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Developing Epistemic Empathy: Shifting Approaches to NOS Teaching

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ABSTRACT

Despite decades of research, NOS is still rarely explicitly and accurately taught in K-12 schools (Abd-El-Khalick & Lederman, 2023). To improve NOS teaching at the K-12 level, it is important for teacher educators and researchers to experience, understand, and acknowledge the daily work of teachers and how that influences teaching NOS in the classroom. In this paper, we describe how teacher educators and researchers can develop greater *epistemic empathy* – an understanding and appreciation of the cognitive and emotional experiences of teaching NOS – through participating in experiences that resemble those of the preservice and inservice K-12 teachers they work with. We illustrate this idea through a discussion of lessons learned through a self-study of the first author's experience teaching NOS in a middle school classroom.

Keywords: nature of science, teacher education, epistemic empathy

Introduction

An understanding of nature of science (NOS) – what science is, how it works, and how scientists operate as a social group within society – is frequently cited as a prerequisite to the development of scientific literacy (Allchin, 2011; Erduran & Dagher, 2014). Yet, Abd-El-Khalick and Lederman (2023) argue that, despite decades of research, NOS is rarely explicitly and accurately taught in K-12 schools. Researchers have attributed this outcome to teachers' lack of adequate knowledge of NOS (Bilican et al., 2021; Brunner & Abd-El-Khalick, 2020), pedagogical knowledge (Hanuscin et al., 2011), and/or a rationale for NOS teaching (Herman et al., 2017). Consequently, interventions aimed at improving NOS teaching have often been designed to provide pre- and inservice teachers with instruction on academic perspectives of NOS and reinforce research-based practices for NOS teaching (e.g., Brunner & Abd-El-Khalick, 2020; Mesci et al., 2020; Wahbeh & Abd-El-Khalick, 2014). However, Stroupe et al. (2024) recently challenged the way researchers position teachers with respect to the construct of NOS. In a review of NOS literature framed by the concept of epistemic injustice, Stroupe et al. found researchers often positioned teachers' knowledge and pedagogy from a deficit perspective; they noted, "teachers' pedagogy is inherently deficient if they do not exhibit an understanding of NOS established by researchers…teachers are viewed as inadequate because the teachers do not meet predetermined criteria for knowledge set by NOS researchers" (p. 927). Stroupe et al. invited NOS researchers to work toward a more expansive vision of science that positions learners and teachers from an asset-based perspective.

To develop an asset-based perspective, we view it as important for teacher educators and researchers to experience, understand, and acknowledge teachers' daily work, adopting a more holistic view of their practice. Yet, at the start of this study, I (the first author) was a teacher educator and NOS researcher with limited experience teaching NOS to K-12 students. Other science teacher educators have found that self-study (LaBoskey, 2004) conducted in elementary classrooms has supported them in developing an identity as a teacher of NOS and, in turn, better understand their preservice teachers' experiences and support them in learning to teach NOS (Akerson et al., 2014). For this reason, I chose to complete a student teaching experience in a middle school classroom as part of my doctoral program. I conducted a self-study to document and navigate the tensions of teaching (Berry, 2007) I encountered as I learned to teach NOS to middle school students. In this paper, I present the findings from this self-study, highlighting how the experience helped me develop epistemic empathy (Jaber et al., 2018) — an understanding and appreciation of the cognitive and emotional experiences of teaching NOS— and rethink my practice as a teacher educator.

Epistemic Empathy

Epistemic empathy is both "the act of understanding and appreciating someone's cognitive and emotional experience within an epistemic activity, meaning an activity aimed at the construction, communication, and critique of knowledge" (Jaber et al., 2018, p. 14) and an "asset-based orientation to all learners as sensible meaning-makers whose ideas and emotions are worthy of attention … and a genuine desire to listen and understand them" (Jaber et al., 2024, p. 143). Epistemic empathy creates a "bridge" between teacher and student points of view in that it leads teachers to listen closely to students, recognize ways student ideas and experiences might be valuable to their science learning, and support students' sense-making through inquiry (Jaber et al., 2024, p. 143). In the classroom, epistemic empathy might look like responding to a student's idea with curiosity and taking the time to understand their thinking as opposed to immediately dismissing ideas that seem not to align with canonical science knowledge.

Teachers can develop greater epistemic empathy through opportunities to participate in learning experiences that resemble those of their students and think deeply about student ideas. Jaber et al. (2022) found that for inservice elementary and middle school teachers engaged in professional development, “first-hand experience with the disciplinary practices of science and the feelings that arise within inquiry (such as excitement, frustration, and vulnerability) helped [teachers] better understand and appreciate their students' experiences in the classroom” (p. 242). Additionally, Jaber et al. (2018) found preservice teachers demonstrated more epistemic empathy when they were repeatedly invited to take a student perspective while examining student work or participating in inquiry. As they develop greater epistemic empathy, teachers reshape their roles and goals as science teachers to prioritize the sense-making process over the acquisition of canonical science knowledge (Jaber et al., 2021; Jaber et al., 2022). Therefore, epistemic empathy facilitates an asset-based mindset.

Research on epistemic empathy has tended to focus on preservice (Jaber et al., 2018; Jaber et al., 2021; Jaber et al., 2024) and inservice (Jaber et al., 2022) teachers, but we argue the principles can also apply to teacher educators and NOS. During teacher preparation, preservice teachers begin to develop the knowledge and skills to teach NOS (i.e., pedagogical content knowledge for NOS) under the guidance of teacher educators. Preservice teachers learn what NOS is, how NOS aligns with science standards and curricula, strategies for teaching and assessing NOS, how to adapt NOS instruction to specific students, and a host of other knowledge and skills (Hanuscin, 2013). This learning about NOS teaching, like all learning, is both a cognitive and emotional experience (Akerson et al., 2014). Just as the teachers in prior studies on epistemic empathy (Jaber et al., 2022; Jaber et al., 2024) developed a greater appreciation for the learning experiences of their K12 students by learning science content in student-centered and inquiry-based ways, teacher educators may develop greater epistemic empathy through immersion in teaching and learning experiences that approximate those of preservice teachers who are learning to teach NOS to K12 students. We expect that, as with other studies of epistemic empathy, reflections on such experiences would likely compel teacher educators to re-examine and reframe their priorities for science teacher education.

Tensions

The Refined Consensus Model of Pedagogical Content Knowledge describes the development and application of teachers’ professional knowledge as influenced by amplifiers and filters related to personal factors (teacher beliefs and attitudes) as well as the learning context (Carlson et al., 2019). Thus, preservice teacher beliefs and attitudes exert a significant influence on their learning and instructional decision-making, including how they develop and apply their knowledge and skills for teaching NOS. Yet, while teaching practice is understood to be influenced by the multiple beliefs teachers hold (often embodied in particular instructional aims such as promoting science achievement, helping students develop their capacity to learn independently, cultivating skills for productive collaboration, creating a sense of community and belonging in the classroom, and supporting the development of students’ science identities), it is well-documented that preservice teachers’ practices often appear out of alignment with their knowledge and/or beliefs about NOS teaching (Cullinane & Erduran, 2023; Hanuscin et al., 2011; Wahbeh & Abd-El-Khalick, 2014).

One explanation for discrepancies between preservice teacher beliefs and practice is that, under certain circumstances, a teacher's aims lend themselves to contradictory courses of action. That is, in making a particular choice, a teacher works toward one aim while working against another. For instance, in certain situations, a decision to support a student in learning to work independently may result in fewer opportunities to collaborate with peers – an instructional decision that would appear out of line with a teacher's belief in the importance of collaboration and community-building. Because teachers seek to exemplify sometimes contradictory beliefs and aims, their practices are characterized by tensions (Berry, 2007), making tensions a useful frame for studying teacher practices and reflections (Vanassche & Kelchtermans, 2015).

Where prior research on NOS tends to focus on deficiencies in preservice teachers' practices and attribute them to a lack of knowledge about NOS and/or NOS teaching (ie., assigning the blame to preservice teachers), a 'tensions' framework embodies a more empathetic and asset-based stance. Building on Stroupe et al.(2024)'s work on epistemic injustice in NOS research, a 'tensions' framework positions preservice teachers as knowers and doers navigating multi-faceted decisions in a complex environment while working to further their personal learning and practice. Even when preservice teachers teach NOS in ways that are out of alignment with their personal beliefs and/or research-based recommendations, they are drawing on specific knowledge and skills to meet alternative aims. These knowledge, skills, and aims are assets that can be leveraged to support preservice teachers in developing their professional knowledge for teaching NOS.

Self-Study

To produce insights that might be useful to other teacher educators and not only ourselves, we utilized a self-study approach (Laboskey, 2004). Self-study is a qualitative methodology that provides an account of both what we learn as teachers and how we learn it. As Pinnegar and Hamilton (2009) wrote, "Most of what we know about teaching and teacher education practice resides in the hearts, minds, and actions of teachers and teacher educators" (p. 5). Self-studies demonstrate how teachers navigate different problems of practice and work to more closely align their practices with their personal values (Berry, 2007; Dinkelman, 2003). Self-studies are useful for teacher educators seeking a greater understanding of the challenges of teacher preparation (Dinkelman, 2003; Mueller, 2003) and have proven an effective means of improving practice (Bullock, 2020; Demirdöğen et al., 2015; Zeichner, 2005). Teacher educators develop greater empathy for the preservice and inservice teachers they support as they work to develop deeper self-understanding of their personal practices and challenges (Kitchen, 2005).

Context

I (first author) collaborated with colleagues (collaborating authors) to conduct a self-study with the goal of developing a deeper understanding of the experience of teaching NOS to K-12 students. Prior to the study, I completed graduate courses on the nature of science informed by a version of the consensus view (e.g., Lederman, 1992) in which NOS issues are framed as questions (Clough, 2007) as well as by the family resemblance approach to NOS (Erduran &

Dagher, 2014). The courses were designed to address both NOS and NOS teaching, and emphasized the importance of approaches that intentionally elicit NOS ideas during classroom instruction (Khishfe & Abd-El-Khalick, 2002) through a variety of question types (Kruse et al., 2022; Wilcox & Lake, 2018) and scaffolded instructional contexts (e.g., decontextualized activities, inquiry-based science, historical and contemporary issues) (Clough, 2006; Kruse et al., 2021). I also had three years of experience teaching a variety of courses to preservice and inservice teachers, including science methods courses and a dedicated NOS course. However, I had limited experience teaching NOS to K-12 students. While I had completed practica in middle school and high school classrooms as part of a graduate degree in education, I had never served as a teacher of record in a K-12 classroom. Therefore, I opted to student-teach as part of my doctoral program to gain a greater appreciation for the experience of teaching full-time.

I was placed with a middle school STEM teacher (third author) in a rural-suburban middle school in the midwestern United States. The school district enrolls approximately 2,300 students across four schools: a high school, a middle school, and two elementary schools. In this school district, 89% of students are White, 3% are Black, 4% are Hispanic or Latino, 2% are Asian, and 1% are two or more races. As part of my placement, I taught in three sections of sixth-grade STEM and two sections of eighth-grade physical science. Each section had approximately 20-25 students and met for 90 minutes every other day.

Sixth-grade STEM was an elective course that engaged students in project-based learning. Students designed orthotics for children with cerebral palsy, created blueprints and models of puzzle cubes to utilize extra wood from a fictional furniture company, and used 3-D modeling to design a home for one of several fictional families. I was also asked to pilot a place-based science unit developed by a team from my university in partnership with our local waterworks facility in my sixth-grade sections. Eighth-grade physical science was required for all students. My student teaching semester occurred within the first year that all eighth graders at the school had to take physical science at a high school level for high school credit. During the fall, the eighth-grade physical science course covered units on Earth's internal processes, geologic time and dating of rocks and fossils, climate, and stars and galaxies.

Data Sources and Analysis

Weekly video diaries were the primary source of data for this self-study. Secondary data sources included lesson plans, student artifacts (note sheets, worksheets, bellringers, and exit tickets), and classroom video recordings. Additionally, I kept a reflective journal throughout the process. Data analysis began with a review of video diaries to identify critical incidents within my experience (Tripp, 1993). These arise from questioning taken-for-granted understandings, beliefs, and assumptions in ways that generate new meaning, and are not necessarily "critical" in the sense of being negative. Then, drawing on additional available data sources related to each incident (e.g., student artifacts, reflective journal, classroom recordings), I constructed narrative vignettes to represent the tensions (Berry, 2007) at the center of each critical incident. Collaborating authors served as critical friends (Fletcher et al., 2016), providing alternative explanations of various experiences, helping identify tensions within my practice, and providing feedback on narratives in an iterative process.

Findings

Narrative vignettes represent both a process and product of the analysis in that they were used as both a tool for reflection and learning from the study (Ambler, 2012; Asim et al., 2023) and a means to represent a complex data set in a way that speaks to and supports the efforts of other teacher educators (Ambler, 2012; Angelides & Gibbs, 2006; Berry, 2007). Below, we share three vignettes that represent my experience teaching NOS to middle school students. We then discuss lessons learned from that specific experience and, more generally, putting ourselves in the shoes of our students.

Vignette #1: A Little Bit Hypocritical

At the beginning of today's lesson, students made predictions about what would happen when I poured a cup of dirty water through an opaque water dispenser, and then shared those predictions with their classmates. After talking about their predictions, students recorded their answer to the question "Why do scientists share all of the things they find?" on a worksheet. Once they had a chance to write down their ideas, we discussed them as a class. Students shared a variety of reasons why scientists might collaborate, mostly focusing on how they could gain more, better ideas by working together. I accepted all student responses, and then we moved on. I had wanted students to understand that science is collaborative, and they gave me a lot of reasons why scientists share, so I felt like I could check "collaborative NOS" off my list.

Later, I reviewed students' responses to the worksheet. About half of the students wrote that sharing ideas made science better, similar to what we had discussed in class. Another quarter wrote about how science is inherently collaborative, so sharing ideas is just part of the job. So far, so good. Finally, a handful of students wrote about why scientists might NOT want to share their ideas. Initially, I felt a little displeased – we had just very clearly talked about how and why scientists share ideas with each other as a class! How did these students get it wrong? Did they not read the question? However, I felt chastened as I read through their responses: "Because they get paid a lot, "Well you can't tell the other scientist because if you tell them then they copy off you and they're gonna get more but it was off you, "So they gain popularity." These students recognized the competitive nature of science – how scientists may be rewarded with money or fame for novel ideas, so might not want to share them with other scientists. The students weren't wrong, it was just a different angle. I wanted my students to understand that collaboration in science is important because we all have different backgrounds and perspectives, but I had just shut out a very important one in my own classroom. I was so concerned about making sure students had the "correct" understanding of NOS that I trampled over one of my most important personal commitments as a teacher – to help students feel valued and to appreciate the diverse ideas of others. I need to do more *thinking about how to challenge and deepen students' ideas about the nature of science while also making space for multiple perspectives.*

Lesson: NOS Must be Connected to Teachers' Broader Purposes for Teaching

My transition to a K-12 classroom induced a great deal of cognitive conflict as I realized I could plan what I thought were the most well-designed NOS lessons – what I might have considered 'A' work as a methods instructor– and those lessons could still fall flat. While I might have believed NOS was one of the most important parts of science teaching, I quickly learned that things went more smoothly in the classroom when I centered students' thinking more than a particular subject matter. Through reflecting on the positive experiences I had in the classroom, I remembered why I returned to school to become a teacher; I wanted to help students learn and grow, and I hoped to create a space where students felt valued and could develop confidence in themselves as science learners. Through reflection on my experiences, I began to situate NOS within my practice in new ways that align with my commitments as a teacher. NOS is, for me, becoming a means rather than an end unto itself. This way of thinking about NOS can be contrasted with my experience as a researcher, where an understanding of NOS is the outcome on which we focus and measure.

Preservice teachers' knowledge development during teacher preparation is "guided by the goals of a student rather than by the goals of a full-fledged teacher" (Hutner & Markman, 2017, p. 724). Goals such as mastering course material, getting good grades, and impressing the instructor may all play a role in motivating preservice teachers in methods courses. Once teachers are removed from training, these 'student' motivations are effectively nullified, replaced by the realities of working with students, colleagues, and administrators. Therefore, it's important to consider and connect NOS to teachers' personal purposes for teaching science – the lasting goals and experiences that brought them into the field in the first place. Teaching NOS has to matter beyond satisfying the requirements of the methods course.

Vignette #2: Am I Making It Worse?

At the end of our last unit, when asked why scientists might have changed their minds about how long people have lived in North America, students called out things like, "I think this is all made up!" and "I don't believe them!" Those were not the ideas I had anticipated I would hear. Students' responses may have been just a bit of silliness, but I'm still afraid some students' trust in science is eroding … and I wonder if it's my fault.

At the beginning of the semester, students described stereotypical views of science: science as an objective endeavor characterized by its close adherence to a single, step-by-step method. I worried that if students viewed science as entirely objective, they wouldn't appreciate the importance of collaboration across diverse perspectives and scientific consensus. So, I pushed students to think about ways scientists' work might be influenced by their prior knowledge and experiences as well as broader sociocultural

> *factors. Now, students seem to grasp that idea, but perhaps they view science as a little too subjective. I know I need to aim for a middle ground in students' understanding: a knowledge of the particular ways science works toward objectivity, coupled with an appreciation for the fact that human endeavors are inherently subjective. Yet, discussions like the one we had today make it hard not to question whether I have the skills to guide students there. Sometimes I wonder if my NOS teaching is really helping students become more informed citizens or if I'm just making things worse.*

Lesson: Teaching NOS is Both a Pedagogical and Emotional Experience

Sometimes choosing to teach (or not teach) NOS had more to do with my emotional state than my knowledge or pedagogical skills. Prior to student teaching, I taught a NOS methods course and published multiple research articles about teaching and learning NOS; so I began the semester feeling confident in my ability to teach NOS. However, as time wore on, the increasing discrepancy between my high expectations and my actual instruction resulted in feelings of disappointment and discontentment. Sometimes, discontent with my instruction led me to double down on my efforts to teach NOS. More often, I felt overwhelmed by my classroom responsibilities and discouraged when things did not go well despite my best efforts.

Other researchers have described ways teacher emotions rooted in classroom experiences influence NOS teaching. Both Akerson et al. (2014) and Lane and Johnston (2022) found that teachers feel anxious about NOS teaching when they question their competence, while Wahbeh and Abd-El-Khalick (2014) noted that teachers can feel embarrassed and frustrated when their NOS instruction ends up reinforcing stereotypes of science. Yet, other studies have described the strain and overwhelm teachers may experience as they seek to balance science content and NOS instruction (Hanuscin, 2013) or manage a classroom during inquiry-based activities (Akerson et al., 2017). My student teaching experience provided a more empathetic view of teachers' "preoccupation with classroom management and other survival issues" (Abd-El-Khalick, 2013), in ways that I now try to use to validate, rather than devalue, their emotional experience. Supplying teachers with techniques and strategies might be an act of care, but empathy requires rooting that support in an understanding of both the cognitive and emotional experience of teaching NOS.

Vignette #3: Why Do We Have to Do This?

> *It was near the end of my student teaching, so time for the eighth graders to take a questionnaire to assess their NOS views. The students were not happy at all. They opened the form and immediately expressed their resistance: "How many questions is this?!", "This is going to take FOREVER!", "Why do we have to do this?". I tried to reassure students that all they had to do was click to indicate the extent to which they agreed or disagreed with each statement, most students would finish the assessment in 15 minutes, and it wouldn't be graded. I just wanted to see what they learned throughout the semester. Alas, they were not really buying it and continued to express their discontent. I was relieved when all the students completed the questionnaire because I felt so guilty while they were taking it. There wasn't a clear benefit of the questionnaire to the students*

– it was something they were doing for me, and they knew it. Come to think of it, what was I even doing giving them a research instrument as an ungraded questionnaire?

As I reflected on this episode, I finally understood the problem that plagued me throughout the student teaching experience. I hadn't approached my NOS instruction as a ***teacher****. I felt comfortable and successful as a* ***learner*** *and* ***researcher*** *of NOS, and held tightly to those roles throughout the semester. Based on what I learned during teacher preparation and research, I had many ideas about what students 'should' know about NOS, how I 'should' approach NOS teaching, and how students 'should' respond to my teaching. I generally based my instructional decisions on these 'shoulds.' Yet, time and time again, I saw how my naive expectations were no match for the complex realities of the classroom. Translating my knowledge of NOS to teaching practice required considering a variety of contextual, personal, and student factors that interacted with each other within a constantly shifting classroom landscape. With tests to prepare for, individual students to support, and the unending challenge of developing my classroom management skills, I felt I was always running out of time and energy to realize my intentions. Perhaps unsurprisingly, my NOS teaching fell well short of what I hoped for, and I often felt discouraged. I had much more work to do to figure out how to situate NOS within my practice.*

Lesson: Contextualizing NOS Teaching is as Important as Contextualizing NOS

Nature of science researchers have stressed the importance of considering the role of context in NOS instruction. In a review of research on NOS teaching by McComas et al. (2020), the "role of context" was identified as one of the primary aspects of NOS teaching alongside explicit attention to NOS and the promotion of students' mental engagement with and reflection on NOS. Researchers recommend teaching NOS within the context of accurate representations of scientific work, such as inquiry-based experiences, historical short stories, or contemporary episodes (Clough, 2006; Cofré et al., 2019). NOS instructional activities can vary in the extent to which NOS is contextualized within science content and/or sociocultural context, and different contexts have different advantages (and disadvantages) for students' learning (Clough 2006; Kruse et al., 2021).

Little attention has been paid to how NOS teaching is contextualized more broadly within the goals a teacher may have for instruction and their students. The majority of NOS studies (e.g., Voss et al., 2023) focus almost exclusively on how teachers' NOS views and pedagogy align (or do not align) with objectives for NOS understanding developed through research on NOS. However, this vignette draws attention to varied aims – like thoroughly addressing NOS ideas and centering students' experiences, as well as other personal and contextual factors like my discouragement with teaching and student attitudes – that influenced my decision-making around NOS. Berry (2007) noted that teachers' practices are guided by many aims and values that sometimes conflict, so teachers may reasonably choose to prioritize other aims under different circumstances. Contextualizing NOS teaching means looking at a teacher's practice more holistically to try to understand their reasoning for instructional decisions rather than evaluating their teaching based simply on whether they are or are not observed addressing NOS according to research-based recommendations.

Rather than viewing teachers' decentering of NOS in their practice as a failure to internalize the importance and utility of teaching and learning about NOS (Abd-El-Khalick & Akerson, 2004), we must recognize that teachers are seeking to balance multiple worthy goals with the complex and varied needs of their students and demands of their teaching contexts. While teachers may work toward multiple goals with the same instructional decision (Clough et al., 2009), these decisions may be more difficult for novice teachers to navigate; for them, teaching involves a higher degree of novelty and uncertainty, resulting in a higher cognitive load and increased cognitive strain when compared to more experienced teachers (Blackley et al., 2021). Exercising epistemic empathy means acknowledging and appreciating preservice teachers' reasoning for each instructional decision, even when their decisions, as revealed by their observable classroom practices, do not appear consistent with what is considered effective NOS instruction.

Developing Epistemic Empathy through Self-Study

In this paper, I have provided an account of my (first author's) experience as a teacher educator teaching NOS to middle school students, and how that experience led me to re-examine my beliefs about science teacher education and strengthen my knowledge and practice. At first, during student teaching, I viewed the limited nature of my NOS teaching as a deficit – I focused on what I wasn't doing (teaching NOS) and felt discouraged. When I took time in self-study to reflect on why I prioritized other aims, I came to recognize the often valid reasons why I sometimes made decisions in service of alternative cognitive and affective instructional goals. This shift in perspective on my own teaching, in turn, prompted me to reframe the way I viewed NOS teaching and rethink how I might best support teachers in preparing to teach NOS. Where I once attributed a lack of effective NOS instruction to the challenges of teachers' inadequate science content knowledge (Wahbeh & Abd-El-Khalick, 2014; Akerson & Abd-El-Khalick, 2003), knowledge of NOS (Bilican et al., 2021; Brunner & Abd-El-Khalick, 2020), and pedagogical knowledge (Hanuscin et al., 2011), the student teaching experience showed me how NOS teaching might be better characterized as tensions teachers navigate as they manage competing demands (Berry, 2007).

Re-framing NOS teaching from challenges to tensions has helped me view the practice of NOS teaching more holistically and identify assets in teachers' knowledge, beliefs, and practices that can be built on to improve their NOS instruction. For instance, rather than taking a deficit view of a teacher who is engaging students in an inquiry-based science activity without asking students questions about NOS and labeling them as lacking the pedagogical knowledge and/or skills to teach NOS explicitly and reflectively (Khishfe & Abd-El-Khalick, 2002), I can identify their strengths in providing student-centered instruction that is epistemically consistent with authentic science – an important foundation for NOS teaching (Hanuscin & Hiann, 2009), and also some admirable practices in and of themselves. When preservice teachers experience tension between their desire to teach science content and NOS, or between devoting time to engaging in science practices versus discussing the scientific endeavor, I draw on my personal experiences with teaching NOS to middle school students to demonstrate epistemic empathy. NOS instruction is just one among many worthy aims teachers have, and there are times when it makes sense to privilege priorities other than NOS. Rather than trying to impart to teachers the knowledge I think they lack, I consider "How do I support them in navigating this complex situation?" and "What are they already doing well, and how can they leverage these strengths?" I hope my validation of the tensions teachers experience, as well as the difficult experience of navigating those tensions, helps preservice teachers feel less anxious about being viewed as unknowledgeable or a failure when they don't teach NOS.

I believe I can also support preservice and inservice teachers by providing them with opportunities to practice navigating NOS-related tensions within the broader context of science teaching. Vignettes, like the one in this article, may be a useful educational support for making tensions related to NOS teaching visible to teachers and giving them an opportunity to think through how they would navigate those tensions. Vignettes provide teachers with an authentic representation of practice (Grossman, 2009a; 2009b) to learn about NOS teaching with the support of teacher educators and without the added complexities (and classroom management concerns) of a real classroom. Additionally, because vignette-writing is a tool for teacher learning (Ambler, 2012; Asim et al., 2023; Davis et al., 2007), pre- and inservice teachers could benefit from opportunities to identify tensions within their own NOS teaching and construct vignettes to represent those tensions. Through vignette-writing, teachers can develop stronger self-understanding of their NOS-related practices and beliefs, and ideas for how to better align them (Asim et al., 2023).

Lastly, through reflection on my classroom experiences, I realized an understanding of NOS was a 'peripheral' rather than a central goal for my teaching (Friedrichsen & Dana, 2005). This is likely the case for many teachers as Demirdöğen (2016) found "Unless teachers' beliefs about the NOS relate to their purposes, they do not attempt to teach the NOS" (p. 518). Therefore, I decided I could best help preservice teachers develop a rationale for NOS by helping them first clarify their personal goals for science teaching, and then identifying connections between those goals and the messages students might receive about science within their classroom. For example, a teacher who desires to empower students to advocate for their communities might be interested in teaching how science is influenced by societal factors, including cultural values, political power structures, and financial systems (Erduran & Dagher, 2014; Jones, 2024). Alternatively, a teacher who hopes each student will see science as a possible career path may be interested in teaching about how science is empirical, but also collaborative and creative in nature (Lederman, 1992). In this way, the broader purposes that bring preservice teachers into the field of science education serve as resources on which to build an identity as a teacher of NOS and a great starting point for instruction.

Looking Forward

A little over a year and a half after my student teaching experience, I unexpectedly found myself the instructor of another group of preservice elementary teachers. During the last week of the quarter, as the students in my course were busily working in groups to plan a unit they would enact in practicum in the fall, I saw one of my students' hands shoot up from across the room. I wandered over to the student and saw they had their lesson plan template pulled up and nearly complete. The student looked at the very bottom of the template – a section where they were prompted to describe connections between their lesson and various dimensions of the NGSS … and the nature of science, and asked, "What is the nature of science?"

I suddenly realized I had not explicitly defined nature of science for my methods class. We reflected on our prior experiences with science and the messages those experiences sent us about what it means to do science. We read diverse scientists' writings about their thinking about science – their motivations and methods – and discussed what science really looks like. We discussed ways to demonstrate respect for Indigenous Knowledge in the classroom, and the value of ways of knowing about the natural world other than Western Science. Yet, I never told students that what we were learning about was called "nature of science". I asked the preservice teachers explicit and reflective questions about NOS, but I hadn't focused on teaching about the nature of science as its own goal.

I began my response: "Nature of science refers to ideas about what science is, how it works, and what it means to be a scientist." I knew the next part would be harder. I paused and considered – what do I want her to know about NOS? Why did I choose not to define science for her? Then, I remembered that, for me, it wasn't really about what I wanted this student to know. It was about helping her think through her own goals and vision for science teaching. I asked, "What do you want your students to know about science and scientists? If students participate in your lesson, how will they know that? How will they know they belong in science?" Moments like these reveal to me how much my practice as a teacher educator has changed as a result of self-study, and also how many challenges I have yet to navigate.

No amount of reading, studying, or conversing with others could have made me understand what it was like to teach NOS in middle school. As a colleague explained: I knew things in my head before, now I know them in my heart. This new depth of understanding, in turn, prompted me to rethink my approach to teacher education. Through self-study, I became "increasingly aware that I often acted as an expert judging the practice of teachers using external criteria rather than as a collaborator celebrating experience and seeking to help teachers discover order in the flowing, changing process of life" (Kitchen, 2005, p. 18). I had fallen into the deficit view of preservice teachers described by Stroupe et al. (2024). Yet, through experience, my perspective on NOS has shifted to view NOS not as the ultimate goal, but a means for achieving other goals– for me, as well as for my preservice teachers. I have learned I can enact a more expansive vision of NOS and take an asset-based view of preservice teachers (Stroupe et al., 2024) by helping them understand how bringing up questions and examples of what science is and how it works (i.e., NOS) can help further their goals for themselves and their students.

Through the self-study experience, I have also developed a greater openness to what and how preservice teachers teach what science is, how it works, and what it means to be a scientist. I aim to support teachers in thinking about science – with the understanding that 'science,' as well as how and why it's addressed, may look different in different classrooms. This is not to say "anything goes" as far as NOS teaching, but I believe we can find space for more flexibility in what and how we teach about NOS. Many researchers have argued NOS ideas are better viewed as controversies (e.g., subjective vs. objective) (Kötter & Hammann, 2017), questions (e.g., To what extent is science creative?) (Clough, 2007), or categories of ideas (Erduran & Dagher, 2014); and non-Western ways of knowing about the natural world (e.g., Indigenous Knowledge) are often overlooked and/or disregarded (Ogunniyi, 2020). Wherever teachers and/or students are at in their thinking about the scientific endeavor is the perfect place to start pushing them to think more deeply about NOS and NOS teaching.

Rather than providing final answers about what effective NOS instruction looks like in teacher preparation, we view this self-study as an invitation for teachers and teacher educators alike to raise questions about their personal goals for NOS teaching and under what circumstances they are most successful at teaching NOS and why. In answer to Stroupe et al.'s (2024), we propose that teacher educators and researchers can develop greater epistemic empathy through self-study, thus paving the way for more equitable NOS teaching and learning.

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