Chapter 13
Preparing Science Teachers to Overcome Common Obstacles and Teach Nature of Science

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13.1 Current State of NOS Teaching and Learning

Calls for school science to promote among students a more accurate understanding of the nature of science (NOS) have a long history, beginning as far back as at least the mid-nineteenth century (Matthews 2012). Beginning with *Project 2061* (AAAS 1989), most science education reform documents (AAAS 1993, 2001; McComas et al. 2009; McComas and Olson 1998; Olson 2018; NRC 1996; NGSS Lead States 2013) have emphasized the crucial role that NOS understanding plays in scientific literacy (Hodson 2009). The emphasis on promoting accurate NOS understanding is well justified because of the role such understanding plays in:

- Considering, understanding, and accepting many science ideas such as biological evolution (Clough 1994; Dagher and Bou Jaoude 2005; Rudolph and Stewart 1998), the law of pendulum motion (Matthews 2014), and global climate change (Herman 2015; Clough and Herman 2017), to name just a few.
- Improving attitudes toward science, science careers, and science classes (Arya and Maul 2012; Eccles 2005; Hong and Lin-Siegler 2012; Tobias 1990).
- More informed socioscientific decision-making (Allchin 2011; Clough and Herman 2017; Mitchell 2009; Rudolph 2007; Zeidler et al. 2013).

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Despite the long-standing consensus regarding the importance of accurate NOS teaching and learning, the most recent survey of NOS in science teacher education programs in the United States (Backhus and Thompson 2006) determined that "at most perhaps 6% of preservice 9-12 science teachers will have taken [a NOS course] as a requirement." However, because NOS issues are inextricably linked to science content and how science is taught, science teachers convey the NOS regardless of their intent (Clough and Olson 2004). Science instruction and curriculum materials that merely present science content without accurately addressing how such knowledge was developed and came to be accepted, typical media portrayals of science and scientists, cookbook laboratory experiences, and standard laboratory reports all contribute to promoting and supporting NOS misconceptions (Clough 2006; Hodson 2009). Altogether, science is presented in a sanitized way that results in a plethora of misconceptions (Clough 2017), some which include wrongly thinking that (a) well-conducted science research follows a rigid scientific method; (b) scientists should and can be objective in their work; (c) scientific ideas arise directly from data and are supported unambiguously by data; (d) science, when well done, produces absolute truth while knowledge falling short of that status is unreliable; and (e) anomalies demand rejection of science ideas.

13.2 Accurately and Effectively Teaching the NOS

Highly effective NOS instruction shares the same fundamental principles as effective science content instruction. First, teachers must accurately understand the NOS. Second, NOS instruction should be purposely planned and implemented consistently in science instruction. While teachers who effectively teach the NOS seize opportunities that arise unexpectedly during instruction (Herman et al. 2013a), they see NOS learning as a cognitive outcome and also overtly plan how to achieve it. This is no different than overtly determining what science content students should learn, the depth that they should learn it, and planning instruction to meet those objectives. Third, effective NOS instruction demands that teachers overtly draw students' attention to targeted NOS issues and ideas, and do so in a manner that mentally engages students in wrestling with those ideas (Abd-El-Khalick and Lederman 2000; Khishfe and Abd-El-Khalick 2002; Khishfe and Lederman 2006). This, of course, is the case when teaching any science content. For instance, effectively teaching about pendulum motion demands that teachers purposely draw students' attention to key features and factors of pendulum motion in a way that has students think about, wrestle with, and confront their misconceptions in order to come to an accurate and deep understanding of the law of pendulum motion. Fourth, effective NOS instruction occurs in a variety of contexts ranging from decontextualized (devoid of science content), moderately contextualized (associated with science content instruction, but with missing or trivial links to the authentic work and/or words of scientists), to highly contextualized (using the work and words of authentic scientists) with significant scaffolding back and forth between those contexts

(Clough 2006, 2017; Bell et al. 2016). Fifth, particular instructional settings present important opportunities for addressing NOS. For example, Allchin (2011), Herman (2015), Hodson (2009), Khishfe (2014), and Sadler et al. (2004) emphasize the importance of addressing the NOS when investigating socioscientific issues. The empirical work of Herman et al. (2013a) provides evidence showing that effective NOS instruction is significantly aided when teachers implement more general reforms-based science teaching practices (GRBSTPs) such as teaching science through inquiry, requiring extensive student decision-making, and asking questions that assist students in meaning-making. They write:

> In summary, implementing inquiry laboratories and other activities that require student decision-making appear to be the GRBSTPs most important for *creating opportunities* for accurate NOS instruction. Asking thought-provoking extended answer questions and playing off students' ideas in ways that scaffold them to desired understandings appear to be the most important GRBSTPs for *seizing on opportunities* to effectively teach the NOS. Implementing inquiry experiences and other activities that require considerable student decision-making and teachers' proficiency at asking highly effective questions together are important "tools" for NOS implementation efforts whether purposely planned for or arising unexpectedly in the act of teaching a lesson. These tools also make accurately and effectively teaching the NOS a far more natural part of everyday instruction. (Herman et al. 2013a, p. 1094)

Finally, students' NOS understanding must be accurately assessed in a variety of ways (e.g., homework, teacher-developed assessments, and high-stakes exams), for as Dall' Alba et al. (1993) and many others note, "assessment gives clear messages to students about what is important in the subject" (p. 633).

13.3 Obstacles That Interfere with Effective NOS Instruction

Despite science education reform documents calling for accurate NOS instruction (McComas and Olson 1998; McComas and Nouri 2016; Olson 2018), science teachers who want to accurately and effectively teach the NOS often encounter many substantial obstacles that interfere with their efforts. These obstacles derive from sources outside and within the schooling system, and together they make inaccurate NOS instruction or, at the very least, inattention to accurate NOS instruction far safer and easier. Over two decades ago, Lakin and Wellington (1994) wrote that accurate NOS instruction appears to be contrary to "expectations held of science and science teaching in schools, not only by teachers and pupils but also those perceived as being held by parents and society" (p. 186), a situation that continues unabated (Abd-El-Khalick et al. 1998; Bell et al. 2000; Clough and Olson 2012; Herman et al. 2019; Höttecke and Silva 2011; Lederman 1999; Schwartz and Lederman 2002). Extensive NOS research literature documents many impediments to effective NOS instruction including the following:

- Inaccurate NOS understanding held by students, teachers, parents, and policymakers along with inaccurate NOS portrayals by media, science textbooks, curriculum materials, and science assessments coalesces in a manner that calls into question the more accurate NOS conceptions held by some science teachers and their efforts to convey those accurate ideas to students (Abd-El-Khalick et al. 1998; Bell et al. 2000; Henke and Höttecke 2014; Herman et al. 2017b; Lakin and Wellington 1994; Schwartz and Lederman 2002).

- Lack of support among science teacher colleagues for accurately portraying the NOS in science instruction (Abd-El-Khalick et al. 1998; Bell et al. 2000; Clough and Olson 2012; Herman et al. 2019; King 1991; Lederman 1999).
- Pressure from administrators and science teaching colleagues to enact precisely the same science curriculum and outcomes that misportray the NOS (Clough and Olson 2012; Herman et al. 2019), focus primarily on recall of science content (Anderson 2002; Bell et al. 2000; Duschl and Wright 1989; Hodson 1993), and other constraints that interfere with efforts to teach science through and as inquiry (McGinnis et al. 2004).
- Concerns regarding high stakes testing that is at odds with reform efforts and either ignore or inaccurately assess NOS understanding (Allchin 2011; Aydeniz and Southerland 2012).
- Insufficient time for planning and implementing accurate NOS instruction (Bell et al. 2000; Lakin and Wellington 1994; Abd-El-Khalick et al. 1998; Clough and Olson 2012; Lederman 2007).
- Lack of support for general reforms-based science teaching practices that would create opportunities to accurately address the NOS in everyday instruction (Herman et al. 2013a; Herman et al. 2019; McGinnis et al. 2004).
- Classroom management concerns associated with implementing accurate NOS instruction because such instruction may appear contrary to what students expect in science classes (Abd-El-Khalick et al. 1998; Brickhouse and Bodner 1992; Duschl and Wright 1989; Hodson 1993; Lantz and Kass 1987).

Understanding why and how some science teachers do accurately and effectively teach the NOS in the face of these formidable obstacles is crucial for preservice and in-service science teacher education efforts directed toward accurate NOS instruction.

13.4 Characteristics and Actions of Teachers Who Overcome NOS Instruction Obstacles

Efforts to promote research-based teaching practices that are aligned with desired ends appearing in science education reform documents have largely been unsuccessful (Banilower et al. 2013; Crawford 2007). This is the case with NOS instruction as well as general reforms-based science teaching practices. Even when teachers understand the complexities of learning and effectively teaching science, research-based pedagogical decision-making and practices require time and effort to master. But the lack of research-based science teaching practices appearing in schools also reflects the complexities in effectively teaching science *and* fierce institutional constraints that promote the status quo. Institutional expectations for teachers to address precisely the same content, provide common instructional experiences, and implement the same assessments all conspire against reforms-based practices including accurate and effective NOS instruction (Ihrig et al. 2014; McGinnis et al. 2004). Schools are long-established social institutions that often provide little support and even less patience for teachers who deviate from familiar traditional practices. Studies reporting the paucity of accurate and effective NOS instruction occurring in science classrooms, despite concerted efforts to promote such instruction, have extensively documented clear impediments to NOS instruction like those noted in the prior section.

Recent NOS research has focused on science teachers who accurately and effectively teach the NOS to determine how they persevere, navigate, and overcome those institutional constraints (e.g., Herman et al. 2019). Such research has determined that science teachers who triumph in their efforts to accurately and effectively teach the NOS exhibit the following:

- *They deeply understand what effective NOS pedagogy entails and are aware of how complex and difficult implementing it can be.* Fully grasping the fundamental principles of effective NOS instruction described earlier in this chapter, teachers who effectively persevere over institutional constraints do not give in to the intuitive, yet incorrect, approach that students' NOS understanding will significantly improve merely through occasional decontextualized NOS activities and/or implicit NOS learning experiences.
- *They possess fervent practical and transcendental rationales for NOS teaching and learning.* Merely valuing the NOS as a learning outcome for its own sake is insufficient for actually teaching it, particularly in the face of real or perceived institutional constraints. Valuing NOS for improving science content learning and improving attitudes toward science and scientists are also important, but even those ends are often insufficient. Herman et al. (2017a) report that high and medium NOS instruction teachers in their study saw accurate NOS instruction as nonnegotiable because of "the value of NOS for citizenship and socioscientific decision-making—goals that transcend their course, high-stakes exams, and other more proximal concerns of schooling" (p. 179).
- *They connect with other teachers who seek to accurately and effectively teach the NOS.* Herman et al. (2019) found that teachers who sought and worked with other teachers who were committed to NOS instruction more extensively valued, understood, and implemented accurate and effective NOS instruction. These support networks entailed contacts with like-minded teachers, often from other schools or school districts, sometimes at great distances.
- *They do not see themselves as having to always follow the lead of their colleagues or take orders from their administrators.* Herman et al. (2019) report that high NOS implementers in their study who faced institutional constraints "worked in a self-directed manner and were not 'owned by' or 'subject to' the constraints found in their school environments" (p. 205). Drawing from the work

of Drago-Severson (2007) and Kegan (1994), they found that these teachers were more able to "balance their concerns in juxtaposition with the concerns of others, and engage in more sophisticated forms of socialization such as critically and objectively analyzing and responding to what is requested of them in conjunction with their own values" (p. 193).
- *They are politically savvy.* Successfully navigating institutional constraints requires accurately assessing social situations and perhaps making decisions not to draw others' attention to NOS instruction efforts. Not talking to colleagues and administrators about their NOS instruction, overtly making statements and providing examples that illustrate instances where curricular expectations are being followed, deftly altering lessons when a colleague or an administrator enters the room so that overt NOS instruction is not observed, and other moves that deflect awareness of the NOS instruction taking place are just a few examples of savvy decisions teachers make in their efforts to accurately and effectively teach the NOS.
- *They leave a school where accurate and effective NOS instruction is not possible.* Some school environments are so filled with constraints and treachery that putting into place reforms-based science teaching practices, such as accurate and effective NOS instruction, is not possible. In these settings, archaic expectations may be imposed on teachers committed to effective science teaching to the extent that such teachers may quit or be forced out of the profession (Ihrig et al. 2014; McGinnis et al. 2004; Veenman 1984). Research documents that teachers who remain in such hostile environments for 2 years became very traditional in their teaching practices while those who leave and find more flexible schools are more likely to persevere in their efforts to put into place research-based teaching practices aligned with science education reform documents (Ihrig et al. 2014).

For teachers who persevere against institutional constraints, teaching is not merely a job. They truly have students' and society's best interests at heart, are knowledgeable and thoughtful, are highly reflective, and will take risks to ensure students receive the very best *education*.

13.5 Preparing Teachers to Navigate Constraints That Work Against NOS Teaching

Because accurate NOS instruction is not the status quo in schools, preservice teacher education programs and professional development efforts must prepare teachers to teach the NOS in the context of the institutional constraints they will likely face. Beginning science teachers are particularly vulnerable to institutional constraints because (a) they have yet to competently put into place the research-based practices they have only recently learned, often struggle with classroom management, and therefore are more easily criticized and pushed into archaic practices; (b) they are new to the school where they teach and are thus unaware of how well their efforts at reforms-based practices will be received and where political landmines exist; and (c) in many school districts, teachers in their first years of teaching can be dismissed with no explanation.

For nearly 20 years, the second and third authors have followed graduates from a secondary science teacher education program they created and directed at a prior university in the Midwestern United States—one with a strong NOS component—to better understand how to best prepare science teachers who understand and implement research-based pedagogical decision-making aligned with science education reform documents, including NOS instruction. Based on this and our more recently published research focusing on successful NOS instruction implementation efforts (Clough and Olson 2012; Herman and Clough 2016; Herman et al. 2013a, b; Herman et al. 2017a; Herman et al. 2019), we recommend the following strategies for preparing teachers who will accurately and effectively teach the NOS despite fierce institutional constraints. These recommendations for navigating and overcoming potential institutional constraints are explicitly addressed in our efforts with preservice teachers, and they certainly apply to assisting experienced science teachers as well.

- *Significant attention should be devoted to exploring compelling rationales for schooling, science content instruction, and NOS instruction.* Several intuitive and commonly stated primary purposes for schooling (e.g., recent emphasis on STEM careers and economic utility) are philosophically unsound, and they do not provide compelling reasons for most students to learn science or for science teachers to devote extensive effort to teach science well. Clough (2008) noted that:

> without commitment to the philosophical and moral aspects of schooling, research-based teaching becomes mechanical and detached from children. Without attention to the sacred nature of teaching, teaching becomes simply a job. (p. 2)

We have teachers read and seriously consider the work of John Dewey (1902), Neil Postman (1995), and others in order to develop a fervent rationale for schooling, teaching science, and NOS instruction. Throughout our science teacher education program, we repeatedly return to more noble and transcendental reasons for each of these, repeatedly emphasizing the differences between education and training. We push our preservice teachers to deeply understand the shortcomings of intuitive and commonly provided rationales for schooling, and develop an internal ethical stance and sense of responsibility for accurately teaching the NOS as part of a noble and meaningful science *education*.

- *NOS content and pedagogical understanding must be promoted at a deep level and revisited throughout a science teacher education program.* In order to overcome barriers to NOS instruction, science teachers must understand the contextual nature of NOS ideas in order to "see" NOS ideas in the context of everyday science content instruction and socioscientific issues (e.g., see Clough and Herman (2017) for the important role NOS instruction plays in global climate change education). Teachers must be taught how to restructure science activities to create opportunities for teaching the NOS and conveying its importance in those contexts. Deep NOS content and pedagogical understanding is also crucial for accurate NOS instruction self-reflection which should occur at several stages in a science teacher education program. Obviously, addressing all this in a single science methods course is problematic in light of all else that must be accomplished in preparing science teachers. Our secondary science teacher preparation program consisted of a series of three required science methods courses (four for those completing the graduate licensure program) and a required NOS course that students completed early in the program. This provided the time necessary to promote NOS content understanding and NOS pedagogy understanding that was repeatedly revisited in further science methods courses.

- *Overtly teach how to navigate potential, but undetected, barriers to NOS instruction.* Until completing their probationary period or achieving certainty that accurate NOS instruction is supported in their school district, we urge preservice teachers to tread carefully when talking about or doing anything that might draw others' attention to their NOS instruction efforts. For instance, we teach preservice teachers how to communicate with clear statements and provide examples to assigned mentors, colleagues, and administrators that convey curricular and pedagogical expectations are being followed, that imply what they are doing is aligned with what others teaching the same subject are doing, how to immediately alter lessons if a colleague or an administrator enters the room so that expected content instruction is observed, and other moves that deflect awareness of the NOS instruction taking place.
- *Encourage preservice teachers to seek a culture of collegiality and support among colleagues who implement accurate NOS instruction.* Our teacher education program purposely used a cohort model approach so that preservice teachers would more likely form strong bonds with one another. We emphasize the need for preservice teachers to stay in contact with one another and us after graduation, and also seek out other like-minded individuals who can support their NOS instruction efforts. Undeniably, some science teaching colleagues in a school or district may support accurate NOS instruction and general reforms-based science teaching practices. Thus, we teach preservice teachers to listen carefully to their colleagues and ask for their activities and other curricular materials to be *certain* they have identified a colleague who will support their NOS and general reforms-based instruction efforts. This strategy also permits them to learn what colleagues are doing and use strategies noted in the prior bullet point.
- *Draw preservice teachers' attention to the characteristics and attributes of teachers who accurately and effectively teach the NOS.* This recommendation is important for convincing teachers that the NOS can and should be accurately taught despite lack of support or outright constraints. Examples of teachers successfully incorporating NOS instruction are important, as well as research addressing the characteristics and attitudes of teachers who accomplish effective NOS instruction (described in the previous section of this chapter). We emphasize the aspects of teaching that are under teachers' control, even if they must be

clever in their efforts. This includes providing examples of program graduates' struggles and strategies they used to navigate institutional constraints. We emphasize that teachers who truly care about students will not permit institutional constraints to dictate what they do and cave into the status quo. This does not mean preparing teachers who ignore very real limits to what they can do, but who listen to, acknowledge, and effectively navigate others' perspectives and expectations without settling for common archaic practices.

- *Remind preservice teachers of the need to leave a school where reforms-based practices, including accurate and effective NOS instruction, are unlikely to be tolerated.* Research following graduates of our previous teacher education program during their first 2 years (Ihrig et al. 2014) determined that most taught in schools where both accurate NOS instruction and general reforms-based science teaching practices were ridiculed in favor of archaic and standardized practices. None of the teachers studied were in a school where a mentor or colleague was particularly knowledgeable of research-based pedagogical practices aligned with reform documents. Beginning teachers often faced hostile environments (e.g., expectations of conformity to trivial worksheets, cookbook activities, multiple-choice assessments; mentors who reported to principals that beginning teachers were deviating from what others were doing; and administrators who threatened dismissal for not teaching in traditional ways), resulting in a deterioration of their teaching practices aligned with accurate NOS instruction and general reforms-based science teaching practices. If teachers in such settings moved after their first year to a more supportive environment, their practices recovered by the end of the second year, but their distrust of colleagues and administrators remained. However, if they remained in such hostile environments, their practices continued to decline and they were far less likely to be aware that their practices were ineffective.

Accurate and effective NOS instruction and the recommendations above should be revisited throughout a teacher education program. Consistent modeling of accurate and effective NOS instruction along with assignments that are more fully developed and extended through a teacher education program are important so that by the end of the program, habits of mind and action are developed. Assignments in each science education course should be intellectually demanding and coupled with very high expectations and support to promote cohort cooperation and interdependence. During the student teaching semester, require a formal meeting one evening each week to ensure students have the support of one another and program faculty in efforts to keep students thinking about the noble ends of science education and what is required to reach those ends. We work hard to create relationships with preservice teachers that extend beyond their graduation and encourage them to contact us when facing constraints in their first years of teaching. The recommendations above assist students in surviving and more likely thriving in their first years of teaching, thus resulting in NOS teaching practices 2–5 years later (Herman et al. 2013b) exceeding that generally reported in the literature.

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