers' Views about Nature of Science (NOS) Using Reconceptualised Family Resemblance Approach to Nature of Science (RFN) Questionnaire. In *Journal of Physics: Conference Series* (Vol. 1747, No. 1, p. 012019). IOP Publishing.

Bell, R. L., Lederman, N. G., & Abd-El-Khalick, F. (2000). Developing and acting upon one's conception of the nature of science: A follow-up study. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *37*(6), 563-581.

Brandon, R. (1994). Theory and experiment in evolutionary biology. *Synthese*, *99*, 59–73.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs, Co: BSCS*, *5*, 88-98.

Cheung, K. K. C., & Erduran, S. (2022). A Systematic Review of Research on Family Resemblance Approach to Nature of Science in Science Education. *Science & Education*, 1-37.

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education*, *15*(5), 463-494.

Clough, M. P. (2018). Teaching and learning about the nature of science. *Science & Education*, *27*(1), 1-5.

Clough, M. P., & Olson, J. K. (2004). The nature of science: Always part of the science story. *The Science Teacher*, *71*(9), 28.

Cofré, H., Núñez, P., Santibáñez, D., Pavez, J. M., Valencia, M., & Vergara, C. (2019). A critical review of students' and teachers' understandings of nature of science. *Science & Education*, *28*(3), 205-248.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage.

Cullinane, A., & Erduran, S. (2022). Investigating Pre-Service Teachers' Understanding of Nature of Science: Contributions of An Assessment Tool Based on the Reconceptualized

Family Resemblance Approach. *Interdisciplinary Journal of Environmental and Science Education*, *18*(4), e2290.

Dagher, Z. R., & Erduran, S. (2016). Reconceptualizing the nature of science for science education. *Science & Education*, *25*(1), 147-164.

Dai, P., & Rudge, D. (2018). Using the discovery of the structure of DNA to illustrate cultural aspects of science. *The American Biology Teacher*, *80*(4), 256-262.

Driver, R., Leach, J., & Millar, R. (1996). *Young people's images of science*. McGraw-Hill Education.

Duschl, R. A., & Wright, E. (1989). A case study of high school teachers' decision making models for planning and teaching science. *Journal of research in science teaching*, *26*(6), 467-501.

Erduran, S. (2014). Beyond Nature of Science: The Case for Reconceptualising" Science" for Science Education. *Science Education International*, *25*(1), 93-111.

Erduran, S., & Dagher, Z. R. (2014). Reconceptualizing nature of science for science education. In *Reconceptualizing the nature of science for science education* (pp. 1-18). Springer.

Erduran, S., & Kaya, E. (2018). Drawing nature of science in pre-service science teacher education: Epistemic insight through visual representations. *Research in Science Education*, *48*(6), 1133-1149.

Erduran, S., Kaya, E., Cullinane, A., Imren, O., & Kaya, S. (2020). Practical learning resources and teacher education strategies for understanding nature of science, In W. F. McComas (Ed.). *Nature of Science in Science Instruction*(pp. 377–397). Springer.

Faikhamta, C. (2013). The development of in-service science teachers' understandings of and orientations to teaching the nature of science within a PCK-based NOS course. *Research in Science Education*, *43*(2), 847-869.

Frey, B. B. (Ed.). (2018). *The SAGE encyclopedia of educational research, measurement, and evaluation*. Sage Publications.

Georgiou, H. (2022). Preservice Teachers' Views of the "Social Embeddedness" Tenet of the Nature of Science: A New Method of Analysis. *Journal of Science Teacher Education*, 1-19.

Hanuscin, D. L. (2013). Critical incidents in the development of pedagogical content knowledge for teaching the nature of science: A prospective elementary teacher's journey. *Journal of Science Teacher Education*, *24*(6), 933-956.

Hanuscin, D. L., Lee, M. H., & Akerson, V. L. (2011). Elementary teachers' pedagogical content knowledge for teaching the nature of science. *Science education*, *95*(1), 145-167.

Herman, B. C., Clough, M. P., & Olson, J. K. (2013). Teachers' nature of science implementation practices 2–5 years after having completed an intensive science education program. *Science Education*, *97*(2), 271-309.

Herman, B. C., Clough, M. P., & Olson, J. K. (2017). Pedagogical reflections by secondary science teachers at different NOS implementation levels. *Research in Science Education*, *47*(1), 161-184.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & education*, *20*(7), 591-607.

Irzik, G., & Nola, R. (2014). New directions for nature of science research. In *International handbook of research in history, philosophy and science teaching* (pp. 999-1021). Springer.

Kampourakis, K. (2016). The "general aspects" conceptualization as a pragmatic and effective means to introducing students to nature of science. *Journal of Research in Science Teaching*, *53*(5), 667-682.

Kaya, E., & Erduran, S. (2016). From FRA to RFN, or how the family resemblance approach can be transformed for science curriculum analysis on nature of science. *Science & Education*, *25*(9), 1115-1133.

Kaya, E., Erduran, S., Aksoz, B., & Akgun, S. (2019). Reconceptualised family resemblance approach to nature of science in pre-service science teacher education. *International Journal of Science Education*, *41*(1), 21-47.

Khishfe, R., & Abd-El-Khalick, F. (2002). Influence of explicit and reflective versus implicit inquiry-oriented instruction on sixth graders' views of nature of science. *Journal of*

Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, *39*(7), 551-578.

Kim, B. S., Ko, E. K., Lederman, N. G., & Lederman, J. S. (2005). A developmental continuum of pedagogical content knowledge for nature of science instruction. In *International Annual Conference of the National Association for Research in Science Teaching. Dallas, TX (April 4-7)*.

Kruse, J. W., Easter, J. M., Edgerly, H. S., Seebach, C., & Patel, N. (2017). The impact of a course on nature of science pedagogical views and rationales. *Science & Education*, *26*(6), 613-636.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of research in science teaching*, *29*(4), 331-359.

Lederman, N. G. (1999). Teachers' understanding of the nature of science and classroom practice: Factors that facilitate or impede the relationship. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *36*(8), 916-929.

Lederman, N. G., & Lederman, J.S. (2014). Research on teaching and learning of nature of science. In *Handbook of research on science education, volume II* (pp. 614-634). Routledge.

Lederman, N.G., Lederman, J.S., & Antink, A. (2013). Nature of science and scientific inquiry as contexts for the learning of science and achievement of scientific literacy. *International Journal of Education in Mathematics, Science and Technology, 1*(3), 138-147.

Lee, H., & Witz, K. G. (2009). Science teachers' inspiration for teaching socio-scientific issues: Disconnection with reform efforts. *International Journal of Science Education, 31*(7), 931-960.

Liang, L. L., Chen, S., Chen, X., Kaya, O. N., Adams, A. D., Macklin, M., & Ebenezer, J. (2008, June). Assessing preservice elementary teachers' views on the nature of scientific knowledge: A dual-response instrument. In *Asia-Pacific Forum on science learning and teaching* (Vol. 9, No. 1, pp. 1-20). The Education University of Hong Kong, Department of Science and Environmental Studies.

Lotter, C., Singer, J., & Godley, J. (2009). The influence of repeated teaching and reflection on preservice teachers' views of inquiry and nature of science. *Journal of science teacher education*, *20*(6), 553-582.

Luft, J. A. (1999). Teachers' salient beliefs about a problem-solving demonstration classroom in-service program. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *36*(2), 141-158.

Mansour, N. (2009). Science teachers' beliefs and practices: Issues, implications and research agenda. *International Journal of Environmental and Science Education*, *4*(1), 25-48.

McComas, W. F. (1996). Ten myths of science: Reexamining what we think we know about the nature of science. *School Science and Mathematics*, *96*(1), 10-16.

McComas, W. F. (1998). The principal elements of the nature of science: Dispelling the myths. In *The nature of science in science education* (pp. 53-70). Springer, Dordrecht.

McComas, W. F., & Clough, M. P. (2020). Nature of science in science instruction. In *Nature of Science in Science Instruction Rationales and Strategies* (pp. 3-22). Springer.

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. In *The nature of science in science education* (pp. 3-39). Springer, Dordrecht.

McComas, W. F., Clough, M. P., & Almazroa, H. (2002). The role and character of the nature of science in science education. *The nature of science in science education: Rationales and strategies*, 3-39.

McComas, W. F., Clough, M. P., & Nouri, N. (2020). Nature of science and classroom practice: A review of the literature with implications for effective NOS instruction. *Nature of science in science instruction: Rationales and strategies*, 67-111.

Mesci, G., Çavuş-Güngören, S., & Yesildag-Hasancebi, F. (2020). Investigating the development of pre-service science teachers' NOSI views and related teaching practices. *International Journal of Science Education*, *42*(1), 50-69.

Mesci, G., & Schwartz, R. S. (2017). Changing preservice science teachers' views of nature of science: Why some conceptions may be more easily altered than others. *Research in Science Education*, *47*, 329-351.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Sage.

Muller, D. [Veritasium]. (2022, April 22). The Man who Accidentally Killed the Most People in History. [Video]. YouTube. https://www.youtube.com/watch?v=IV3dnLzthDA&ab_channel=Veritasium

Mulvey, B. K., & Bell, R. L. (2017). Making learning last: teachers' long-term retention of improved nature of science conceptions and instructional rationales. *International Journal of Science Education*, *39*(1), 62-85.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press.

Nouri, N., Saberi, M., McComas, W. F., & Mohammadi, M. (2021). Proposed teacher competencies to support effective nature of science instruction: A meta-synthesis of the literature. *Journal of Science Teacher Education*, *32*(6), 601-624.

Nouri, N., & McComas, W. F. (2021). History of science (HOS) as a vehicle to communicate aspects of nature of science (NOS): Multiple cases of HOS instructors' perspectives regarding NOS. *Research in Science Education*, *51*(1), 289-305.

National Research Council. (1996). *National science education standards*. National Academies Press.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Pajares, M. F. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of educational research*, *62*(3), 307-332.

Patton, M. Q. (1990). *Qualitative evaluation and research methods*. SAGE Publications, inc.

Piliouras, P., Plakitsi, K., Seroglou, F., & Papantoniou, G. (2018). Teaching explicitly and reflecting on elements of nature of science: A discourse-focused professional development program with four fifth-grade teachers. *Research in Science Education*, *48*(6), 1221-1246.

Reinisch, B., & Fricke, K. (2022). Broadening a nature of science conceptualization: Using school biology textbooks to differentiate the family resemblance approach. *Science Education*.

Schwartz, R. S., & Lederman, N. G. (2002). "It's the nature of the beast": The influence of knowledge and intentions on learning and teaching nature of science. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *39*(3), 205-236.

Shamos, M. H. (1995). *The myth of scientific literacy*. Rutgers University Press.

Thomas, G., & Durant, J. (1987). Why should we promote the public understanding of science? Scientific Literacy Papers, edited by M. Shortland (Oxford: Department of External Studies), pp. 1-14.

Verma, G., Campbell, T., Melville, W., & Park, B. Y. (2020). Science teacher education in the times of the COVID-19 pandemic. *Journal of Science Teacher Education*, *31*(5), 483-490.

Voss, S., Kent-Schneider, I., Kruse, J., & Daemicke, R. (2023). Investigating the development of preservice science teachers' nature of science instructional views across rings of the family resemblance approach wheel. *Science & Education*, 1-37.

Wan, Z. H., & Wong, S. L. (2016). Views from the chalkface: Values of teaching nature of science in Hong Kong. *Science & Education*, *25*, 1089-1114.

Ward, G., & Haigh, M. (2017). Challenges and changes: developing teachers' and initial teacher education students' understandings of the nature of science. *Research in Science Education*, *47*(6), 1233-1254.

Williams, B., Kruse, J.W., Clough, M.P., Stanley, M., & Kerton, C. Data makes sense only in light of theory the story of cosmic microwave background. Story Behind the Science. https://www.storybehindthescience.org/_files/ugd/790356_38cb8551dcfd4b1a8dde6023bf50167d.pdf

Wittgenstein, L. (1958). *The blue and brown books* (Vol. 34). Blackwell.