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Nature of Science Conceptions and Identity Development among Science Education Doctoral Students: Preparing NOS Teacher Educators

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Abstract

Research on Nature of Science (NOS) conceptions and identity development for NOS contains a gap in the realm of examining doctoral students aiming to be science teacher educators. This research examines the NOS identity development of participants in a course focused on the philosophy of science and research about NOS education. The data analyzed for this study were recordings and notes taken during class discussions in a NOS seminar, as well as NOS research and teaching assignments associated with the course. These data sources were analyzed for development of four influences on identity development for NOS: 1) personal influences on NOS identity, 2) contextual influences on NOS identity, 3) competing identities with NOS, and 4) persistence in overcoming barriers to development of a NOS identity. Findings emphasize the need to target NOS identity development among teacher educators, as they hold the primary responsibility for instilling a NOS identity in their own students, who are future teachers.

Introduction

Understanding of Nature of Science (NOS) is considered to be a major component of developing scientific literacy (Lederman, 2007), and thus should be considered a necessary outcome of science education. NOS identity refers to educators who have developed a professional identity as someone who not only understands NOS, but can also teach NOS to others (Akerson et al, 2015). In light of the importance of NOS, teachers and researchers have sought to effectively implement NOS in science education at all levels, from early childhood (Akerson, Buck, Donnelly, Nargund, & Weiland, 2011) to university science, both undergraduate and graduate (Koksal & Koksal, 2012; Desaulniers Miller et al., 2017). Despite the wide variety of demographics previous NOS research has focused on, there are few studies examining the NOS conceptions of science education doctoral students. The future role of many science education doctoral students is the role of a science teacher educator, holding the primary responsibility for educating future science teachers about NOS. The purpose of this study was to examine the NOS identity development and NOS conceptions of science education doctoral students from a wide variety of backgrounds. More specifically, the following research questions guided this study:

1. What are the NOS conceptions of science education doctoral students at the beginning of a seminar focused on NOS teaching and learning, and how do those conceptions change by the end of the seminar?

2. How do the varied backgrounds and experiences of science education doctoral students intersect with their NOS identity development in a NOS-based doctoral course?

Although there is not an agreed upon single definition of NOS, these are key aspects that are less controversial and are accepted by scientists, historians, and philosophers and considered as most practical in school settings, and useful in developing scientific literacy for students K-12 (Bell, 2009; Lederman, 1992; Lederman, 2007; Lederman et al., 2002; Lederman et al., 2013). These aspects are as follows: science is 1) tentative, 2) empirical, 3) creative and imaginative, 4) subjective, 5), socially and culturally embedded, 6) not limited to one universal scientific method, and 7) grounded in theories and laws, whose differences are important. Though participants in this study come from a variety of international contexts, we chose to ground in the NGSS-aligned view of NOS because each of the participants is learning to teach in the United States.

Theoretical Framework

It is vital that we as science teacher educators continue to explore the complexities of science teacher identity development. Zembal-Saul (2016) offers that there is a lack of clear definitions associated with science educator identity. Additionally, Kelly (2012) speaks to the deficiency of studies focused on science educator identity that expose cultural experiences where cultural practices afford opportunities but limit potential future identity development. Further, Mensah (2016) challenges the lens of science teacher identity through the intersectionality of race and cultural experiences. When dealing with science educators' identity development, we have to consider the complexities of the teacher. They can be reformed and shaped throughout their careers. This aspect of science teacher identity is foundational to this study, as participants come from a variety of social and cultural backgrounds.

Regarding NOS identity, research has been conducted to develop a framework to identify whether teachers have developed a professional identity as someone who not only understands NOS, but can also teach NOS to others (Akerson et al, 2016; McClain et al., 2022). These characteristics of the individuals include personal and contextual influences, as is noted as important by Beijaard et al (2004). This framework discusses personal factors and overcoming barriers to teaching NOS as aspects of NOS identity, but as we did not follow participants into their actual practice (necessary for examining the influence of these aspects), they are not discussed. Contextual influences and competing identities with NOS were those most prevalent in the data, as they could be discussed and examined without examining actual teaching practice.

Contextual influences include influences beyond the scope of the individuals themselves, but still influence their identities. Support from others is a strong contextual influence, as individuals who are in situations where they are not supported or discouraged from teaching NOS may struggle with developing a NOS identity, as they will question the importance of it. However, those who have support through socially mediated means generally are able to develop a NOS identity. This support can take place through professional development programs, coursework, or communities of practice, for example.

Competing identities could either strengthen or inhibit development of NOS identity. For example, if an individual strongly holds an identity that includes science making progress through controlled experiments via "the scientific method," this individual may find conflict with aspects of NOS, such as science being contextualized in a social and cultural context. This individual may grapple with these discrepancies and it could slow the development of NOS identity. However, if an individual holds an understanding that knowledge itself is contextualized in social and cultural context, they may find relief in learning that scientific knowledge also develops within such a context (and not isolated in a method). This can ease the conflict the individual has with the aforementioned competing identities.

Literature Review

Because participants were doctoral students with backgrounds in science and science education, this review focuses on the NOS conceptions of graduate students. Also addressing identity aspects of developing teacher educators, the existing literature on NOS identity is discussed.

Graduate Conceptions of NOS

Previous research has been conducted on NOS instruction at the graduate level. Graduate students' understanding of NOS was addressed as early as 1997, with Eichinger and colleagues development of a NOS course for science education graduate students. Grounding in their craft knowledge of teaching NOS, the authors discuss the importance of future science teacher educators having a developed understanding of NOS in order to facilitate scientific literacy in their own students (future teachers).

The NOS conceptions of graduate researchers in the hard sciences were examined by Koksal and Sahin (2013). They analyzed questionnaires (VNOS, version C) of graduate researchers from several scientific fields, in order to determine the effectiveness of simply participating in science when it comes to developing conceptions of NOS. They found the participants had expert conceptions on the social and cultural embeddedness of science, and the creative nature of science. However, they showed naive understanding of the hierarchy of theories and laws, and mixed understandings of subjectivity, tentativeness, and the idea that there is not one universal scientific method. The authors conclude that simply participating in science is not sufficient to develop NOS understanding. They recommend explicit-reflective NOS instruction at the graduate level.

Sumranwanich and Yuenyong (2014) examined the conceptions of NOS and attitudes toward teaching NOS of masters students in science education. The course these students were enrolled in engaged them in explicit-reflective NOS instruction grounded in inquiry lessons. They used the Views on Science and Education (VOSE) questionnaire (Chen, 2006) to examine their views of each tenet of NOS, and their attitudes toward teaching NOS. After participating in a course employing explicit-reflective inquiry-based NOS activities, participants displayed mixed conceptions of NOS. Despite these mixed conceptions, however, the majority of participants held positive attitudes toward teaching NOS, particularly the tentative and subjective NOS. However, they also displayed value for teaching one scientific method, rather than the variety of methods reflecting actual scientific practice.

Explicit-reflective methods were also employed by Wheeler and colleagues (2019) in their instruction of STEM graduate students in a higher education course focused on NOS. The course was targeting graduate students in STEM who are often assigned to teach undergraduate science courses. Using the VNOS-C, researchers found NOS conceptions among participants improved substantially from pre- to post-course, especially when it came to the tentative NOS and the hierarchy of theories and laws. Perhaps the most impactful finding was the increased intention to teach NOS from the participants, specifically with explicit-reflective instruction.

NOS Identity

Teacher educator identity development is a critical area of study, as individual teachers are complex, ever-changing, and grounded in individual social and cultural backgrounds (Mensah, 2016). This remains the case as attention is turned specifically to an identity for NOS. This study is framed in NOS identity (Akerson et al, 2015), focused on personal and contextual influences on NOS identity, competing identities with a NOS identity, and overcoming barriers to developing a NOS identity.

Research has shown that even young science students can develop an identity for NOS. In a study of third graders learning about gravity, Akerson et al (2019) found connecting to real-life experiences, discussions as a class, and connecting to other science concepts were all supportive of students' NOS identity development. Development of an identity as a teacher of NOS has been shown to be less than straightforward. As present in the NOS identity framework grounding this study (Akerson et al, 2016), developing a NOS identity requires balancing a variety of personal factors (emotions as identity is formed and reformed) and contextual factors (administrative pressures, time constraints). This characteristic was found in a self-study on NOS identity development conducted by Akerson et al (2015). Ultimately, the development of a NOS identity required balancing a variety of sometimes conflicting sub-identities. Even once one has developed an identity for NOS, it requires continual work to maintain and continue in the development of a professional identity teaching NOS.

Research has examined the intersection of science identity and NOS understanding (Avraamidou & Schwartz, 2021; Celik, 2020; Elcan Kaynak, Akerson, & Cevik, 2020); El Takach & Yacoubian, 2020). Conceptions of NOS will shape individuals' ideas about who can or cannot be a scientist, or who is allowed to participate in science. Embracing a subjective and diverse view of NOS allows for disruption of the traditional view of who a scientist is (white male). Emphasizing the socially and culturally embedded NOS also allows individuals to see themselves as science people, developing a science identity, and more specifically a NOS identity.

Development of a NOS identity does not rely solely on an understanding of NOS, but also individual factors such as beliefs and backgrounds. In a study of the impact of NOS understanding on sociopolitical scientific disagreements, researchers found participants' political and religious views were predictive of whether they would accept scientific claims. However, regardless of political and religious affiliation, individuals with a greater understanding of how science works were more likely to accept scientific claims (Weisberg et al., 2021). What each of these studies shows is that personal factors outside of scientific understanding alone influence development of one's NOS identity. Individual cultures, backgrounds, experiences, and religious/political affiliations will influence how one perceives NOS. It is with these influences in mind that we examine the development of a NOS identity for developing science teacher educators from a variety of backgrounds.

Method

We use phenomenology as our epistemological framework. Phenomenology rejects that the external world and facts exist independently. Instead, it argues that knowledge is consciously constructed by each individual in interpreting their immediate experience (Groenewald, 2004). Such immediate experiences that are used in constructing knowledge consciously are the "phenomena" (Eagleton, 1983, p.55). In qualitative research, phenomenology can be used to study people's conscious experience of their world; that is, their "everyday life and social action" (Schram, 2003, p.71). Researchers who apply phenomenology in the study are concerned with "understanding social and psychological phenomena from the perspectives of people involved" (Welman & Kruger, 1999, P.189). Phenomenology is appropriate to this study because the purpose of this study is to understand the phenomena of a group of doctoral students' experience of understanding NOS during a course. Phenomenology requires that researchers be aware of their own positionality, beliefs, and assumptions while gathering data that can reflect the perspectives of the participants (Hammersley, 2000). In this study, we use discourse analysis and content analysis as our methods. As we are both researchers and participants, we make our own understanding explicit while analyzing data to get the essence and underlying NOS conceptions and identity development of the doctoral students. Specifically, the components of NOS identity development were used as codes and themes to analyze data sources to further understand participant NOS conceptions and identity.

Context and Participants

The context was a semester-long doctoral seminar with a focus on NOS. The goals were two-fold: to develop doctoral students' ideas about NOS so they can be prepared to teach it, and to establish a foundation in philosophy of science to be able to distinguish philosophy of science more generally from classroom-adapted NOS. It is of note that NOS was defined according to the consensus view presented above, focusing on the agreed-upon aspects most relevant at a K-12 level (Bell, 2009).

Course readings about philosophy of science were anchored in Alan Chalmers book "What is this thing called science" (4th edition, 2013). Additional readings included seminal research in teaching and learning NOS providing an overview of various research trends in NOS. Student coursework included the crafting of individual NOS teaching philosophies as well as NOS lesson plan development and delivery of NOS lessons to peers in the course. Discussions at the beginning and end of the semester focused on participant responses to the VNOS-B (Lederman et al., 2002), which were critical data sources when it came to participants' NOS conceptions. Participants in this study were the doctoral students enrolled in this NOS course. The group represented a variety of backgrounds and a diversity of experiences; participants came from a variety of gender/sexual orientation, cultural, educational and career backgrounds. In light of the personal and context-laden nature of NOS identity development, it is pertinent here to include a brief description of the background of each of the participants of this study. This information is included in Table 1.

Table 1. Background Information on the Participants/authors of This Study at the Time of Data Collection

Participant	Background Information
Andrea	White American female, second year in program, undergraduate degree in biological science education, teaching experience in science labs and student teaching, experience teaching in elementary science field experience course
Shukufe	Bangladeshi female, first year in program, five years experience in non-profit educational organizations, experience in materials development promoting inquiry-based science, and teaching English in China
Qiu	Chinese female, second year in program, undergraduate degree in applied chemistry and masters degree in environmental science, five years experience in public and private high schools in China, experience teaching scientific inquiry course
Claire	White American female, second year in program, seven years experience teaching middle-school science in both suburban and urban schools, informal science education experience, experience teaching elementary science methods course
Conghui	Chinese female, first year in program, masters in ecology, three years experience in informal education, and six months in outdoor science education
Tulana	Sri Lankan gay male, first year in program, undergraduate in chemistry and physics, masters in chemistry, experience teaching undergraduate chemistry and physics
Jessica	African American female, second year in program, masters degree in biology, teaching experience four years in middle school science, experience teaching elementary science field experience course
Valarie	White American female, undergraduate in psychology, masters in elementary education, PhD in science education, professor of science education, 20 years experience teaching elementary science methods and doctoral courses, experience teaching elementary school

Data Sources

Each data source stemmed from the NOS course taken by the participants, and included 1) audio recordings of weekly class discussions about assigned readings, 2) notes from these discussions taken by the instructor (Valarie), 3) a position statement toward NOS teaching written by each participant toward the end of the semester, and 4) a lesson plan prepared by each student with the goal of teaching NOS tenets. For the purpose of brevity in reporting the source of data excerpts, the abbreviation DR indicates the excerpt comes from a discussion recording, the abbreviation NPS indicates a NOS position statement, the abbreviation IN indicates instructor notes, and the abbreviation LP indicates a prepared lesson plan. The number following the abbreviation indicates which class session is being referred to.

Data Analysis

Concepts related to NOS identity were used as *a priori* codes to apply to each of the data sources. Specifically, artifacts were broadly coded for 1) participants' value for NOS or lack thereof (related to personal factors and competing NOS identities) 2) discussion of NOS curriculum, assessment, and difficulties related to teaching NOS (related to contextual factors). Additionally, discussion of NOS content was identified to determine the development of participants' NOS conceptions over the course of the semester.

The coding process for this study varied depending on the data source. For the recordings of classroom discussions, researchers listened to the discussions, and when discussion relevant to NOS identity development or NOS conceptions, the researcher recorded the statement/conversation block, time, and the participants speaking. For written data sources (Instructor notes, NOS lesson plan, NOS position statement), researchers read the document, and blocked out areas of text relevant to NOS identity development or NOS conceptions. Each data source was coded by two researchers, who then met to reconcile their coding to reach agreement.

Results

Addressing the first research question focusing on participants' NOS conceptions, these findings will discuss participants' conceptions of NOS at the beginning and end of the doctoral seminar on NOS. Addressing the second research question on the participants' NOS identities, findings are then organized in accordance with the aspects of an identity for NOS framing the analysis: 1) contextual influences on NOS identity, and 2) competing identities with a NOS identity. The aspects of the Akerson et al. (2016) NOS identity framework pertaining to personal influences on NOS identity and overcoming barriers to teaching NOS were not included in this analysis, considering the fact that data was not gathered on participants' actual teaching of NOS–data had more reference to participants' perceived contextual influences on NOS identity, and on existing identity factors that may or may not conflict with a NOS identity.

NOS Conceptions Early in the Semester

Despite being actively involved in different roles in science education, most of the doctoral students in the course had never heard of NOS formally or informally prior to beginning the doctoral program. Claire was the exception, having taught NOS previously to her middle school students, though she never had formal training on NOS or NOS instruction (Claire, DR1). This did not exclude them from seeing the value of NOS. Andrea mentioned her views had drastically changed, and she became aware of aspects of science not previously on her radar (Andrea, DR7).

As the course progressed and participants became more familiar with NOS through readings and discussions, Shukufe doubted the role of creativity in the nature of science. Specifically, she wondered what makes creativity specific to science when all jobs are done by people and are therefore creative (Shukufe, IN4). Conghui agreed that all jobs include creativity, but scientists must be creative while still being grounded in evidence (Conghui, IN7). Questions and discussions about these ideas aided in developing understandings about NOS aspects.

When it came to the socially and culturally embedded NOS, various ideas were brought up over the course of the semester relating to emotions. Jessica, who held a strong resonance with socioculturally embedded NOS, stated that all aspects of NOS were important, despite not being taught, and that that social and cultural backgrounds would influence scientific interpretations (Jessica, DR7). Claire strongly believed that the tentative NOS should be emphasized because science changes, is emotion-driven, and is socially and culturally embedded. Qiu agreed that there is emotion in science, but that emotion is not visible in a scientific paper. She believed that the inclusion of emotion was not a weakness, but a part of the creativity of science, and partly why science is based on subjectivity (Qiu, DR4). Tulana also noted the role of subjectivity, commenting that given his background, he tends to think through the lens of chemistry, showing his realization of his own subjective understanding (Tulana, IN7)

In reference to the tentative NOS, Andrea mentioned that it may be less likely for students to notice that scientific knowledge is tentative because the scientific ideas and theories taught at the K-12 level are not likely to change (Andrea, DR7). Most scientific change occurs at the cutting edge of science, so the idea of tentative NOS needs to be pointed out to students when it comes to scientific theory. Claire noted that NOS and inquiry are connected, but that you can teach inquiry without focusing on NOS; ideas need to be pointed out to students explicitly for NOS and inquiry to be intertwined (Claire, DR1). In most if not all situations, the doctoral students addressed the need for explicit instruction of NOS concepts.

NOS Conceptions at the End of the Semester

Below, we describe some of the final ideas about NOS that were shared in the class. These final ideas came from the discussion of questions making up the Views of the Nature of Science Survey, Version B (VNOS-B; Lederman et al., 2002), and thus gave insight into participants' NOS content knowledge development. All data shared in this section come from the discussion seven recording (DR7).

Regarding the tentative NOS, at the end of the semester participants discussed question 1 of the VNOS-B on whether theories change. Andrea said that theories change based on new evidence, or new ways of thinking about the evidence we have. We need to teach theories because they're the best tools we have, and even if they might change later the changes will likely be based off of what we already had. Additionally, the theories we teach at a K-12 level are in all likelihood not going to change. Qiu agreed and said that in chemistry we still need to teach students the theories so they can learn and perhaps add to the theories. Andrea pointed to the role of theories as a means of teaching the tentative NOS. Claire agreed that teaching the tentative nature of scientific theories combats the idea of science as a set of facts. Tulana discussed that his conceptions of scientific theories have changed over the course of the semester, and shared that just because we learn new things doesn't mean we have to disagree with what we knew before. Theories just become more sophisticated, and more generalized. Conghui added that the process of theory change is very slow, and if we don't know the currently accepted theories we may not be able to do further research and know what has already been ruled out by the scientific community. Therefore, participants conceptualized that scientific knowledge can change, and yet we need to understand the current knowledge base as it is explanatory now and can help develop new knowledge.

Next, participants discussed observation and inference, specifically whether you have to "see" something to draw conclusions about a scientific idea. Andrea shared Rutherford's experiment to say that we can't necessarily see atoms, but we can infer things about them based on how we interact with them. Therefore, observations can be indirect. Qiu added that it's hard to understand things like how Newton's laws of gravity don't necessarily apply at the atomic level. Instead, we need a new way of thinking in a microscopic world. Andrea added that theoretical physicists can't see anything they are studying; all they know is based on past theories. Claire agreed, and brought up the role of technology in making things "studiable" and helping us rely on theory a little less the more technology advances. "Technology solidifies, or helps us advance, or helps us accept theory" (Claire, DR7). Therefore, participants understood that there was a relationship between observation and inferences, and how observations did not need to be direct for scientists to make reasonable inferences (and that those inferences could change.)

Regarding the distinction between scientific theory and laws, Andrea stated that laws describe what happens, theories describe why, and there may be multiple theories associated with any given law. Andrea and Qiu described how the law of gravity was a good explanatory law with no widely accepted theories. Qiu and Claire asked toward the end of the semester, when a new idea is found and stated, does it matter whether it is a theory or a law? They stated that laws have to be conditional, only applying under certain conditions. This question raised at the end of the semester may indicate that some students held continued misconceptions regarding the type of knowledge that creates scientific laws versus scientific theories.

Participants further explored the role of empirical evidence, and creativity and imagination in science. Claire stated that both art and science involve creativity; art and science are similar because of an aesthetic element, appreciating beauty in our world. Tulana shared that he thought art and science were different because art is more emotionally driven than science. Andrea, Claire, and Jessica thought that science was also sometimes emotion-driven. Qiu believed that science is portrayed as very non-emotional in research publications, which could lead people to believe that science does not include emotions. Andrea shared the idea that anywhere there is subjectivity there is emotion, and because science is partially based on subjectivity there is emotion involved. We are able to see emotion in art, but not necessarily in science. Conghui stated that science and art differ because art is personal, while collaboration is more important in science. Andrea compared art and science in the respect that both have accepted rules and conventions; what makes good art is agreed upon, and what makes good science is agreed upon. She stated that she was coming up with fewer differences between art and science than at the beginning of the semester. Claire followed up with "yeah, art can be collaborative, too" (Claire, DR7). At this point in the discussion the course instructor, Valarie, raised the question, "What about evidence? Does art require it? For me that's the main distinction. Everyone is creative, but science requires evidence for argumentation" (Valarie, DR7). Participants didn't really respond to the question, but continued talking about creativity, which could indicate a need for more emphasis on the empirical NOS.

Regarding differences between scientific fact and opinion, Andrea stated that there was a difference between fact and opinion, but science does have subjectivity in its interpretation. Qiu shared that interpretations will change based on opinion depending on what is valued. She felt this was especially true in politics, where people interpret the same data differently depending on their political view. Claire said that we can have opinions based on evidence, and opinions based on emotion. Shukufe thought that opinion comes into play when we are trying to convince others with and about scientific claims. Conghui raised a question: “We say there are different opinions from the same data, but when does this become knowledge? How do we differentiate between scientific knowledge and opinion (Conghui, DR7)? The course instructor responded “seeing it as regular opinion versus scientific opinion based on evidence. For example, vaccine fear. Regular opinion doesn’t have to have evidence, but a scientific opinion would require evidence that the vaccine works” (Valarie, DR7). Qiu stated, “couldn’t there be different scientific opinions based on the same evidence? Like the nature of light” (Qiu, DR7). Claire responded with her idea that there could be different opinions on some science like medicine--you may have your opinion on medicine but that might change when you are sick. She stated, “it’s a privileged point of view to have certain opinions when you’re healthy. Eastern medicine works for some people even where it isn’t supported by science” (Claire, DR7). This was followed by a lively discussion which included ideas about scientific evidence and subjectivity in interpreting data, indicating a growth in participants’ understanding of these ideas.

Regarding the social and cultural influences on scientific interpretations, and why scientists may make different interpretations of the same data, Claire stated that it is possible for different scientists to interpret universe data differently depending on the theory they subscribe to. Tulana elaborated, stating that different scientists have different background knowledge and ideas that come into play when interpreting the same evidence. Claire agreed, stating that an element of creativity played a role here. Qiu shared that NOS is based on a western science system, that NOS itself might vary in Eastern or African theories of the world, and that cultural background plays a role. Claire agreed, stating that there is a role for both subjectivity and sociocultural influences.

Contextual Influences on NOS Identity

Despite being actively involved in different roles in science education, most of the doctoral students in the course had never heard of NOS formally or informally prior to beginning the doctoral program. Claire was the exception, having taught NOS previously to her middle school students, though she never had formal training on NOS or NOS instruction (Claire, DR1). Though all participants had strong science backgrounds, most held no prior conceptions of the aspects of NOS addressed in the course. This did not exclude them from seeing the value of NOS. Andrea mentioned that her views had drastically changed, and that she became aware of aspects of science that had not previously been on her radar (Andrea, DR7).

During the semester, the doctoral students had a variety of readings and discussions about different aspects of NOS. As they were becoming exposed to the aspects of NOS, they raised questions regarding the meanings of some of the aspects, especially the more nuanced meanings. Prevalent in course discussions across the semester was the need for more curriculum and assessment materials for NOS instruction, and the need for improvement of what is already used. The remainder of this section is more representative of *ideas* that came out of course discussions and participant data sources than necessarily representing emergent findings. This section is divided into three further sub themes of ideas that came from data sources, focusing on 1) the lack of resources for teaching NOS, 2) the need to embed NOS explicitly in curriculum to facilitate conceptual change and understanding, and 3) the need for NOS assessments that are culturally relevant and aligned with instructional practices. Each of these ideas relate to contextual influences on NOS identity development, or things teachers may struggle with as they attempt to teach NOS.

Lack of Resources

Resources are critical for teachers to implement effective science teaching, and the resources for NOS instruction are scarce. Teachers would benefit greatly from NOS-embedded texts, trade books, activities, lesson planning ideas, and aligned assessments. The research that exists when it comes to resource development has shown some success. Andrea discussed a study examining the development of trade books to facilitate teacher learning and teaching of NOS without the need for professional development (Brunner & Abd-El-Khalick, 2020). She discussed the benefits of making NOS cross-disciplinary and more accessible to teachers, placing science in other subjects (DR1). Participants also discussed the potential benefits of software development to help teachers facilitate students' understanding of NOS (DR2).

One participant in particular, Shukufe, discussed in depth the role of curriculum, specifically textbooks, in facilitating learning of NOS. She said,

> "when such materials have been produced it will be possible to set about systematically developing students' understanding of NOS with a high probability of success. I believe that until such a time as these materials exist, one of the most important objectives of science teaching will largely fail to be achieved" (Shukufe, NPS)

Another major issue with science teaching curriculum materials is that the scientific method is still widely taught where NOS should be. Claire mentioned her experiences looking for science teaching materials in online stores, only to find there were few materials available, including a scientific method poster (Claire DR1) Jessica concurred, stating that teachers needed more resources to encourage and facilitate NOS teaching and learning (Jessica, IN1).

Explicit and Subject-Embedded NOS Curriculum

Conceptual change and understanding in science education would be enhanced with a NOS curriculum that is both explicitly taught and embedded in the subject matter. Textbooks, for example, should contain embedded NOS concepts. Shukufe again pointed out the need for instructional curriculum that mimics student ability to uptake NOS tenets (Shukufe, DR1). Shukufe, Claire, and Conghui discussed the need for materials that could be integrated with existing curricula, perhaps in the form of a NOS book or curriculum that could be used across grade levels (DR1). Some participants discussed the need for better and more curriculum materials in their position statements on NOS teaching. Conghui referred to NOS understanding of preservice teachers specifically when she said, "I believe NOS should be a part of the current curriculum and combined with science content to constantly challenge preservice teachers' view of and develop better understanding of NOS" (Conghui, NPS). Tulana discussed the benefits of a historical approach to NOS curriculum when he said, "historical evidence is a good avenue for embedding NOS into the curriculum. I am hoping to make an activity to let them understand NOS using historical evidence" (Tulana, NPS).

Creating textbooks including NOS are critical to the creation of a holistic science curriculum. The participants discussed the fact that you cannot "cookbook" NOS (in other words, go through the motions of what NOS is without effective application or critical thinking), because doing so is too surface-level and general (DR2). Shukufe elaborated on this point in her NOS position statement, stating,

> "I think textbooks are an influential component, as they greatly influence the content taught. The textbook is accepted as the ultimate source of knowledge, provides the majority of instructional support beyond the teacher, and in many cases actually becomes the curriculum" (Shukufe, NPS).

In light of the critical role textbooks play in curriculum implementation, NOS should be included in these textbooks to ensure its implementation into science instruction.

Culturally Relevant NOS Assessments

Assessment should be adequately aligned with class instruction, and take into account culturally-relevant science practices. Assessing NOS is difficult in light of the variety of cultural backgrounds that influence how science is perceived. It is also difficult to differentiate understanding from memorization without an in-depth teacher understanding of NOS and how to assess it. Indeed, teachers' confidence and PCK for NOS instruction would ideally involve deeper dives into science content and application for both themselves and their students. This kind of instruction is more difficult to assess in certain contexts, especially if the teachers themselves are unsure about the content or the application of NOS to that content. Assessment has been shown to be a limiting factor for development of PCK for NOS for elementary teachers, even if they have a strong orientation toward NOS (Akerson, Pongsanon, Park Rogers, Weiland, & Galindo, 2017). Qiu discussed NOS assessment in the scientific inquiry course she was teaching at the time of data collection, where NOS knowledge was assessed via a multiple-choice exam. After taking the NOS course, she did not feel this was the appropriate way to assess NOS in the course (Qiu, DR3)

NOS assessment needs to take into account the cultural context of those being assessed. Qiu once again brought assessment into the course discussions by discussing whether different versions of NOS questionnaires may be needed for research purposes based on differing cultural backgrounds and experiences. Valarie agreed, but mentioned the need for commonalities to allow for comparison (Valarie DR7) Participants discussed this further with the idea that NOS ideas are based on a western science system. Others around the world have different ways of thinking about science; different cultures may influence peoples' ideas about NOS. Researchers need to be careful using a western scientific approach and value system to measure against a potential different scientific approach and value system (IN7).

Competing Identities with NOS Identity

Participants in this study held different views of science education, and thus had different beliefs about NOS, due to differing background careers and cultural experiences. First-year participants from an eastern context were more hesitant when it came to embracing a NOS identity. Shukufe doubted NOS would be accepted in her context of origin, stating, "in my country we would have to convince them that knowing NOS is important" (Shukufe, IN7). Despite doubting the applicability of NOS in a Bangladeshi context, Shukufe discussed the benefit of "presenting NOS within the context of inquiries and [scientific] processes" (Shukufe, NPS). She believed the issues with NOS acceptance in an eastern context could potentially be overcome by embedding NOS in the curriculum used by teachers. "This involves restructuring science teacher education programs in a way to promote reconsidering the curriculum in a way that allows and promotes the learning of science and its nature in a meaningful way" (Shukufe NPS). Tulana also hesitated to embrace NOS, stating

> "as a person who studied hard sciences, I had very limited exposure to NOS in my life. When I started studying NOS, I was struggling to understand the outcomes of this (that may be because of my cultural and social background). I am understanding slowly what the use of this is and still exploring" (Tulana, NPS).

Tulana doubted the role of NOS when it came to its connection with his experiences in science. "After I started learning NOS, I started to question the science I learned. However, as a person who had enough exposure in science, I can still maintain my faith in science while learning NOS" (Tulana, NPS). This dissonance Tulana felt between NOS and science as a practice led him to initially believe NOS should not be introduced to young students, before they have had much content exposure (Tulana, NPS). This belief shifted over the course of the semester due to exposure to course readings on effective NOS instruction. "I would agree that NOS must be taught explicitly to anybody despite their age" (Tulana, LP). Participants from an eastern context had much to contribute when it came to how science is perceived differently from their context. Qiu, Conghui, and Tulana discussed how social expectations and culture affect personal choices about choosing science as a career, especially when it comes to women who may be encouraged in some cultures to focus on family roles over career roles (DR4). This idea provides support for the idea of NOS as socioculturally embedded- who practices science is highly influenced by contextual factors.

Overall, participants holding an eastern cultural identity felt dissonance with a NOS identity, expressing that their previous experiences and cultural contexts were in competition with a value for NOS. However, they came to believe those barriers to NOS in their cultural contexts could be overcome, perhaps indicative of their ability to overcome barriers to teaching NOS.

Other participants readily embraced NOS, displaying an identity embracing NOS in science instruction. Jessica embraced NOS for its benefits when it came to scientific literacy, pointing to the need for explicit NOS to support student attainment of science content and literacy (Jessica, NPS). Qiu also discussed the importance of explicit-reflective NOS, specifically in the context of inquiry activities, to help students reflect "not only about the science content knowledge, but also NOS that related to the content knowledge and their daily life" (Qiu, NPS). Qiu specifically valued NOS instruction embedded in inquiry activities. It is of note that Qiu differed from other participants in an eastern context in her immediate value for NOS. This is likely due to her having a year of the doctoral program completed at the time of data collection, including opportunities teaching about NOS in an inquiry course. The other three participants from an eastern context were just beginning the program, and did not have these experiences to draw from yet. In other words, her identity prior to beginning to the course was more conducive to acceptance of NOS.

One participant's identity for NOS was already established at the time the course took place, having learned about and taught NOS in a middle school context before entering the program. "I feel like middle school is prime time for NOS" (Claire, IN4). She discussed her experience cutting the scientific method poster on the wall into its constituent pieces and rearranging it with her students, discussing the many shapes and methods science can take. Claire's background experiences and exposure to NOS contributed to a clear NOS teaching identity.

The influence of background experiences on NOS identity was apparent in a conversation about the roles of science and religion as epistemologies. This discussion began with the role of science as an epistemology. Participants pointed out the differences between eastern and western practice in medicine, and what is based in science and what is not (DR4). Conghui raises the question "what can be accounted as science?" (DR4) Participants recognized the role that culture plays in how science is practiced, and what methods are employed. Ideas around the role of culture in science practice and perception gave way to a discussion about different ways of knowing and how they relate to science. Jessica pointed out that people from different cultures have different values, and different ways to "make sense" of things (Jessica, DR4). Andrea and Claire expanded on this idea, pointing out that individuals may have different ways of knowing for different aspects of life. For example, one may employ science in their academic work, but have religious beliefs, and those ways of knowing can coexist (DR4). Qiu took a stance that science and religion are to be held separate, stating "we can have multiple boxes to be in. When I do science, I am in the box of science, when I do religious stuffs, I am in another box" (Qiu, DR4).

The participants came to the conclusion that employing multiple ways of knowing, such as religion and science, are necessary to answer all of the questions life presents us with. Andrea pointed out the necessity for allowing for multiple ways of knowing with the statement, "You can't put science in a box, you can't put God in a box" (DR4). These ideas are summarized well by Tulana with the statement, "I think you really limit yourself as a person intellectually and spiritually and academically if you limit yourself to one epistemology" (DR4). These ideas and comments communicate the strong influence that participants' backgrounds had on their perceptions of science and its role as a way of knowing, also illustrating the sociocultural embeddedness of science as represented by NOS.

Influences on NOS Identity Development

By the end of the semester, most participants held a value for NOS as an important outcome of science education, and those who were still hesitant held more value for NOS than they had early in the semester. The final meetings of the course were focused on why participants valued NOS; why is NOS important?

First, participants valued NOS for its benefits to teachers and students when it came to science understanding. Claire and Jessica discussed the benefits of NOS to teachers specifically. Jessica discussed how NOS helps practitioners take research into practice, especially for teachers with limited content knowledge (DR5). Claire discussed how NOS makes science accessible to science educators to help students apply the knowledge in their daily life (DR8). Other participants focused on the benefits to student understanding. Andrea took the perspective of NOS contributing to student scientific literacy specifically. “NOS is important because it is important for students to walk away from my classroom understanding what science is and how science works” (DR8). Many participants specifically mentioned the need to begin teaching NOS early. Shukufe mentioned the difficulty of changing conceptions of science once they are already formed (DR5). Qiu stated “it is hard to say which student will become a scientist and which will not. However, NOS does help the student know science better and probably turn them into a science path. So, NOS education should be for everyone” (DR8).

Second, participants valued NOS for its congruence with their experiences in science. Andrea stated, “having a science background, NOS made perfect sense, it clicked, of course this is how science is and how we should teach science” (DR5). Shukufe also stated that her science background helped her connect to NOS (DR5), while others pointed to a lack of science content understanding potentially leading to difficulties accepting NOS (Tulana, Shukufe, DR5). Conghui pointed out that NOS can help scientists think more critically and make progress in challenging existing ideas in science (DR8). Interestingly, despite pointing out the clear congruence between the practice of scientists and aspects of NOS, when asked who NOS is most important for, Andrea and Tulana answered that NOS is more important for those who do not go into science to make better and more informed decisions as citizens (DR8).

Third, participants valued NOS for its sociocultural aspects. Jessica in particular held sociocultural approaches in high regard, and discussed this aspect of NOS often. “It is really important to consider the context when we teach NOS. The social and economic underrepresented students in the US do not have many opportunities to learn NOS” (DR8). She pointed out that the sociocultural embeddedness of NOS is discussed less than other NOS tenets, and needs more attention (DR8). Others pointed to the importance of the connection of science to personal lives. Shukufe said, “How to make science applicable in my life is more meaningful to me than the content knowledge. Maybe NOS can help us to see science in other ways” (DR8). Similarly, Qiu pointed out the benefit of learning about the philosophy of science throughout the semester when it came to connecting science to humanity. She said it helped to see scientists as humans with stories and difficulties, allowing us to have a better understanding of what factors contributed to their findings (DR5).

Discussion and Conclusion

Most of the doctoral students (except Claire) had never heard of NOS prior to the science education program, despite strong backgrounds in both science and science education careers. This provides additional support for the fact that NOS knowledge is best obtained through explicit instruction; implicit instruction relying on participation in science practices is insufficient for gaining knowledge of NOS (Khishfe & Abd-El-Khalick, 2002). During the semester, through a variety of readings, discussions, and activities, their NOS content knowledge was growing. In all cases, discussion of NOS was explicit and reflective as the tenets were discussed. Participants were able to increase their understanding of NOS regardless of their cultural background, aligning with previous studies that have shown growth in NOS conceptions around the world (Cil, 2014; Örnek, 2014; Erduran et al., 2020). Although they had good discussions of all aspects of NOS, some aspects received more attention than others. Creativity, social and cultural factors in science, and tentativeness raised some lively discussion both during and at the end of the semester. During these discussions, they explored the more nuanced meanings of some aspects (e.g. creativity in science).

Participants' development of a NOS identity seemed to be independent of their previous career experiences; it was not dependent on whether they had a stronger background as a scientist or a science educator when it came to personal and contextual factors. Rather, their value for NOS instruction varied based on their cultural background, or competing identities with a NOS identity. Previous research has established the sociocultural and tentative NOS, including the idea of theoretical descriptions of NOS themselves being subject to change (Lederman & Lederman, 2014). This study establishes the role of cultural backgrounds when it comes to accepting NOS as a necessary outcome of science education--depending on the background of the teacher or teacher educator, this value for NOS is not a given. Cultural experiences, specifically the role of religion and science as varying epistemologies, seemed to bear equal influence for participants from both eastern and western contexts, reaching the general conclusion that religion and science do not need to be considered at odds with one another, but rather different ways of knowing (Avraamidou & Schwartz, 2021).

Regardless of where they ended when it came to NOS identity development, each participant held more value for NOS instruction at the end of the course than the beginning. First, they valued the greater scientific understanding engendered by increased knowledge of NOS. The benefits to critical thinking (Yacoubian & Khishfe, 2018) and scientific literacy (Dani, 2009) that NOS provides were valued by the participants. Second, participants valued NOS because they saw its alignment with their own experiences with science (Schwartz & Lederman, 2008). Third, participants valued the sociocultural aspect of NOS, finding this particularly relevant to their own practice as science educators. Participants valued the opportunity to make science accessible to all by taking their social and cultural backgrounds into account.

Those with less experience in the program also happened to be from an eastern cultural context, and their concerns about teaching and learning NOS seemed to be related to their experiences in a different context, thus representing a contextual factor hindering NOS identity development. The context of students is critical to take into account when teaching any science content (Hofstein et al., 2010), and NOS is no exception (especially in light of the sociocultural embeddedness of science). Participants from an eastern context were hesitant to embrace NOS instruction, but this was only as they reflected on their own context and brought that knowledge to the table as they discussed NOS.

Contextual restraints on teachers' NOS identity development was a frequent topic of discussion throughout the course. In many cases, teachers rely on the provided curriculum to structure and enact their science instruction (Chiappetta et al., 1987). Where NOS-embedded curriculum materials are not available, it may be difficult for teachers to successfully implement explicit-reflective NOS learning in their curriculum. Providing NOS materials for teachers to use, whether that be NOS-embedded activities or entire curricula, may be a critical step for teachers to implement NOS in their classrooms, especially with the need for continual professional development when it comes to NOS instruction (Akerson & Hanuscin, 2007). Professional development is not always an option depending on the availability of teacher educators, funding, and/or teachers willing to participate due to constraints on their time or other factors.

These findings point to the importance of targeting NOS identity among science education doctoral students. Most participants entering the science education doctoral program had never heard of NOS. Science teacher educators hold the primary responsibility for educating preservice teachers when it comes to NOS and implementing NOS instruction into their future classrooms. To effectively implement NOS instruction among preservice teachers the teacher educators teaching them must also value NOS as an outcome of science education, and have implemented NOS into teacher education courses, all evidence of a NOS identity (Akerson, Weiland, & Elcan, 2015). This is not a given. Doctoral programs have the prerogative to address NOS identity among future teacher educators to ensure the value for and understanding of teaching NOS is present.

Considering the lack of widespread availability of professional development programs, teacher education programs provide the prime opportunity to instruct preservice teachers on NOS and its importance to their science teaching. Through targeted methods courses and field experiences, preservice teachers can be given the opportunity to practice NOS instruction for themselves (Akerson, Buzzelli, & Donnelly, 2010). Not instilling the importance of NOS during their teacher education experience is, ultimately, a missed opportunity.

Recommendations

From our study we have found that context matters in teaching and learning NOS. In teacher preparation programs we need to consider how to relate NOS to preservice teachers' experiences in different contexts, and prepare them to teach NOS across contexts. As part of the context, culture plays a large role in development of NOS understandings. Relevant research, curricula, and instructional strategies will support NOS development. As such, it would be important to focus on NOS conceptions globally, and ensure curricula around the world include NOS content for K-12 science learners. Science educators could focus on developing such curricula which would be helpful. Future considerations for graduate students and NOS instruction could be to learn how explicit and reflective instruction of the sociocultural aspects of NOS can facilitate deeper global perspectives and personal connections in science epistemology. Research that centers on intersectional identities and NOS identity development is important as we strive to support all learners at all levels in developing scientific literacy.

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