



Investigating the Development of Preservice Science Teachers' Nature of Science Instructional Views Across Rings of the Family Resemblance Approach Wheel

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Abstract

While much is known about teacher learning of nature of science (NOS) concepts, less is known about how teachers develop an understanding of how to effectively teach NOS or how instructional views might differ across levels of the Family Resemblance Approach (FRA) wheel. Therefore, this study investigated the NOS instructional views related to different levels of the FRA wheel of preservice secondary science teachers as they completed a semester-long NOS course. At four times during the semester, data was collected through written documents and interviews about NOS instructional views. Participant NOS instructional views were evaluated in terms of three aspects of NOS teaching: explicit, reflective, and role of context (McComas et al., 2020). In terms of the explicit and reflective components of NOS instruction, participants generally progressed from utilizing inaccurate representations of NOS to inclusion of accurate implicit messages, and finally to explicit reflective instruction often mimicking course activities. As the semester progressed, their questioning also moved toward targeting more specific NOS aspects. As far as the role of context, participants moved from treating NOS as its own topic to a more embedded approach. Other findings include that preservice teachers tended to use more abstract and contextualized activities for social institutional aspects of NOS as opposed to concrete and moderately contextualized activities for cognitive-epistemic NOS. Features of the NOS course may account for some aspects of the learning progressions observed.

1 Introduction

Nature of science understanding has long been a goal of science education, but getting teachers to teach NOS has proven challenging. Even science teachers with an adequate understanding of NOS often do not teach it or do so implicitly (Bell et al., 2000; Supprakob et al., 2016). Thus, teachers need both an understanding of NOS and NOS pedagogy in order

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to effectively implement NOS instruction. While scholars have noted the need to attend to NOS pedagogy in teacher preparation courses (e.g., Akerson et al., 2017; Demirdöğen et al., 2016), more specific guidance on how to support preservice teachers' development of NOS instructional views is needed, especially for the recently developed Family Resemblance Approach (FRA) to NOS (Irzik & Nola, 2011; Erduran & Dagher, 2014). Therefore this study sought to understand how a semester-long NOS course impacts the development of the NOS instructional views of preservice secondary science teachers across the levels of the FRA wheel.

1.1 Nature of Science

Clough (2006) described nature of science (NOS) as “what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors” (p. 463). Though scholars debate exactly what constitutes NOS, most recent conceptualizations of NOS draw on constructivism and describe scientific knowledge as socially-constructed (Deng et al., 2011). Epistemic aspects of NOS describe scientists as collecting empirical evidence and interpreting that evidence in light of their prior experiences and beliefs. Scientists' interpretations of natural phenomena are then subject to a social certification process; ideas that have been validated through peer review and accepted by the larger scientific community become established knowledge. Throughout this process, scientists influence and are influenced by the historical and cultural contexts in which they work.

1.2 Consensus Approach to NOS

NOS “appears in nearly all characterizations of scientific literacy” (Pleasant et al., 2019, p. 2), and is present in many standards documents including the *Next Generation Science Standards* (NGSS Lead States, 2013). However, though NOS has been an important aspect of science education for decades, teachers and students often hold misconceptions of NOS (Cofré et al., 2019; Lederman, 1992). Some scholars have reasoned that a simplified, yet accurate description of NOS that addresses misconceptions more directly might ease the burden of teaching such a complex construct and thereby facilitate improved NOS understandings (Abd-El-Khalick, 2012a; Kampourakis, 2016; Lederman, 1992). In an effort to make NOS more manageable, attention has been focused on aspects of science that are generally agreed upon by scientists (Schwartz & Lederman, 2008) and the academic community (Osborne, 2003). These agreed-upon aspects of NOS have been compiled in lists for classroom use in what is referred to as the “consensus view” of NOS. Several scholars have curated slightly different consensus lists (Abd-El-Khalick et al., 1998; Lederman, 2007; McComas, 2004; McComas & Nouri, 2016; Lederman et al., 2002) identified seven ideas to be addressed in science education: (1) science is empirical, (2) science is creative and imaginative, (3) science is theory-laden, (4) science is embedded in society and culture, (5) science is tentative, (6) there is no one method to science, and (7) differences between theories and laws. As a logical outgrowth of targeting widespread agreement, the consensus view tends to paint scientists and science in broad strokes. This level of generality allows consensus view ideas, or tenets, to be expressed in lists of short, declarative statements. By simplifying NOS into a handful of generalized statements, the consensus view allows for

NOS ideas to be more easily communicated to teachers and their K-12 students (Kruse et al., 2022).

While the consensus view holds certain advantages for the field of science education due to its accessibility, there has been increasing recognition of its limitations (Allchin, 2011; Matthews, 2012; Rudolph, 2000; Van Dijk, 2011). The consensus view might create the appearance of a simpler and more unified NOS, but a list of general characteristics is necessarily limited in its ability to accurately portray science, and Van Dijk (2011) noted that the result may be that students replace misconceptions of science with “new stereotypes” (p. 1092). For example, students who learn that all science is theory-laden might simply shift from seeing science as entirely objective to seeing it as entirely subjective – a view that leaves them vulnerable to science denial. More specifically, the consensus view has been criticized as an essentialist approach to NOS (do Nascimento Rocha & Gurgel, 2017; Wan et al., 2013) that largely ignores the differences between the practices and worldviews of different scientific fields (Wong & Hodson, 2009; Irzik & Nola, 2011; Rudolph, 2000; Schizas et al., 2016), and portrays science as more of a straightforward process than it often is (Allchin, 2011). Students who do not understand that there are significant differences in the practices of diverse scientific fields may not understand, for example, why a physicist might not have the expertise necessary to accurately interpret studies produced by environmental scientists on the topic of climate change. Additionally, the consensus view’s emphasis on epistemic aspects of science may make it ill-suited for addressing social justice issues related to science (Allchin, 2020; Dagher, 2020).

Although several scholars have faulted the tenets of the consensus view for being over-generalized, Dagher and Erduran (2016) criticized them for the opposite: “Because of their level of specificity, they are highly prescriptive and narrow in scope about what students ought to know” (p.152). As such, it seems that the consensus view might be criticized as normative in more ways than one. By dwelling on what science should be and the specifics of what students should know, the consensus view condenses NOS into a handful of conclusions that might limit students’ understanding of NOS.

1.3 The Family Resemblance Approach to NOS

Given the critiques of the consensus view (Allchin, 2011; Hodson & Wong, 2017; Matthews, 2012; Van Dijk, 2011), the family resemblance approach (FRA) has emerged as a promising framework for guiding inquiry into NOS (Dagher & Erduran, 2016; Erduran & Dagher, 2014; Irzik & Nola, 2011, 2014). The family resemblance approach to NOS was proposed by Irzik and Nola (2011, 2014) to provide a more nuanced alternative for conceptualizing NOS. Irzik and Nola (2011; 2014) considered science to be both a cognitive-epistemic and social-institutional system, and conceptualized scientific disciplines as “a ‘family’ with some characteristics that are similar as well as specific to each member” (Kaya et al., 2019, p. 24). Thus, rather than a list of statements about NOS, their FRA provided a set of categories to be interrogated with respect to particular scientific domains and historical contexts. These categories serve as flexible frames for examining features that are common across the sciences as well as features that are specific to particular scientific disciplines or even particular historical episodes. In this way, the FRA captures what Irzik and Nola (2014) refer to as the “unity-within-diversity” (p. 14) of science.



Fig. 1 *FRA Wheel*

Note. From *Reconceptualizing Nature of Science for Science Education* (p. 28) by S. Erduran and Z.R. Dagher, 2014, Springer. Copyright 2014 by Springer Netherlands. Reprinted with permission.

The family resemblance approach to NOS was reconceptualized for science education by Erduran and Dagher (2014). In an effort to better communicate the holistic view of science espoused by the FRA for the purposes of science education, Erduran and Dagher (2014) created a visual tool, the FRA Wheel (Fig. 1), to illustrate the relationships between FRA categories. In this wheel, the nature of science is visualized as three concentric circles or rings. The inner ring consists of cognitive-epistemic categories, the middle ring categories address social-institutional influences from within the field of science, and the outer ring categories address societal influences. All of the categories in the FRA wheel can be considered fluid; each category may interact with categories both within and outside of its ring. Because this study focused data collection and analysis at the level of each ring, we further describe each of these rings below. Examples of how the various categories of the FRA might be applied to a historical episode can be found in Table 1.

The inner ring of the FRA focuses on science as a cognitive-epistemic system. This ring invites investigation into the thinking of scientists and how scientific knowledge is developed. The four categories in this ring are aims and values, methods and methodological rules, practices, and knowledge. Generally speaking, these categories might be said to encompass the relationships among the goals, work, and products of science. Goals such as “consistency, simplicity, objectivity, empirical adequacy, and novelty” (Erduran & Dagher, 2014, p. 48) influence the choices scientists make in their work including which ideas they pursue, which methods they use, and their practices. These choices in turn influence the products of science which are the theories, laws, and models that reflect what scientists have learned about nature. Importantly, the products (e.g., theories) of science exert influence over the goals and practices of science as well. That is, the relationships within cognitive-epistemic aspects of science are multidirectional.

Table 1 *Application of FRA Categories to the Context of DNA Discovery*

FRA	DNA example
Aims and values	Although the base, sugar and phosphate unit within the DNA was known prior to the modeling carried out by Watson and Crick, the correct structure of DNA was not known. Their quest in establishing the structure of DNA relied on the use of such existing data objectively and accurately to generate a model for the structure. Hence the values exercised included objectivity and accuracy
Practices	In their 1953 paper in <i>Nature</i> , Watson and Crick provide an illustration of the model of DNA as a drawing. Hence they engaged in providing representations of the model that they built. They also included the original X-ray diffraction image generated by Franklin on which their observations were based. The scientific practices of representation and observation were thus used
Methodology	The methods that Watson and Crick used Franklin's X-ray diffraction data which relied on non-manipulative observation. Hence the methodology involved particular techniques such as X-ray crystallography and observations
Knowledge	The main contribution in this episode of science is that a model of the structure of DNA as a double helix was generated. This model became part of scientific knowledge on DNA and contributed to a wide range of scientific disciplines including chemistry, molecular biology and biochemistry
Social and institutional context	This episode illustrates some of the gender and power relations that can exist between scientists. There is widespread acknowledgment in the literature and also by Crick himself, for instance, that Franklin was subjected to sexism, and that there was institutional sexism at King's College London where Franklin worked (Sayre, 2000 /1975, p. 97). The DNA case also illustrates that science is both a cooperative and a competitive enterprise. Without Franklin's X-rays, Watson and Crick would not be able to discover the correct structure of DNA. This is the cooperative aspect. However, there was also competition within and across teams of researchers

Note. From *Reconceptualizing Nature of Science for Science Education* (p. 30) by S. Erduran and Z.R. Dagher, 2014, Springer. Copyright 2014 by Springer Netherlands. Reprinted with permission.

The middle and outer rings of the FRA wheel are both concerned with science as a social-institutional system. The middle ring focuses on social-institutional aspects of science emerging from within the field of science. Categories within this ring include social values, scientific ethos, professional activities, and social certification and dissemination. This ring provides a framework for investigating the institutional and social norms of science/scientists that influence the work of scientists and the reliability of scientific knowledge. Scientists, as a group, are guided by values such as “universalism, organized skepticism, disinterestedness, and communalism, intellectual honesty, respect for research subjects, respect for the environment” (Erduran & Dagher, 2014, p. 40). These values are reinforced by the peer review process through which scientific knowledge is validated. Once validated, scientific knowledge is shared both in journals and conferences whereby it can gain acceptance within the scientific community. While there are aspects of institutional and social norms that transcend science, differences in norms and conventions will necessarily differ across discipline and history.

The ideas of the outer ring were added to Irzik and Nola's (2014) FRA by Erduran and Dagher (2014) to more clearly address the impact of societal and cultural forces on science/scientists. The categories in this ring include social organizations and interactions, political

power structures, and financial systems. While these categories may initially seem outside the scope of NOS, Kaya and Erduran (2016) argue,

Economic and political factors are inherent to the conduct of science and thus are part of NOS. In other words, they are not factors outside the sphere of the scientific enterprise influencing science from a societal perspective. Rather, they are integral aspects of how science is practiced in organizational and institutional settings (p.1128).

Scientists are influenced by the organizational structures within their institutions. These structures often dictate the type of work individual scientists are allowed to do, the perceived reliability of their data/ideas, and the interactions between scientists. Scientists are also influenced by the expectations and interests of the businesses and governments that fund their work, and as a result of these relationships, scientific knowledge may be used for profit or to reinforce different ideologies. Science and society are reciprocal, each influencing the other.

The broad range of NOS ideas on which the FRA draws and the interconnections between those ideas make it a useful framework for helping teachers understand and teach NOS. By providing discrete categories, the FRA provides a manageable, yet complex view of NOS and highlights the need to inquire about science rather than demonstrate a simplified view of how scientists work (Erduran et al., 2018; Erduran et al., 2019). Dagher and Erduran (2016) note the pedagogical advantage of the FRA: “The higher level of organization in the expanded FRA is precisely its strength as it lends itself to flexible selection, exploration, and comparison of those aspects about science that are most relevant to the target science content” (p.153). In addition to K-12 (e.g., Akbayrak & Kaya, 2020) and preservice teacher education (e.g., Barak et al., 2022; Erduran et al., 2021; Kaya et al., 2019), the FRA has also proven useful in curriculum analysis (e.g., Caramaschi et al., 2022; Mork et al., 2022; Park et al., 2020), textbook analysis (e.g., Okan & Kaya 2022; Reinisch & Fricke, 2022), and investigating scientists’ views of NOS. (Wu & Erduran, 2022).

1.4 A Pluralistic Approach to NOS

Importantly, the consensus view and FRA approaches to NOS instruction are not mutually exclusive. Given the benefits of the consensus view, scholars have proposed that the best use of the consensus view might be as a starting point for NOS instruction (Abd-El-Khalick, 2012a, b; Kampourakis, 2016) outlined a developmental approach to NOS that involves NOS instruction “at increasing levels of depth along a developmental continuum from a treatment that is general, simple, and unproblematic at the elementary school level to one that is specific, complex, and problematized (or controversial) in science teacher education settings” (p. 1056). Continued use of consensus view tenets does not necessarily preclude complex investigations into a broader range of perspectives. To facilitate deeper understandings, Clough (2007) suggested turning consensus tenets into questions, while Galili (2019) proposed they be investigated from both sides (e.g., science as both subjective and objective). However, it should be noted that although it is possible to utilize the consensus view to promote a more nuanced understanding of NOS,

Once it is decided that the tenets are the basic and general meaning of NOS, the tendency to disregard particular contexts and to not consider other ways of seeing science is inevitable, even if this is not the educational intention” (do Nascimento & Gurgel, 2017, p. 413).

Thus, it seems important to utilize a more descriptive approach to conceptualizing NOS (i.e., FRA) once students have a basic understanding of the consensus view of NOS. Yacoubian and Hansson (2020) noted that there is also value in utilizing multiple models of NOS as it teaches students to recognize the value of different perspectives and to weigh their advantages and disadvantages. A move toward pluralism is necessary to prepare students to deal with the complexity of current issues across the globe. Bazzul (2017) argued “a culture of pluralism will lead to more relevant and engaged understandings of NOS, Scientific Knowledges and Practices” (p. 67).

We recognize the benefits of both the consensus view and FRA approaches to NOS instruction. That is, our view is that consensus lists have value for introducing NOS and providing an easily accessible list for planning of instruction. Yet, the FRA approach allows for exploration of more depth and nuance of NOS and comparison across science fields. Thus, the course in which this study was conducted utilized a pluralistic approach to NOS wherein NOS was introduced via a decontextualized activity and a discussion of consensus view tenets. The FRA then guided subsequent instruction to help preservice teachers establish more nuanced conceptions of NOS and more deeply examine ideas related to social-institutional NOS. Below, we discuss the research-based instructional strategies for teaching NOS that were taught to preservice teachers during the NOS course which served as the context for this study and also guided data collection and analysis.

1.5 NOS Instructional Strategies

Students are frequently exposed to misrepresentations of science in the media and at school through textbooks and cookbook labs, and this often results in misconceptions of NOS (Buingo et al., 2022; Miller et al., 2018; Walls, 2011). To effectively teach NOS, teachers must work to provide more accurate representations of the scientific endeavor while drawing student attention to NOS ideas (Abd-El-Khalick, 2013; McComas et al., 2020) described three primary features of NOS instruction: (1) explicit (i.e., purposeful) attention to NOS, (2) promoting students’ mental engagement with and reflection on NOS, and (3) the role of context in NOS instruction. We discuss each of these features in the paragraph detail below. While this framework of NOS instruction draws heavily upon science education research that utilized a consensus perspective of NOS, these three aspects of NOS instruction are also recognized within the FRA-NOS literature. For each of the three aspects of NOS instruction, we have provided supporting citations from both consensus- and FRA-framed studies of NOS teaching and learning.

Nature of science instruction should be explicit. While it is important to accurately represent science in classroom activities, simple exposure to accurate depictions of science is not enough to help students develop more accurate ideas about NOS. For instance, simply engaging students in inquiry-based science learning has not been shown to lead to more accurate understandings of NOS (Buingo et al., 2022; Çilekrenkli & Kaya, 2022; Khisfe & Abd-El-Khalick, 2002). Rather, teachers must target NOS ideas as they would any other

instructional objective in science (Abd-El-Khalick & Lederman, 2000; Çilekrenkli & Kaya, 2022; Khisfe & Abd-E-Khalick, 2002). Teachers should include NOS in their planning, explicitly discuss NOS with students, and assess students' NOS knowledge (Cullinane & Erduran, 2022; Hanuscin et al., 2011; Mesci et al., 2020).

Nature of science instruction should be reflective in nature. In tandem with activities that accurately represent science, reflective questioning helps students actively construct an understanding of NOS (Khisfe & Abd-El-Khalick, 2002). Kim et al. (2005) wrote that effective NOS instruction requires, "NOS-specific pedagogical knowledge of making connections between what students do and what scientists do and between NOS and the conceptual structure of science content" (p. 29). Reflective questions may relate science and the work of scientists to students' in-class experiences or explore students' own sense-making about science. Goren and Kaya (2022) found that the use of metacognitive prompts is important for helping students develop an understanding of NOS.

To create consistency between constructivist NOS ideas and pedagogy, it is recommended that teachers utilize student-centered questioning in their NOS instruction (Abd-El-Khalick, 2013; Allchin, 2011; Erduran & Dagher, 2014; Voss et al., 2022). Teachers should strive for "educative" questions that guide students to an accurate understanding of NOS (Clough, 2020). Reflective questions about NOS may take different forms, some more suitable to particular purposes than others. NOS questions that target specific NOS ideas (e.g., "How are scientists creative?") have been found to yield more accurate responses, and students address a wider variety of NOS ideas when asked specific questions on multiple different NOS ideas (Kruse et al., 2022). Divergent NOS questions (e.g., "How were you acting like scientists?") may be more useful at the beginning of an NOS discussion to make visible students' current thinking about NOS or at the end of a lesson or unit to assess student learning about NOS (Kruse et al., 2022; Voss et al., 2022). Convergent questions (e.g., "Why would it be inaccurate to say that scientists use the same step-by-step method?") that guide students to respond with a particular position about an NOS idea are better suited for guiding students toward accurate understandings of NOS. Conversely, convergent questions can also be used to challenge accurate, but oversimplified conceptions of NOS (e.g., "In what ways do scientists use similar methods?") (Voss et al., 2022).

Finally, the role of context should be considered in NOS instruction. NOS can be addressed within different instructional contexts, each with their advantages and disadvantages. Clough (2006) developed a framework to guide the use of different types of context for NOS instruction. Clough's "context continuum" describes different contexts based on the degree to which they represent authentic science. The continuum spans from decontextualized activities (e.g., black box activities) that exclude science content or historical context to highly contextualized activities (e.g., historical short stories, contemporary episodes) that include both science content and cultural context. Whereas the differentiation between topic and embedded approaches is more about connections to the science content within the curriculum, contextualization is related to how connected the NOS activities are to the work of real scientists.

Different contexts of NOS instruction have different strengths, so teachers should implement NOS instruction at multiple levels of contextualization. Decontextualized activities (e.g., black box activities) are engaging for students and, because they do not involve science content, allow students to focus on NOS ideas. Thus, decontextualized activities may be a good choice for introducing NOS to students. Moderately contextualized (e.g., inquiry-

based labs) and highly contextualized (e.g., socioscientific issues) activities can help students connect the NOS ideas they learned in a decontextualized activity to authentic science. Engaging students in the practices of scientists while learning science content provides an important foundation for understanding NOS ideas, and historical and contemporary cases are essential for helping students understand the role of social and historical context (Erduran & Dagher, 2014; Papadouris & Constantinou, 2014) noted improvements in the NOS views of lower secondary students who were provided both decontextualized and contextualized NOS instruction. Thus, teachers' knowledge of NOS instructional strategies should include how to teach NOS at multiple levels of contextualization (Cullinane & Erduran, 2022). Importantly, teachers must provide scaffolds to help students make connections across contexts (Clough, 2006).

Since the publication of McComas et al. (2020), Kruse et al. (2021) explored the extent to which middle school students perceived various contexts to reflect authentic science. Kruse et al. found that students privileged their own actions when making decisions about what most resembled "real" science. Thus, a decontextualized activity in which students were behaving like scientists (e.g., collecting data, asking questions) was rated as more like real science than a highly contextualized activity (e.g., reading about the work of real scientists). Höttecke (2008) predicted this result, noting that students privilege the concreteness of the context of NOS instruction. Therefore, in addition to a continuum of decontextualized to highly contextualized, context also exists on a concrete to abstract continuum. In a concrete context, students are engaged in activities they view as similar to scientists, whereas in an abstract context students perceive themselves to be doing things that are not like what scientists do (e.g., reading).

While teachers engage in multiple aspects of NOS teaching simultaneously, the aspects of NOS pedagogy we have discussed do not inherently overlap. That is, teachers can engage in a variety of combinations of the different aspects of NOS teaching. For example, explicit-reflective and implicit approaches can be used in diverse instructional contexts. Even very highly contextualized approaches can be implicit if students' attention is not being drawn to NOS ideas. Indeed, learners might engage in authentic science work (resulting in both concrete and highly contextualized learning experiences), but not significantly improve NOS views if the instruction is insufficiently explicit and reflective (Kruse & Wilcox, 2010; McComas, 1993). Of course, highly contextualized approaches can also be explicit and reflective. Clough's (2011) reported on the use of historical short stories including explicit-reflective questions embedded within highly contextualized stories reflecting a more abstract approach. Thus, an increase in context or concreteness does not automatically move instruction toward explicit-reflective pedagogy. Additionally, while highly contextualized NOS instruction is often embedded within science content instruction, it may also be utilized within a topic approach. For instance, if a local scientist came to speak to a physics class, but the scientist's field is genetics, the guest visit would be highly contextualized, but likely not embedded. While collapsing these various dichotomies may be more efficient and even accurate in many instances, the literature contains all of these categories and we find that considering the various aspects of NOS teaching is helpful for describing teachers' NOS instruction in a thorough yet concise manner.

1.6 Development of NOS Instructional Views

Research has provided insight as to how preservice teachers' NOS instructional views develop in response to teacher preparation courses that include instruction on NOS. Several studies have demonstrated that preservice teachers tend to plan lessons that either do not include NOS or take an implicit approach to NOS instruction towards beginning of courses or workshops that include NOS (Akerson et al., 2017; Bilican et al., 2012; Cullinane & Erduran, 2022; Demirdöğen et al., 2016) studied preservice teachers who were enrolled in a NOS course in which the first half of the course was spent learning about NOS and the second half on how to teach NOS. The preservice teachers were asked to create one lesson plan after learning about NOS and a second lesson plan at the end of the course after learning about NOS pedagogy. Only 1 out of 30 preservice teachers addressed NOS in their first lesson plan and that preservice teacher took an implicit approach. However, the majority of preservice teachers utilized an explicit reflective approach for the second lesson plan. Bilican et al., (2012) noted a similar shift from an implicit to explicit reflective approach in the lesson plans of preservice teachers enrolled in a science methods course. While some preservice teachers are able to shift to an explicit approach by the end of a course or workshop, many preservice teachers still tend teach NOS implicitly (Cullinane & Erduran, 2022) even when they seem to have an understanding of NOS pedagogy (Akerson et al., 2017). Although Akerson et al. (2017) noted that preservice teachers could provide feedback to each other on how to make NOS more explicit in their instruction despite not teaching NOS explicitly themselves, preservice teachers may not recognize that they are teaching NOS only implicitly without significant support from science teacher educators (Cullinane & Erduran, 2022; Hanuscin, 2013).

The development of teachers' instructional views for teaching NOS also seems to undergo a predictable course wherein NOS becomes increasingly integrated with science content teaching. Inservice teachers in professional developments addressing NOS have been found to progress from an implicit approach to NOS instruction, to teaching NOS explicitly but separate from science content, to teaching NOS explicitly and reflectively in conjunction with science content (Kim et al., 2005; Piliouras et al., 2018). The process of increasing integration with content is likely uneven as Bektas et al., (2013) found that preservice teachers enrolled in a practice teaching course that included NOS could integrate some NOS ideas in their instruction by the end of the course, but not others.

The majority of the research on NOS instructional views has drawn upon the consensus view of NOS, yet initial work has begun to describe how preservice teachers learn to teach NOS from a family resemblance approach perspective. Both Kaya et al. (2019) and Cullinane & Erduran (2022) facilitated elective workshops on NOS from an FRA perspective for preservice teachers. Kaya et al. (2019) interviewed preservice teachers pre and post intervention and found that "after the intervention they were more verbal about specific pedagogical approaches such as the use of technology and discussions in science lessons" (p. 38). Saribas et al. (2019) examined the NOS pedagogical knowledge of 40 preservice teachers enrolled in a course that included six weeks of NOS instruction. As part of the course, the preservice teachers designed two lesson plans (one group lesson plan, one individual) centered around a socioscientific issue. The researchers examined what categories of the FRA were included in the lesson plans, finding that preservice teachers most frequently addressed aims and values, methodology, scientific knowledge, and social values. No pre-

service teachers addressed the FRA categories of scientific ethos, professional activities, social organizations and interactions, political power structures and financial systems.

Most of the studies that describe the development of preservice teachers' NOS instructional views provide examples of the contexts and strategies that those preservice teachers utilized (or planned to use), but did not discuss the development of teachers' use of contexts over time. For example, Akerson and Volrich (2006) described how one preservice teacher was observed explicitly addressing NOS during student teaching: discussing the relationship between inferences and observations, embedding NOS questions in content instruction, and asking "How is what we did like what scientists do?" at the end of a lesson. From an FRA perspective, Kaya et al. (2019) noted that the preservice teachers in their study described using embedded NOS instruction through highly contextualized activities such as school trips and discussions of contemporary social issues. Preservice teachers in Kaya et al.'s study also described using moderately contextualized activities; one preservice teacher intended to have students perform an investigation, mimic the collaborative publication/review process, and then "At the end, the relation between what the students have done and science could be revealed" (p. 39) to teach some of the social-institutional aspects of science. While examples of contexts and strategies are helpful, they provide a limited view of the progression of preservice teachers' NOS instructional views.

1.7 Summary

While having students read, write, think, and even act like scientists is a worthy goal, the nature of science asks students to think metacognitively about these practices (Abd-El-Khalick, 2013). Unfortunately, though NOS appears in many major standards documents including the *Next Generation Science Standards* in the U.S., even teachers who demonstrate an adequate understanding of NOS often do not explicitly teach it to their students (Bell et al., 2000; Supprakob et al., 2016). Scholars have sought ways to make NOS more accessible to teachers and students, including the consensus view of NOS. However, while it may make NOS easier to communicate to teachers and students, the consensus view of NOS has been criticized as over-generalized and prescriptive. In contrast, the family resemblance approach (FRA) to NOS instruction entails a more descriptive approach to examining characteristics of science and scientists. By providing discrete categories, the FRA provides a manageable, yet complex view of NOS and highlights the need to inquire *about* science. An approach to NOS instruction that utilizes the more accessible consensus view of NOS as a precursor to the more nuanced conception of NOS afforded by the FRA may be able to better balance accessibility and accuracy in depicting NOS to preservice teachers (, 2012a, bKampourakis, 2016). Such an approach may be especially appropriate for teacher preparation programs given that preservice teachers may be asked to teach NOS at different grade levels and thus different levels of complexity.

Past research into the development of preservice teachers' NOS instructional views has been limited by a focus on consensus views (e.g., Hanuscin 2013; Mesci et al., 2020; Schwartz & Lederman, 2002) and an explicit reflective approach (e.g., Akerson et al., 2017; Bilican et al., 2012; Demirdögen et al., 2016). Additionally, though prior studies have identified which aspects of NOS preservice teachers address in lessons (e.g., Saribas et al., 2019) and which contexts they use (e.g., Akerson & Volrich 2006), they have not investigated (or not reported) the development of instructional views among different aspects of NOS and

contexts of NOS instruction over time. Cullinane and Erduran (2022) noted “Acquiring an understanding of how preservice teachers conceptualize NOS for lesson preparation is currently limited (Cofré et al., 2019; Schwarz et al. 2008), but it is important to capture it as it provides insight into how NOS materializes in future teaching (Erduran & Kaya, 2018; Schwarz et al., 2008)” (p. 19). Therefore, this study intends to look at preservice teachers’ development of NOS pedagogical views during a semester-long NOS course across different kinds of NOS ideas in terms of several aspects of effective NOS instruction (explicit, reflective, role of context).

1.8 Research Question

- How do preservice secondary science teachers’ NOS instructional views for each ring of the FRA develop across a semester-long NOS course?

2 Context of Study

The context for this study was a semester-long, dedicated NOS course at a mid-sized university in the Midwestern United States. The course is required for all secondary science education majors including both graduate and undergraduate preservice teachers. Classes were held one evening a week for three hours for a period of 15 weeks. The aim of the NOS course was to help preservice teachers develop an understanding of NOS and how to teach NOS. To this end, the course could best be described as divided into three sections: (1) understanding NOS concepts, (2) understanding NOS pedagogy, and (3) implementing NOS instruction.

The goal of the first four weeks of the NOS course was to help students develop an initial understanding of NOS. Students were first introduced to NOS through a black box (or decontextualized) activity – mystery tubes (Lederman & Abd-El-Khalick, 1998). As students explored the tubes, the instructor prompted students to reflect on their experiences and how they might relate to science and the work of scientists. During the course of these initial discussions, the course instructor referred to NOS ideas in a way that is most aligned with the consensus view of NOS (McComas, 2004). Following this introductory activity, the instructor proceeded to refer to this conceptualization of NOS, but also introduced aspects of the FRA wheel throughout subsequent activities including the paint chip activity (Wilcox & Potter, 2008), an investigation of pendulum motion (Kent-Schneider & Kruse, 2020), and multiple historical short stories (e.g., Clough 2011; Kruse & Borzo, 2010). Throughout these activities, the instructor made sure that each aspect of FRA to NOS was addressed at some point, with special emphasis given to categories in the outer two rings of the FRA wheel.

In the second section of the course (weeks 5–8), the instructor targeted ideas related to the teaching of NOS. First, the instructor helped students develop rationales for teaching NOS through a discussion of goals for students. Subsequently, the role of learning theory in guiding instructional decision-making was discussed along with various NOS-specific instructional frameworks including the explicit reflective framework (Khishfe & Abd-El-

Khalick, 2002), specific vs. general question types (Kruse et al., 2022), context continuum (Clough, 2006), and concrete to abstract framework (Höttecke, 2008). During this section of the course, the instructor engaged preservice teachers in additional decontextualized activities including the dot trick activity (Kruse, 2011 ; Kruse & Klocke, under review) and a modified NOS card sort (Cobern & Loving, 2008). Throughout discussions, the instructors asked questions to help preservice teachers connect their experiences as a learner in the NOS course to new pedagogical knowledge for teaching NOS.

During the final section of the course (weeks 9–15), preservice teachers participated in a practicum wherein they were tasked with implementing NOS teaching. All preservice teachers were assigned to the same suburban middle school for their practicum experience. Preservice teachers were assigned to one of three sixth-grade teachers at that school and attended one school class period each week. For the first few weeks of practicum, preservice teachers simply observed the teaching of one of the host teachers who had herself graduated from the same teacher preparation program and exhibited exemplary NOS teaching. Following each classroom observation, preservice teachers participated in reflective discussions with their peers and course instructor. After a few weeks of observations, the preservice teachers were expected to plan and implement their own lessons with small groups of sixth-grade students. Lessons were required to address the *Next Generation Science Standards* (NGSS Lead States, 2013) while also connecting to NOS ideas. During this time period, the NOS course continued to meet weekly, and became centered on planning for and supporting preservice teachers' practical work. Students participated in additional NOS activities in class which served as models of effective NOS instruction including but not limited to: “tricky tracks” and gestalt switch activities (Lederman & Abd-El-Khalick, 1998), a debate on a socioscientific issue surrounding the use of genetically modified organisms (GMOs), a funding activity (Clough, n.d), and a genetics activity (Brauer & Kruse, 2017).

3 Methods

3.1 Participants

Preservice teachers were recruited directly from the NOS course which served as the context for this study and was taught by the third author. On the first day of class, the instructor informed all preservice teachers about the study and provided them consent forms to be filled out independently and returned to one of the research assistants. Only two students opted out of participation in the study with the remaining 14 preservice teachers volunteering to participate. Eight of those participants were undergraduate students and five were graduate students. Because all students in the NOS course were required to complete any in-class data collection (e.g., CoRe document), the course instructor remained unaware of which students were and were not participating in the study.

3.2 Data Collection

Our data collection was focused on obtaining descriptions of preservice teachers' stated individual knowledge and beliefs about teaching NOS. To that end, participants' understanding of NOS and how to teach it were collected through a Content Representation (CoRe) docu-

ment (Loughran et al., 2006) and interviews. In filling out a CoRe, a teacher identifies the “big ideas” of a particular topic and then answers questions about how they would teach that topic. The CoRe has been widely used in the pedagogical content knowledge (PCK) literature and has been shown to be an effective way to represent science teachers’ PCK (Bertram & Loughran, 2012). Given that NOS instructional views are related to personal pedagogical content knowledge (Carlson & Daehler, 2019), the CoRe data collection tool ought to provide sound insight about participants’ NOS instructional views. This study focuses on the “pedagogical knowledge” aspect of PCK (Carlson & Daehler, 2019).

For this study, the CoRe was modified to specifically address NOS teaching across the FRA wheel. The modified CoRe included three columns each representing the teaching of a particular ring of the FRA wheel (Erduran & Dagher, 2014). We sought to use more accessible language, therefore we modified the language of the FRA wheel. The cognitive epistemic ring became “Goals, Work, and Products of Science/Scientists,” the middle social-institutional ring was worded as “Institutional and Social Norms of Science/Scientists,” and the outer social-institutional ring was phrased as “Impact of Societal and Cultural Forces on Science/Scientists.” For each FRA ring preservice teachers’ responded to questions such as, What are the difficulties/limitations connected with teaching NOS? What knowledge of student thinking influences your teaching of NOS?, What are your procedures for teaching NOS?, and What are ways of ascertaining students’ knowledge of NOS?

Data was collected four times throughout the semester. Preservice teachers completed an initial CoRe on the first day of the NOS course. Thereafter, they filled out CoRes at the end of each section of the NOS course (NOS content, NOS pedagogy, NOS practicum). Participants maintained one CoRe document that they updated at each interval to reflect their changing understanding of how to teach NOS. The instructor of the course also provided feedback on each round of CoRes, suggesting different ways participants might refine their ideas about teaching NOS. Importantly, feedback was only given related to ideas students were already exposed to. That is, when students had not yet learned about NOS pedagogy, feedback was limited to NOS content clarifications.

Interviews were conducted by the first and second author following each of the four collection periods for the CoRe document. In the first interview, participants were primarily asked to clarify their various responses to the CoRe. In subsequent interviews, participants were asked to justify any changes they made to their CoRe document. Additionally, participants were generally questioned on how ideas from the course and experiences in practicum might have influenced their knowledge for teaching NOS. Although not the main source of data for this study, interviews provided insight and clarity on participant thinking.

Pedagogical content knowledge is composed of many different aspects of teaching: pedagogical knowledge, knowledge of students, knowledge of curriculum, and knowledge of assessment (Carlson & Daehler, 2019). We view preservice teachers’ knowledge of instructional strategies as a vehicle for strengthening the other aspects of their PCK (Demirdöğen et al., 2016; Juhler, 2016) noted that preservice teachers primarily focus on instructional strategies when planning lessons. Therefore, for this study, we opted to focus exclusively on the development of preservice teachers’ instructional views, which would be part of the “pedagogical knowledge” aspect of PCK (Carlson & Daehler, 2019). By limiting our focus to preservice teachers’ instructional views, we were able to explore their development with increased specificity.

Table 2 *Categories and Codes*

Explicit	Reflective	Instructional Context
Misconception	Lecture	Decontextualized
Implicit	General	Moderately Contextualized
Explicit	Specific	Highly Contextualized
		Concrete
		Abstract
		Topic
		Embedded

3.3 Data Analysis

Researchers analyzed participants' intended procedures for teaching NOS ideas within each of the three rings of the FRA wheel (cognitive-epistemic, social-institutional norms, societal influences) in terms of the three dimensions of NOS instruction identified by McComas et al. (2020): explicit, reflective, and role of context. Researchers utilized provisional codes drawn from the literature to describe aspects of participants' intended instruction (*see Table 2 for a list of codes*). Table 3 provides example quotations for each code at the level of each of the three rings of the FRA wheel,

For the “explicit” dimension, part of a framework developed by Kim et al. (2005) was used to describe how participants planned to include NOS in their instruction. If participants planned to teach NOS in a way that was not aligned to generally accepted ideas about NOS, their response was coded “misconception.” If they planned to teach NOS implicitly through the use of inquiry-based labs or historical short stories, their response was coded “implicit.” Participant responses communicating an intention to explicitly address NOS were categorized as “explicit.”

The reflective dimension of NOS instruction was coded in terms of how participants intended to structure their verbal interactions with students. If participant responses had been coded “misconception” or “implicit” along the explicitness dimension, they would have no codes along the “reflective” dimension. Participant responses that described addressing NOS through direct instruction were coded “lecture.” Additional codes were drawn from Kruse et al. (2022). Responses that included questions about specific aspects of NOS were coded “specific” while responses that included questions that did not target a particular NOS idea were coded “general.” Participant responses were coded in terms of each type of verbal interaction they described, so participants could have multiple codes along the reflective dimension (e.g., both “specific” and “general”).

Finally, instructional context was analyzed in terms of contextualization, embeddedness, and concrete vs. abstract. Degree of contextualization was analyzed through the use of codes drawn from Clough's (2006) context continuum: decontextualized, moderately contextualized, and highly contextualized. Responses were coded in terms of each type of context the participant planned to use to address NOS. Thus, a participant could have multiple codes along the “context” dimension (e.g., both decontextualized and highly contextualized). Responses were also coded in terms of how NOS was to be addressed in relation to content learning. Participant responses that communicated an intention to explicitly address NOS could be categorized as “topic” or “embedded” depending on whether NOS to be taught as its own topic as opposed to included alongside science content instruction (Kim et al., 2005). “Embedded” instruction is considered a more highly developed way to address NOS

Table 3 *Example Quotations for Codes*

Code	Goals, Work, Products	Institutional and Social Norms	Impact of Society and Culture
Misconception	"It is important to inspire inquisitive minds to question things using the scientific method before introducing the rigid, objective constraints of experimental design."	none	none
Implicit	"Use an activity that plays out like "real" science does, asking students to think about what they are trying to discover/ answer and how they are being limited by the methods they chose."	"Students should do an inquiry on some topic and in the final step another group should correct it, without knowing who the owners of the work they are correcting are. In this way, blind peer review will be working."	"Give students lots of examples of values affecting science throughout history, as well as develop an activity that highlights students' own values through their decisions in a science setting."
Explicit	"Have students make predictions on whether each object [paper clip and a pumice rock] will float. After dropping each item in the water, have students discuss whether their observations fit their predictions (if not, how did that change their thinking? How might a scientist's approach change if their observations didn't fit their predictions?)"	"Because students may not understand how social and collaborative science is, this would definitely be something I would emphasize in class, for example- 'you all worked in groups to accomplish this task, how do scientists work together? Why might scientists want to work with others rather than by themselves?'"	"Questions need to be specifically tailored to addressing students' views on how society and culture affects scientists during class. The instructional strategy is not just assuming that students are understanding these things from the investigations or discussions they are having in class. It needs to be explicitly addressed."
Lecture	"Describe the process with a presentation (with information, images, and real-life examples across different scientific fields). Showing real-life scientific research and highlighting the scientific methods inherent will provide connections."	N/A	N/A
General	"My strategies for teaching students about scientific goals, work, and products are to sprinkle in questions related to these topics during lessons— 'how is what we are doing today like what scientists do in their field?' or 'how do the varied methods we used in class today reinforce the idea that there is not one scientific method in science?'"	"ask students to compare and contrast how they work in the classroom to the work of professional scientists"	"I would start by asking a general question such as, 'how is what you did today similar to what scientists do?,' have the students discuss with partners and then share out their thoughts. Then, depending on the activity, I would ask a question that relates NOS concepts to specific things done in class."

Table 3 (continued)

Table 3 (continued)

Code	Goals, Work, Products	Institutional and Social Norms	Impact of Society and Culture
Code	Goals, Work, Products	Institutional and Social Norms	Impact of Society and Culture
Specific	"My strategies for teaching students about scientific goals, work, and products are to sprinkle in questions related to these topics during lessons 'how do the varied methods we used in class today reinforce the idea that there is not one scientific method in science?'"	"Asking open ended questions like: 'What would happen if scientists were to lie about their data'"	"how does the government affect scientific work/progress?" You would have to ensure that you have talked about these topics in class before asking this on an exam so that students would have some background to go off of for their answer."
Decontextualized	Black box activity. Have sealed boxes with varying objects inside (wood blocks, marbles, bolts, cottonballs, marker). Students work in groups and are tasked with identifying as much as possible about the box using a few tools...Discussions with groups/class to discuss when might scientists have to study things they can't clearly see? (dark matter, Earth's core, plate tectonics, dinosaur behavior)."	"To teach these ideas, students must face a 'mystery tube.' At each stage of the activity, reflections will be made about what is being done and its importance."	"Tricky Tracks. Students observe same series of images that appear to be from two animals. Through reflection, TPS, and class discussion students need to make inferences as to what made them and what they were doing (SLT)."
Moderately contextualized	"Through the use of investigations and experiments, the students themselves will be able to experience how the development of ideas and goals."	"Build in NOS questions and time for partner, table, and class discussions so that students may learn with/from their peers (SLT)"	"If students are constructing something using materials, I could give them a budget and assign a cost to materials so that they can see that money plays a role in science and that it can be a huge limitation."
Highly contextualized	"Have students read some historical background about the scientist. This is useful to help express that scientist don't just work in labs but also a lot of them had setbacks."	"start teaching NOS ideas in decontextualized situations and move towards more contextualized"	"holding a mock grant-funding process and then discussing how this plays out in the real world and affects scientific research. "

Table 3 (continued)

Code	Goals, Work, Products	Institutional and Social Norms	Impact of Society and Culture
Topic	“To teach these ideas, students must face a “mystery tube”. At each stage of the activity, reflections will be made about what is being done and its importance.”	“utilize investigations or black box activities to guide the students through similar processes as scientist. For example, having them collaborate and share ideas while conducting trials for said investigation (i.e. change a variable on whirligig)”	“Each group would have different “country” in which they would be working for. This country would have a specific task that would be a similar, but a slightly different set of parameters, laws, “funding” (reward), and desired outcomes. The class would go about constructing the desired outcome determined by the group’s country.”
Table 3 (continued)			
Code	Goals, Work, Products	Institutional and Social Norms	Impact of Society and Culture
Embedded	“Having them come up with their own questions and experiments will help them demonstrate curiosity and confidence.”	“Build in NOS questions and time for partner, table, and class discussions so that students may learn with/from their peers (SLT)”	“Introducing socio-scientific issues in class (for example, instituting a debate about GMOs) can tie to the content students are learning while also allowing for discussion about how science and society interact.”
Concrete	“Having students actually behave like scientists in class will help them understand the work and the goals scientists have in the field (making it more of a concrete experience based on developmental learning theory). This means not having students just reading a textbook or completing worksheets/packets but being hands-on in class, using creativity, and participating in discussion.”	“In order to teach students about the norms of science, I think instituting those norms in the classroom is key- having students behave like scientists in their science class. They can then use their experiences in class and apply them to how science actually works (this allows them to have concrete experiences consistent with developmental learning theory.”	“Role play processes beyond scientific investigation including securing funds and sharing their information?”
Abstract	“Using historical references to show how scientists made discoveries and asking questions relating to the thought process of the scientists: ‘Why did the scientist setup the experiment that way?’ ‘What prior knowledge were they building on,’ ‘What kind of methods and activities were they using, etc...’”	“I think the teacher could introduce a disagreement or argument between scientists and then discuss rational disagreements with the class and why scientists may reach different conclusions based on the same evidence.”	“Students will be introduced to historic events by reading a historical narrative, and they would be asked how they would respond to the situation if they were a scientist. After they do this, there will be a classroom discussion about factors influencing their decision making as a scientist.”

in the classroom (Kim et al., 2005; Piliouras et al., 2018). Finally, participant responses were coded as concrete or abstract (Höttecke, 2008) depending on whether procedures involved engaging students in scientific practices or learning about NOS through more abstract strategies (e.g., reading historical short stories). Tables 2 and 3 provide further illustration of how data was coded. Table 2 includes a list of codes used in the study. Codes are divided into three categories that correspond to the dimensions of NOS teaching identified by McComas et al. (2020) framework: explicit, reflective, and instructional Context. Table 3 provides example quotations for each code at the level of each of the three rings of the FRA wheel.

Participant responses were coded separately for each of the three FRA NOS rings included on their CoRe (“Goals, Work, and Products of Science/Scientists,” “Institutional and Social Norms of Science/Scientists,” and “Impact of Societal and Cultural Forces on Science/Scientists”). For instance, each participant had one set of codes for “Goals, Work, and Products of Science/Scientists” and a different set of codes for “Institutional and Social Norms of Science/Scientists.” Coding was repeated at each of the four time points.

Once the first reviewer finished coding the CoRe documents, a second reviewer went through and scored a randomly selected three out of the 14 preservice teachers for each column and time point equating to 21.4% of the total responses. Following these coding procedures, there were 468 potential responses. Of these responses, coders disagreed on 14 responses resulting in 97% initial agreement. Coders discussed using data to come to 100% agreement. Line charts were created for each dimension of NOS instruction (e.g., explicit) to help better visualize changes in student responses across codes and NOS topics over time (Figs. 2, 3, 4, 5 and 6).

4 Results

Figure 2 illustrates the extent to which preservice teachers planned to make NOS instruction explicit and reflective within their future classes. When compared across the inner, middle, and outer rings of the FRA, preservice teachers began the course as more likely to teach

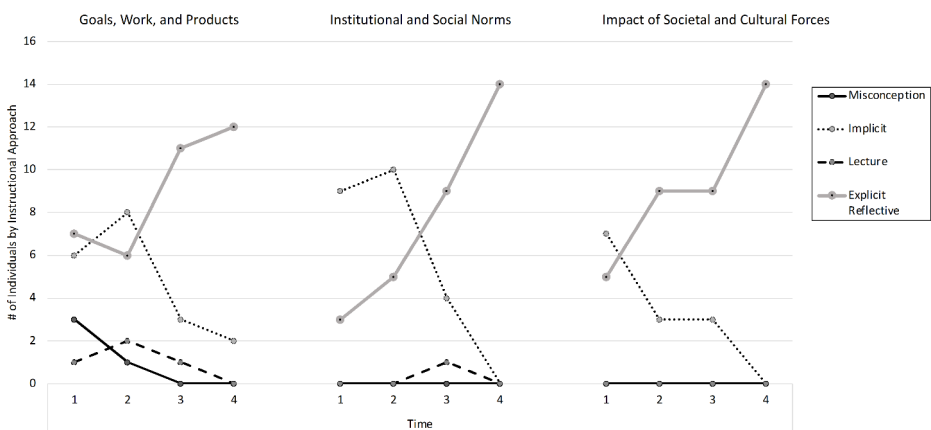


Fig. 2 Explicit NOS Instruction Over Time by FRA Ring
Note. N=14

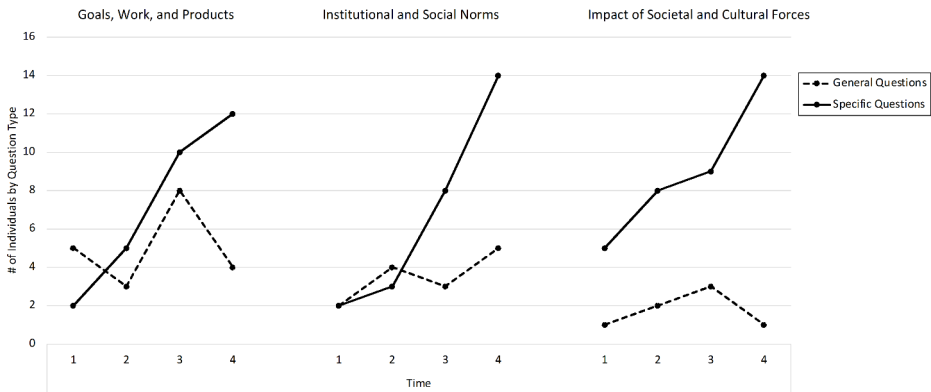


Fig. 3 NOS Question Types Used Over Time by FRA Ring

Note. N = 14. Individuals could be counted for more than one activity type if they included multiple activity types in their response.

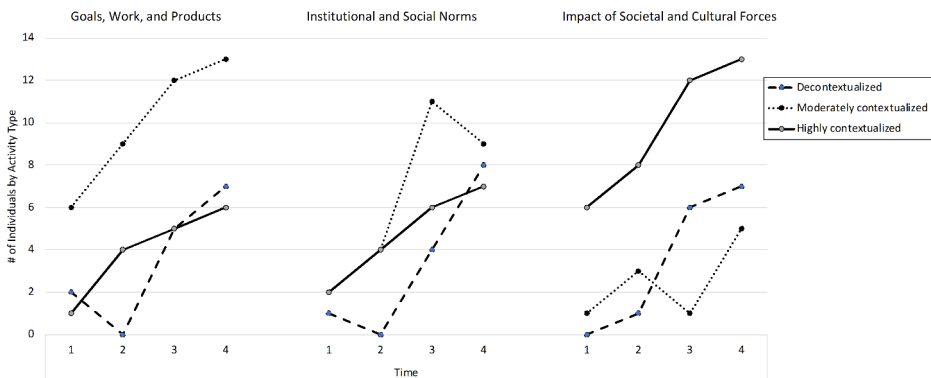


Fig. 4 Contextualization of NOS Over Time by FRA Ring

Note. N = 14. Individuals could be counted for more than one activity type if they included multiple activity types in their response.

NOS implicitly or through lecture than to use an explicit reflective approach to instruction. For example, at Time 1, one preservice teacher described how they would teach the goals, work, and products of science as “Introduce the scientific method. Describe the process with a presentation (with information, images, and real-life examples across.” By the end of the course explicit-reflective instruction had grown across the inner, middle, and outer rings of the FRA and the combination of implicit and lecture based instruction dropped or disappeared. At Time 4 that same preservice teacher wrote “To understand the scientific process, students will need explicit NOS questions to prompt critical thinking” and provided several specific examples of questions they might ask.

While comparing pre and post course numbers demonstrates overall effectiveness, looking closer at all four time points illustrates nuances in student learning. For example, the most dramatic increase for explicit-reflective instruction for the inner two rings of the FRA wheel occurred between Time 2 and Time 3. During this time the NOS course shifted from

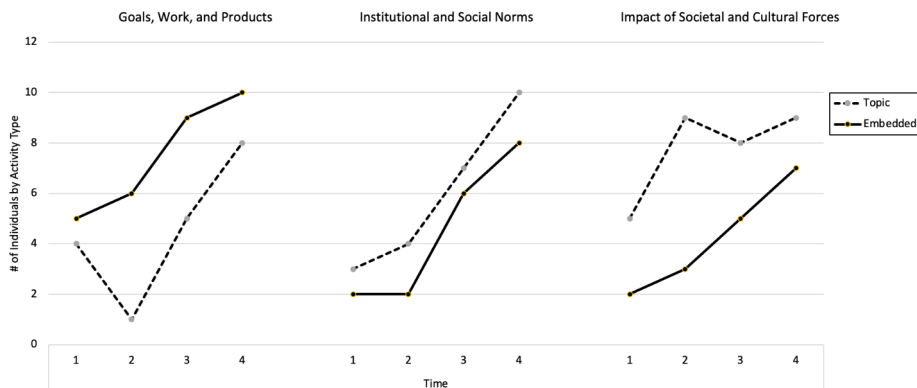


Fig. 5 Topical vs. Embedded NOS Instruction Over Time by FRA Ring

Note. N=14. Individuals could be counted for more than one activity type if they included multiple activity types in their response.

teaching NOS content to including explicit NOS pedagogy alongside NOS content. This trend continued from Time 3 to Time 4 as the inner and middle rings saw further increases in explicit-reflective NOS instruction.

The outer ring of the FRA demonstrates a different pattern. Five preservice teachers moved toward explicit-reflective instruction from Time 1 to Time 2 with no additional participants moving toward explicit-reflective instruction during the Time 2 to Time 3 interval. However, the remaining participants did move to explicit-reflective instruction of the outer FRA wheel ring during the final third of the course.

When teaching NOS in an explicit-reflective fashion, the type of questions the preservice teachers were planning on asking was further analyzed and reported in Fig. 3. Just as most students began the course without planning on using an explicit-reflective approach, less than half of students mentioned using questions of any type to teach NOS across the inner,

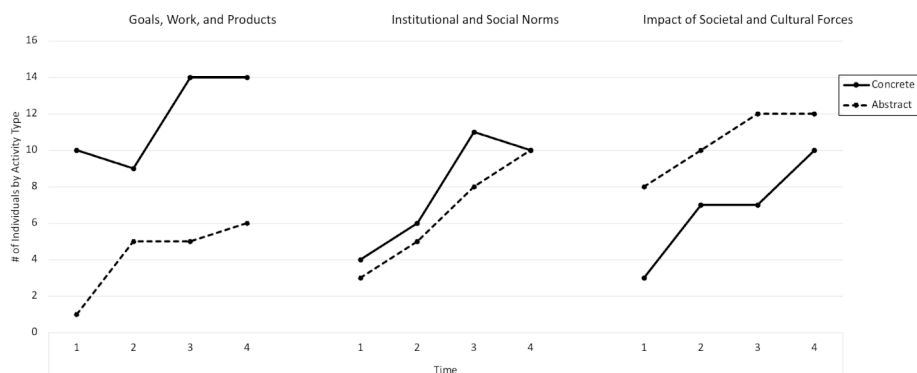


Fig. 6 Concrete vs. Abstract Contexts Over Time by FRA Ring

Note. N=14. Individuals could be counted for more than one question type if they included both question types in their response.

middle, and outer rings of the FRA wheel at Time 1. Participants who did include questions in their teaching practices at the beginning of the course tended to use general questions for the inner ring, for example, “How is what we are doing today like what scientists do in their field?” At this same point, more specific questions were used for the outer ring such as, “How has the discovery of electricity changed society?” By the end of the course, the total number of students planning to use questions across the inner, middle, and outer ring of the FRA wheel increased dramatically (to 85.7%, 100%, 100% of participants, respectively). The types of questions also shifted so that the teaching of NOS across the rings of the FRA was more often done with specific questions rather than general questions.

Unsurprisingly, use of questions mirrored the results for use of explicit-reflective NOS instruction. For example, between times two and three preservice teachers began using questions in their instruction more often for the inner and middle ring of the FRA wheel. Again, an initial improvement during the first third of the course for the outer ring of the FRA wheel was followed by a plateau and finally another sharp increase during the final third.

Figure 4 shows the contextualization of NOS activities preservice teachers planned on using in their future classes. Use of each level of contextualization generally increased from time one to time four across all rings of the FRA. Interestingly, as the class progressed participants became more likely to use different kinds of contexts within instruction regardless of what ring of the FRA they were addressing. Each type of context (decontextualized, moderately contextualized, highly contextualized) has its advantages and disadvantages, thus teachers should have the knowledge and skills to utilize diverse contexts within NOS instruction (Clough, 2006; Kruse et al., 2021).

In comparing contextualization across the FRA wheel rings, we note preservice teachers were much more likely to teach the inner and middle rings of the FRA wheel using moderately contextualized approaches than in a highly contextualized or decontextualized way. One example of using a moderately contextualized approach was when a preservice teacher mentioned they planned to “sprinkle in questions related to these topics” during regular science content lessons. When observing the trends in the outer ring of the FRA, the number of preservice teachers who mentioned moderately contextualized instruction was much lower. Instead, preservice teachers more often chose to teach aspects of the outer ring of the FRA in a highly contextualized approach. This highly contextualized instruction was often centered around historical short stories or modeled after a funding lesson modeled in the methods course. For example, one individual described “Using historical context to show how society and culture has impacted science (use story about Watson, Crick and Franklin for example)”.

Figure 5 illustrates participants’ approach to NOS instruction with respect to including NOS as a separate topic or embedding NOS within content instruction. In general, the number of participants including NOS as both a separate topic and embedded increase over time. Of interest, participants did not replace a topic-based approach with a more embedded approach. When the preservice teachers began embedding NOS into their courses and activities, they maintained or grew the frequency of the topic approach as well, noting that they planned to use both strategies in their future teaching. By the end of the course, at least 50% of preservice teachers planned to use both topic-based and embedded instruction across the inner, middle, and outer rings of the FRA wheel. For example, one preservice teacher wrote at Time 4 that “Blackbox activities are really helpful when teaching these ideas,” but they would also embed NOS ideas within content by having the class “come up

with a common procedure together and then ask questions like, ‘Why would scientists need to have a common procedure?’” When further looking across the inner, middle, and outer rings of the FRA wheel, we note that participants were more likely at all times to teach the inner ring using embedded approaches. However, to teach the outer ring of the FRA wheel participants tended to articulate more topic-based approaches.

Figure 6 demonstrates results of analysis focused on the use of concrete and abstract activities by participants. Findings were very similar to the trends of the context continuum findings in Fig. 4. Throughout the semester, participants consistently planned to teach the inner ring of the FRA wheel in a concrete manner more so than via abstract approaches. Many preservice teachers discussed having the students engage in hands-on, inquiry-based labs and asking NOS questions relating students’ actions to the work of scientists. For example, one preservice teacher wrote that after having students come up with a way to record data during an investigation, they would ask “Why is it important for scientists to collect and record data?” The outer ring of the FRA showed an opposite trend with more participants consistently choosing to teach these ideas in an abstract way compared to concrete. For instance, the preservice teachers tended to describe the use of historical short stories as a way to help students think about these ideas. One preservice teacher wrote they would “Start by presenting a historical short story of a scientific discovery that clearly highlights power structure(s), or in this case sexism. Ask students, ‘What things do you see that affect the role of [certain scientist]?’”

4.1 Summary

In summary, preservice teachers’ generally experienced the greatest changes in their instructional views after they were explicitly and reflectively taught about NOS teaching. While, across all rings, preservice teachers tended toward an implicit approach to NOS instruction at the beginning of the course, they shifted to an explicit-reflective approach by the end of the course. Preservice teachers were also more likely to utilize specific NOS questions for each of the three rings by the end of the course. Changes in instructional views related to explicit-reflective and question type (general vs. specific) for the outer ring generally lagged behind similar changes in the inner and middle rings.

With respect to contextualization, preservice teachers were more likely to use decontextualized and moderately contextualized and embedded NOS instruction for the inner and middle rings. For the outer ring, preservice teachers tended toward highly contextualized NOS instruction. Differences in approaches for the inner and outer ring were also observed in preservice teachers’ instructional views related to concrete vs. abstract NOS activities. Preservice teachers tended to describe more concrete instruction for the inner ring as opposed to abstract instruction for the outer ring.

5 Discussion

5.1 The Role and Nature of Explicit-reflective NOS Pedagogy Discussions

Two main implications about NOS pedagogy learning can be drawn from this study in combination with existing literature. (1) Modeling is not enough. Discussion of NOS peda-

gogy must actively draw teachers' attention to how NOS instruction can be enacted effectively. Such discussion can be enhanced through detail beyond the rather vague conclusion that NOS instruction must be explicit and reflective. (2) NOS pedagogy discussions should occur after preservice teachers have learned NOS content rather than concurrently. Each of these implications is discussed further below.

Our study both supports and extends prior research on the necessity of explicit-reflective discussions of NOS pedagogy in science teacher education. The results of this and other studies (e.g., Demirdöğen et al., 2016) illustrate the need to explicitly and reflectively engage teachers in more detailed conversations about NOS pedagogy. During the first third of the course, which focused on NOS understanding and where NOS pedagogy was only implicitly addressed, very little change in instructional views was observed. That is, the course instructor enacted explicit-reflective NOS instruction, used a variety of contexts, and carefully scaffolded NOS ideas using general, specific, convergent, and divergent questions at appropriate times, but the preservice teachers were not asked to think about the instructional strategies they were experiencing. However, once the course instructor began to engage preservice teachers in explicit and reflective discussions related to NOS pedagogy during the second third of the course (e.g., "How did the questions asked during this lesson help you attend to the NOS ideas?"), participants' knowledge of NOS instructional strategies increased more dramatically.

While studies have established the need to explicitly address NOS pedagogy in science teacher education there is a need for more clarity as to how explicit-reflective NOS pedagogy can be enacted. That is, just as the explicit-reflective framework for NOS content lacks clarity needed to help teachers enact such instruction (Voss et al., 2022), the literature targeting NOS pedagogy development may also lack the clarity needed to support teacher educators in enacting explicit-reflective NOS pedagogy instruction. For example, Akerson et al. (2017) noted, "To foster the development of PCK [pedagogical content knowledge] for teaching NOS, scaffolding in terms of modeled lessons and activities should be provided." (p. 298). We agree, but there is much left to interpretation as to how the instructor should use model lessons to support the development of preservice teachers' NOS instructional views. Some readers might even think that simply modeling NOS activities is enough to generate NOS pedagogical learning. However, similar to the Demirdöğen et al. (2016) study, our participants' lack of NOS pedagogy growth during the first third of the course in which NOS pedagogy was not explicitly addressed illustrates that modeling alone is not enough.

Research elaborating on the teaching of NOS pedagogy has been limited by a broad focus on the explicit and reflective aspects of NOS instruction. Demirdöğen et al. (2016) noted the importance of engaging in "explicit-reflective discussions of PCK for NOS components" (p. 605) and that "consideration should be given as to not only the knowledge of NOS teachers need to understand NOS, but also the complex knowledge required to teach NOS" (p. 605). However, the findings and discussion around instructional strategies was limited to explicit-reflective instruction despite having collected data concerning embeddedness and lesson context. More detail concerning the nature of what it means to enact explicit-reflective NOS instruction as well as other NOS pedagogical constructs may be useful in supporting teacher enactment of NOS instruction.

Our study illustrates that preservice teachers are ready to understand NOS pedagogy in greater detail than just "explicit-reflective." While explicit-reflective instruction is clearly a key part of effective NOS instruction (e.g., Khishfe & Abd-El-Khalick, 2002), recent

research has explored various ways the construct is enacted and provided empirically-based recommendations for clarifying explicit-reflective instruction to better support teacher implementation. Kruse et al. (2022) found that although explicit-reflective NOS instruction is often operationalized as asking questions, the nature of those questions varied across the literature. When assessing the impact of question types on student thinking, the Kruse et al. found that specific NOS questions (e.g., How does this excerpt illustrate that scientists are influenced by the wider culture?) help students attend to a wider variety of NOS ideas than more general questions (e.g., What can this excerpt tell us about how science works?). Similarly, Voss et al. (2022) found that convergent questions in which students are prompted to consider a more accurate view of NOS (e.g. How does this excerpt illustrate that scientists do not all follow a single step-by-step method?) are more useful for instructional purposes than divergent questions (e.g., “What does this excerpt tell us about scientists’ methods?). Yet, more divergent questions are useful for formative and summative assessment purposes. Given the findings of our study, science teacher educators can help teachers understand NOS pedagogy beyond the vague need for explicit-reflective instruction. Indeed, Fig. 3 illustrates that participants’ use of specific questions increased markedly in the second and final third of the course. The teachers in this study not only learned to utilize the explicit reflective framework to teach NOS, they also came to understand how particular types of questions asked in different contexts can support students’ NOS learning. Helping teachers understand the ways particular kinds of reflective questions can guide student thinking about NOS will leave them better equipped to facilitate NOS discussions.

NOS instructional strategies go beyond questioning strategies. The role of context for teaching NOS was also a key component of the course studied. That is, the preservice teachers were engaged in explicit conversations comparing and contrasting various context-based approaches for NOS instruction. For example, teachers were asked to consider how including authentic stories about historical science might prevent students from dismissing NOS ideas (Clough, 2006). Participants were also asked to consider the value of having students act like scientists so that students might have personal experiences on which to build an understanding of NOS (Höttecke, 2008). Preservice teachers discussed recent research findings of Kruse et al.(2021) in which sixth-grade students seemed to privilege their own actions over more historical accounts when determining whether an activity authentically reflected the work of scientists.

The number of participants including both embedded and topic approaches to including NOS increased throughout the course (see Fig. 5). When planning for the outer rings of the FRA, participants tended to take a topic approach whereas the inner ring was more embedded. Similarly, the number of participants using decontextualized, moderately contextualized, and highly contextualized contexts increased over time (Fig. 4). However, participants tended to use more contextualized approaches for the outer rings of the FRA. Participants also tended to use more abstract contexts when teaching the outer ring of the FRA (Fig. 6). Given these findings, more examples or strategies to help teachers engage students in the outer ring of the FRA using moderately contextualized and concrete contexts may be needed. This is further discussed in the next section.

Clearly, more detail can be provided to teachers around instructional strategies for effective NOS instruction than just “explicit-reflective.” The teachers in this study learned that not only should they explicitly target NOS learning through the use of questions, but can also ask particular types of questions in different contexts to support students’ NOS learn-

ing. To further support science teachers in teaching NOS, science teacher educators might include discussions with teachers about the types of questions used to enact explicit-reflective NOS instruction (Kruse et al., 2022; Voss et al., 2022) and the role of context in explicit-reflective NOS instruction (Clough, 2006; Höttecke, 2008; Kruse et al., 2021). By including additional detail, teachers will have a wider repertoire on which to draw when planning and enacting explicit-reflective NOS instruction.

This study, along with related literature, also illustrates that teachers benefit from developing an understanding of NOS ideas before learning about NOS pedagogy. NOS understanding is clearly necessary, but not enough to enact NOS instruction effectively (Lederman, 1992), thus both knowledge of NOS and knowledge of NOS pedagogy must be addressed in teacher preparation. Sequencing NOS learning before NOS pedagogy is likely better than attempting to engage both at once. For example, Kruse et al. (2017) found that preservice teachers encountering a combination of NOS content and NOS pedagogy in a first course really only came to understand NOS content. However, in their second course, which also included a mix of NOS content and NOS pedagogy, preservice teachers came to understand NOS pedagogy.

In the course in which the current study took place, NOS content learning was the only explicit goal of the first third of the course, and NOS pedagogy was the explicit goal of the second third of the course. Separating these two learning goals recognizes the cognitive load required to learn about NOS content and NOS pedagogy, and this seems to have provided a useful scaffold for participants. Demirdöğen et al. (2016) similarly separated the course they studied into two parts: NOS content and NOS PCK. They recommend that “teachers should be provided with the opportunities where they study NOS as learners (developing an understanding of NOS) but also from a teaching perspective” (p. 605). Including both components is important. Yet, clearly separating NOS content learning from NOS pedagogy learning may be key in providing reduced cognitive load to support teacher learning of both NOS content and NOS pedagogy. Of course, NOS content learning ought to implicitly address NOS pedagogy by modeling effective NOS instruction, but NOS teacher education seems to be more successful when at least some NOS content learning is achieved before attention is drawn to NOS pedagogy.

5.2 Difficulties with Social-Institutional NOS

The results of this study seem to indicate that preservice teachers have more difficulty conceptualizing how to effectively teach the social-institutional aspects of NOS. A dramatic shift toward explicit-reflective instruction was not observed for the middle and outer rings of the FRA until the very end of the course. In contrast, the most dramatic increase in explicit-reflective instruction for cognitive-epistemic NOS occurred between the second and third data collection times. This finding aligns with prior research demonstrating that preservice teachers tend to have more difficulty (or avoid) teaching the social aspects of science. Multiple studies have demonstrated that teachers (preservice and inservice) infrequently address social-cultural aspects of NOS (Cullinane & Erduran, 2022; Lederman et al., 2001; Guerra-Ramos et al., 2010; Saribas et al., 2019; Saribas & Ozer, 2022). Specifically, Saribas et al. (2019) noted that preservice teachers tended to emphasize cognitive-epistemic aspects of NOS in their lesson plans, often neglecting social-institutional aspects of science. One reason preservice teachers’ instructional views for the social-institutional aspects of science

might be observed to lag behind their instructional views of the cognitive-epistemic aspects is that preservice teachers have a limited understanding of the social aspects of science (Georgiou, 2022). Strong subject matter knowledge (in this case, knowledge of NOS) is required for effective teaching (Carlson & Daehler, 2019; Shulman, 1986), thus preservice teachers are likely to struggle planning for teaching social-institutional NOS if they do not grasp those ideas themselves. Given these struggles, teachers may simply need more time to develop deeper NOS content and NOS pedagogical views (Akerson et al., 2006; Bell et al., 2016; Kruse et al., 2017).

The need for additional support to develop NOS content and NOS pedagogy knowledge, particularly for the outer rings of the FRA are further supported by our study. Between the third and fourth data collection points, the instructor of the NOS course in which the preservice teachers were enrolled modeled several activities that could be used as vehicles to address social-cultural factors influencing science. For example, preservice teachers engaged in a funding activity, historical short stories, and a debate on a socioscientific issue. However, helping teachers move beyond activities they have experienced themselves is a recurring problem. In our study, most of the activities for teaching social-institutional NOS that the preservice teachers then described in their responses to the CoRe reflected activities they had participated in themselves during their NOS course. Previous studies (Akerson et al., 2017; Schwartz & Lederman, 2002; Wahbeh & Abd-El-Khalick, 2014) have also found that preservice teachers have difficulty designing novel NOS activities and tend to mimic activities from their methods or NOS courses. While model activities play an important role in scaffolding preservice teachers' learning of NOS pedagogy (Akerson et al., 2017), Schwartz and Lederman (2002) expressed concern that, "the provision of too many activities may only serve to equip the preservice teacher with a set of procedures and instructions to mimic" (p. 231). Additionally, Donnelly and Argyle (2011) found that teachers who had completed a professional development attempted to utilize NOS activities despite lacking adequate knowledge of NOS which highlights "the possible danger that the provision of engaging, ready-to-go NOS activities may promote NOS instruction that does not meet the *necessary* condition [of adequate NOS knowledge] described in previous literature" (Donnelly & Argyle, 2011, p. 487). To consistently address NOS throughout the school year (Kruse, 2008), preservice teachers will need the knowledge and skills to create and modify NOS activities to fit within a variety of science topics. Thus, future work might investigate how to encourage and support preservice teachers to design their own NOS activities, especially for teaching social-institutional aspects of science.

5.3 Limited Use of Contexts

Preservice teachers may need support for engaging various NOS aspects through a wide variety of instructional contexts. Preservice teachers in our study utilized a limited set of contexts for teaching both cognitive-epistemic aspects of science. That is, participants tended to focus on moderately contextualized and concrete contexts for planning instruction for the inner ring of the FRA wheel. In contrast, but demonstrating a similarly narrow approach, preservice teachers tended to describe highly contextualized and abstract activities for teaching ideas in the outer ring of the FRA wheel. The middle ring of the FRA wheel was more of an even mixture of concrete and abstract activities at different levels of contextualization. Preservice teachers' instructional views seem to increase in contextualization

and abstraction going from the center of the FRA wheel outward. Additionally, preservice teachers seemed more willing to embed cognitive-epistemic NOS as they exhibited a tendency to teach NOS related to the outer rings as its own topic. Thus, preservice teachers may need additional support to help them use highly contextualized and abstract strategies for the inner ring of the FRA, and embed and utilize more concrete strategies for the outer ring of the FRA wheel. We discuss each ring of the FRA and recommendations further below.

For the most part, the preservice teachers in this study described addressing cognitive-epistemic NOS in the context of inquiry-based investigations. Engaging students in a concrete representation of scientific process moderately contextualized in science content was likely viewed as a natural fit since cognitive-epistemic NOS includes ideas about science practices and methods. Additionally, this embedded approach is an efficient way to include cognitive-epistemic NOS since teachers need only to add in a few NOS questions to activities they would likely already be planning to do to facilitate students' learning of science content. Another advantage of concrete, moderately contextualized activities is that students think of classroom investigations as being like real science (Höttecke, 2008; Kruse et al., 2021).

While there are some advantages of using inquiry-based investigations to teach cognitive-epistemic NOS, students are unlikely to develop the “functional” understanding of NOS needed to effectively navigate contemporary science-related issues unless they are asked to consider more authentic contexts (Allchin, 2011). Additionally, Erduran and Dagher (2014) wrote that “the purpose of the FRA as applied in educational settings is neither to teach students individual ideas nor to teach them specific philosophical doctrines about science but rather to promote holistic and contextualized understanding of science” (p. 25). Promoting a holistic account of science means addressing social-institutional factors that interact with the cognitive-epistemic aspects of science (Erduran & Dagher, 2014). Thus, teachers must also know how to teach cognitive-epistemic NOS using highly contextualized, often abstract, activities such as historical short stories or written accounts of contemporary issues (Clough, 2006) also recommended that students be asked to maintain a personal journal throughout their participation in an inquiry-based investigation as a way to provide concrete, but highly contextualized NOS instruction.

The limitations in preservice teachers' instructional views for broader aspects of social-institutional NOS (the outer two rings of the FRA wheel) are likely a consequence of the difficulties of teaching these ideas. Preservice teachers may tend to gravitate toward a “topic” approach because it is simpler to implement. Studies by Kim et al. (2005) and Piliouras et al. (2018) demonstrated that, with increasing knowledge and experience, inservice teachers tended to progress from teaching NOS as its own topic to teaching NOS embedded in content. One reason that teachers may initially tend toward a topic approach to NOS is that it requires less subject matter knowledge to implement. A topic approach requires only a basic knowledge of NOS, while embedding NOS requires a deep understanding of both content and NOS so that connections can be identified between the two subject matters. With social-institutional NOS, in addition to a knowledge of NOS and science content, teachers also likely need an understanding of the social-historical context in which scientific knowledge was/is developed or applied. Historical short stories, which are highly contextualized, are a good scaffold for teachers because they generally include a description of social-cultural context, thus lowering the demand of teaching social-institutional NOS (Clough, 2011). Additionally, while contemporary cases have clearer relevance to students, historical cases

allow students to see how things resolve over time and thus are easier to critique (Allchin, 2011).

Preservice teachers may also view decontextualized approaches as less suitable for teaching social-institutional NOS. Decontextualized activities, such as the mystery tube, may not register as legitimate methods of teaching social-institutional NOS since they involve a “made-up” context. Preservice teachers may view such NOS activities as inauthentic or lacking a representation of the social-cultural factors that influence science in real life (Clough, 2006). However, decontextualized activities may make NOS learning more accessible to students since they can focus solely on NOS rather than dividing their attention between NOS and content learning (Clough, 2006). Furthermore, contexts in which students perceive themselves to be acting like scientists feel more authentic to young learners (Kruse et al., 2021). In a decontextualized mystery tube activity when students have presented lots of ideas and the class is now evaluating the proposed ideas, a question could be asked such as “How is this social evaluation of ideas valuable for science?” to help students learn about the middle ring. To target the outer ring, the teacher might pose a situation in which one of the ideas receives external funding and then asks, “How might the funding influence how the ideas are perceived?”.

Importantly, concrete representations of the social-institutional aspects can also be highly contextualized, but may be difficult to implement on a wide scale. For example, Erduran and Dagher (2014) recommended that, for a more authentic concrete experience, opportunities are available to high schools students in the United States to apply for research grants through “federally sponsored research by the National Science Foundation, 9–12 Program funded by the US-Army research Labs, or STEM grants sponsored by private businesses” (p. 144) to support learning of financial aspects of science. Such concrete activities, regardless of contextualization, are valuable for teaching social-institutional aspects of science to students who highly value the “doing” of science (Höttecke, 2008; Kruse et al., 2021). Teacher educators should both model concrete NOS activities and explicitly discuss the role concrete activities can play in developing students’ conceptions of social-institutional NOS. Given the dearth of high quality curricular materials for addressing social aspects of NOS (Abd-El-Khalick et al., 2017; Summers & Abd-El-Khalick, 2019), it will be important for teacher educators to help preservice teachers develop instructional views that include multiple means of teaching social-institutional NOS.

5.4 Summary

In summary, modeling of effective NOS teaching is important but insufficient for helping preservice teachers develop the necessary instructional views for teaching NOS effectively. After preservice teachers have learned NOS content, their attention must be drawn to particular aspects of effective NOS instruction including the types of questions asked (i.e., specific vs. general) and how particular contexts were used (decontextualized, moderately contextualized, highly contextualized). Preservice teachers are likely to have more difficulty conceptualizing how to teach the social-institutional aspects of NOS. Thus, teacher educators may need to devote extra time to help preservice teachers apply their understanding of NOS pedagogy and designing activities that target social-institutional NOS. Because preservice teachers tended toward moderately contextualized and concrete activities for teaching aspects of NOS in the inner ring of the FRA wheel, but highly contextualized and abstract

activities for teaching aspects of NOS in the outer ring, they may also need additional support to teach the various aspects of NOS through a wide variety of instructional contexts.

6 Limitations

Our study is limited by its somewhat unique context, a lack of teaching observations, and uncertainty as to why preservice teachers choose to discuss certain approaches to NOS instruction. Firstly, there is a wide range of approaches to science teacher preparation programs, and NOS may be introduced in different contexts. For instance, preservice teachers may receive NOS instruction in an NOS course like the one in which this study took place (e.g., Demirdöğen et al., 2016; Herman et al., 2013), a science methods course (e.g., Bilican et al., 2012), across two science methods courses (Bell et al., 2016), a practice teaching course (Bektas et al., 2013), or any other number of specialized courses or workshops (e.g., Cullinane & Erduran 2022). Additionally, some programs may address NOS in a single course or in multiple courses (Kruse et al., 2017). We acknowledge that few programs have a NOS course similar to the one in this study, but hope that our findings can inform NOS pedagogy instruction in various contexts.

Additionally, our study is limited in that we did not observe preservice teachers teach NOS. Enacting NOS instruction presents many challenges beyond simply thinking through procedures (e.g., classroom management), and thus preservice teachers' implementation may not match their stated instructional views. Preservice teachers often struggle to implement student-centered instruction generally even when they recognize the importance of doing so (Akin & Uzuntiryaki-Kondakci, 2018; Schneider & Plasman 2011; Yang et al., 2020), and preservice teachers may not recognize when their NOS instruction is merely implicit (Hanuscin, 2013; Kinskey, 2022). However, teachers' NOS pedagogical views can align well to their enacted instruction (Edgerly et al., 2022). Thus, our study may provide a starting point to think about how teachers develop instructional views that impact instruction, but further research is needed to investigate differences in how preservice implement those views for cognitive-epistemic versus social-institutional NOS.

We also do not fully know why preservice teachers did or did not discuss certain aspects of effective NOS instruction in their CoRes. For instance, if a preservice teacher discussed using only a moderately contextualized activity for teaching some of the cognitive epistemic aspects of science, we are unsure whether that is because they do not know how to use other contexts or do not value other contexts. Prior research has shown that teachers recognize the importance of using multiple strategies for teaching NOS (Faikhamta, 2013; Mesci et al., 2020), but teachers must understand both the importance of knowing multiple strategies for teaching NOS generally and also be able to utilize multiple strategies for teaching one NOS idea. Further investigations may probe preservice teachers' reasoning for their instructional views.

Finally, in addition to the limitations detailed above, this study is also limited by its small sample size, lack of a control group (preservice science teachers not participating in the course), and absence of follow up. It is not known if the preservice teachers in this study maintained their NOS instructional views after the conclusion of the course. Future studies may investigate preservice teachers' development of NOS instructional views on a large scale and over a longer period of time.

7 Conclusion

Teaching NOS effectively involves making sure instruction occurs within multiple contexts and is both explicit and reflective. However, effective NOS teaching is more than the sum of its parts. McComas et al., (2020) wrote:

... how explicit NOS instruction must be, what level of assistance should be provided to students as they wrestle with NOS ideas and issues, how frequently NOS instruction should occur in each of the three broad contexts, and the level of scaffolding that is most optimal cannot be laid out in an algorithm (p. 73).

Rather, teachers must have the knowledge to make real-time decisions about how they will teach NOS based on their instructional context and knowledge of students as well as their knowledge of how people learn and goals for students (Clough et al., 2009). Not only must teachers know how to guide students in making connections between NOS ideas learned at different levels of contextualization (Clough, 2006), they must also help students make connections between different aspects of NOS (Erduran & Dagher, 2014; Peters-Burton et al., 2019). While we recognize that NOS teaching is significantly more complex than what is portrayed in this study, we view a knowledge of multiple instructional strategies for teaching the various aspects of NOS as a precursor to helping preservice teachers make such important connections. We hope our work provides a starting point for understanding how to help preservice science teachers develop the multifaceted instructional views, dispositions, and skills necessary for effective NOS teaching.

Declarations

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