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Outcomes of nature of science instruction along a context continuum: preservice secondary science teachers' conceptions and instructional intentions

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ABSTRACT

This investigation examined outcomes associated with nature of science (NOS) instruction along a science-content context continuum on the development of secondary preservice science teachers' conceptions of and plans to teach NOS, moving beyond the common dichotomy of contextualized versus noncontextualized instruction. Participants comprised six teacher cohorts ($n = 70$) enrolled in a two-year Master of Teaching program. Participants were explicitly taught current NOS conceptions using activities that incorporated varied degrees of contextualization and were informed by conceptual change principles during the first program year. Participants' pre- and post-instruction conceptions were assessed using VNOS-C questionnaire written responses and follow-up interviews. Participants' views were classified by degree of alignment (non, partially, or fully aligned) with current NOS conceptions. Interview transcripts were analyzed using analytic induction to verify/refine VNOS responses and to identify patterns in NOS instructional plans and rationales. Wilcoxon signed ranks tests were run to assess possible statistical significance of pre- to post-instruction changes. Participants' responses shifted markedly toward more aligned NOS conceptions post-instruction, with substantial and statistically significant gains for each assessed tenet (all p-values <.001). All participants planned future NOS instruction and most expressed a sophisticated rationale for this choice, including that NOS supported the teaching of key concepts such as evolution. These results indicate that teaching and scaffolding NOS lessons along a context continuum can be effective in eliciting desired changes in preservice teachers' NOS conceptions and instructional intentions within the confines of the science methods course. Future research will examine post-methods course and post-program NOS instruction.

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Although many agree that the nature of science (NOS) is an important component of student learning and teacher preparation, the most effective context in which NOS activities and instruction should be situated remains to be established. On the one hand are researchers who emphasize the need for appropriate context when teaching NOS concepts (e.g. Allchin, Andersen, & Kielsen, 2014; Ault & Dodick, 2010). On the other are researchers who report positive results from noncontextualized approaches (e.g. Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Hanuscin, 2007). The resulting body of research has emphasized interventions situated at the extremes of highly contextualized and noncontextualized in specific contexts. The present investigation seeks to make a contribution by exploring NOS outcomes as a result of instruction situated within varied degrees of context to move beyond the common dichotomy.

NOS refers to generalizations about science as a way of knowing, as well as the characteristics of scientific knowledge. These overarching conceptions of NOS are considered key components of scientific literacy (Lederman, 2007). As such, NOS comprises a set of fundamental concepts to explore at all grade levels (American Association for the Advancement of Science, 1993; NGSS Lead States, 2013). Teaching NOS encourages students to understand the bigger picture of science as a way of knowing, what science is, and how it functions, as recommended by the *Next Generation Science Standards* (*NGSS*).

There has been considerable discussion among science educators regarding the concepts that constitute NOS. Despite disagreements, science educators and reform documents converge on a set of generalizations that are recognized as appropriate for school-aged children (Driver, Leach, Millar, & Scott, 1996; Lederman, 2007; McComas, Clough, & Almazroa, 1998; McComas & Olson, 1998; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). This includes the concept that evidence plays an essential role in the development of scientific knowledge. While scientific knowledge is robust, all scientific knowledge has the potential to change with either the introduction of new data or the examination of existing data from different perspectives. Scientific knowledge is influenced by theory that acts as a lens through which questions are developed; investigations are designed; decisions are made about what, when, and even where data should be collected; and results are interpreted. Creativity permeates all aspects of scientific investigations. The conception that scientists use many methods to develop scientific knowledge and answer questions of interest also supports K-12 students' and teachers' NOS conceptions. A scientist's background knowledge plays a role in the development of scientific knowledge, as do society and culture by way of funding, technological innovations, and societal problems fueling the need for certain investigations. Finally, scientific theories explain whereas scientific laws describe generalizations about the natural world; one cannot become the other and both are supported by evidence and have the potential to change.

The set of general concepts presented in Table 1 and described above provides a framework for K-12 NOS instruction (Lederman, 2007; Lederman & Lederman, 2014; McComas & Olson, 1998; Osborne et al., 2003). Taken together, these interrelated concepts address students' well-documented alternative conceptions and provide a framework for understanding science and what scientists do (Lederman, 2007). Further, these tenets are well aligned with NOS as presented in the *NGSS* (NGSS Lead States, 2013, Appendix H). Although presented as a list in Table 1 for brevity, students best learn these tenets

Table 1. Alignment of NOS tenets with the *NGSS* (NGSS Lead States, 2013).

NOS tenets associated with present investigation	Alignment with *NGSS* NOS understandings (Appendix H, High School)
Empirical. Scientific knowledge is based on empirical evidence	Scientific knowledge is based on empirical evidence • Science knowledge is based on empirical evidence • Science disciplines share common rules of evidence used to evaluate explanations about natural systems • Science arguments are strengthened by multiple lines of evidence supporting a single explanation • Science includes the process of coordinating patterns of evidence with current theory
Tentative. Scientific knowledge is durable yet tentative	Scientific knowledge is open to revision in light of new evidence • Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation
Multiple methods. There is no single scientific method	Scientific investigations use a variety of methods • Science investigations use diverse methods and do not always use the same set of procedures to obtain data • Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge
Role of scientific theory and law. Scientific theories and laws serve very different, not interchangeable functions	Science models, laws, mechanisms, and theories explain natural phenomena • Theories and laws provide explanations in science, but theories do not with time become laws or facts • A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment, and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence • Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory • Laws are statements or descriptions of the relationships among observable phenomena • Scientists often use hypotheses to develop and test theories and explanations
Creativity. Creativity plays an important role throughout scientific investigations	Science is a human endeavor • Science is a result of human endeavors, imagination and creativity
Social/cultural embeddedness. Society, culture and technology influence each other with respect to science	Science is a human endeavor • Individuals and teams from many nations and cultures have contributed to science and to advances in engineering • Technological advances have influenced the progress of science and science has influenced advances in technology Scientific investigations use a variety of methods • New technologies advance scientific knowledge
Subjective. Scientific investigations are influenced by theory, scientists' backgrounds	Science is a human endeavor • Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings

through active reflection on how scientific knowledge is developed, the characteristics of that knowledge, and how science is done, relating these ideas to their inquiry and other instructional experiences. For the purposes of this paper, these tenets represent target conceptions for science instruction and are referred to as *fully aligned* when consistent with currently accepted conceptions about NOS described above.

Despite wide consensus on the importance of NOS instruction (e.g. Driver et al., 1996; McComas et al., 1998; McComas & Olson, 1998; Osborne et al., 2003), research indicates that few teachers address this critical component of scientific literacy or even possess desired conceptions themselves (Lederman, 2007). Successful efforts to improve teachers' and students' NOS conceptions involve explicit NOS instruction coupled with reflective discussions (e.g. Abd-El-Khalick & Akerson, 2004; Akerson & Hanuscin, 2007; Abd-El-Khalick, Bell, & Lederman, 1998; Bell, Matkins, & Gansneder, 2011; Ryder, Leach, & Driver, 1999; Scharmann, Smith, James, & Jensen, 2005; Schwartz, Lederman, & Crawford, 2004).

The role of context

There are many different ways to enact explicit, reflective NOS instruction. In particular, researchers have debated the optimal extent of contextualization to support learning. Noncontextualized NOS instructional interventions have shown some success (e.g. Akerson et al., 2000; Bell et al., 2011; Khishfe & Lederman, 2006). Larger gains have been reported for interventions using an explicit conceptual change approach (Abd-El-Khalick & Akerson, 2004) and in very extensive interventions (e.g. Akerson & Hanuscin, 2007). Studies in which NOS was taught in a contextualized manner have also demonstrated limited success with learners of varying ages (e.g. Abd-El-Khalick & Lederman, 2000; Lin & Chen, 2002; Matkins & Bell, 2007). For example, preservice teachers who learned how to use the history of science to teach chemistry based their NOS explanations mostly on their intuition but drew from the history of science for examples (Lin & Chen, 2002). Possible contexts for explicit NOS instruction include specific science content, history of science, socio-scientific issues, and science inquiry contexts. Examples of science-content-based NOS instruction include teaching that scientific knowledge is based on evidence in a chemical reactions lesson. History of science-based instruction may explore how science ideas can change with new data/perspectives while teaching atomic model modifications. Teaching about science as socially and culturally embedded in lessons on genetically modified organisms is an example of NOS instruction in a socio-scientific-issue context.

For the purpose of this investigation and in this paper, from this point forward, we refer to 'contextualized' NOS instruction as occurring within the context of science content. NOS instruction also can be noncontextualized, addressing NOS as a topic of instruction itself through activities and discussion not directly connected to other contexts. We use 'noncontextualized' NOS instruction to mean instruction occurring outside the context of science-content instruction (e.g. situated within inquiry, process skills). An example of noncontextualized NOS instruction is teaching a simple lesson that scientific ideas change as new evidence emerges through a burning 'candle' activity (e.g. Bell, 2008).

Only two studies have compared the outcomes of noncontextualized and contextualized NOS instruction, both used global climate change as the context: Bell et al. (2011)

and Khishfe and Lederman (2006). Bell et al. (2011) compared implicit and explicit NOS instruction using both contextualized and noncontextualized approaches, utilizing a sample of 75 preservice elementary teachers. The preservice elementary teachers who experienced explicit NOS instruction substantially improved their conceptions equally in either context. The researchers concluded that the key to successful NOS learning was explicit, reflective instruction, rather than the specific context in which the instruction occurred. When Khishfe and Lederman (2006, 2007) compared secondary environmental science students' NOS views, NOS activities explicitly integrated with the socio-scientific issue of global warming compared to NOS activities not explicitly integrated with global warming content resulted in no 'conclusive evidence in favor of one approach over the other' (p. 773). Thus, the findings of neither study support the selection science content as context or the lack thereof when the goal is to improve teachers' or students' NOS conceptions.

The *NGSS* (NGSS Lead States, 2013) emphasize a context of science content (e.g. Disciplinary Core Ideas) for Science Practices, Crosscutting Concepts, and NOS. It is important to recognize that, while intuitively appealing, empirical research has yet to show a science-content contextualized approach to be more effective than noncontextualized instruction (Bell et al., 2011; Lederman, 2007). Some research (Brickhouse, Dagher, Letts, & Shipman, 2000; Driver et al., 1996; Ryder et al., 1999) has indicated that the science-content frame in part influences students' NOS conceptions, which Clough (2006) interprets as support for contextualized NOS instruction. Clough (2006) suggested that a mixed contextualization approach may be effective. What remains to be seen is whether a mixed approach that involves a context continuum could more effectively improve teachers' and students' NOS conceptions.

Facilitating NOS instruction

Science teacher educators aim not only to address science teachers' NOS conceptions, but also to facilitate the teaching of these conceptions to K-12 students. Certainly, teachers who do not understand NOS cannot effectively teach it to their students (Lederman, 2007). However, research demonstrates that even teachers who understand NOS commonly do not incorporate it into their instruction (e.g. Abd-El-Khalick, Bell, & Lederman, 1998; Akerson & Abd-El-Khalick, 2003; Bell, Lederman, & Abd-El-Khalick, 2000). Implementation of NOS instruction is hindered in part by a lack of recognition of how NOS fits into science instruction and state-mandated standardized testing (Abd-El-Khalick et al., 1998; Southerland, Gess-Newsome, & Johnston, 2003). Thus, an important aspect of NOS professional development is to foster the recognition that NOS is an integral part of science instruction.

The emphasis of almost all previous investigations and theoretical articles (e.g. Ault & Dodick, 2010) has been on the context extremes of NOS instruction (noncontextualized or highly contextualized) or the identification of lessons as either contextualized or not. For example, Donnelly and Argyle (2011) explored improvements in grade 4–9 teachers' NOS views after they completed a physical science professional development course—involving both contextualized and noncontextualized NOS lessons. The NOS instruction was informed by conceptual change and included contextualized NOS lessons such as a physical science theory/law activity, mystery magnet box and electric circuit activities

(Lederman & Abd-El-Khalick, 1998), and brief history of science discussions. Results indicated teachers made statistically significant improvements in their NOS views for two of the six assessed tenets. The teachers also reported teaching an average of three NOS activities from the course.

Yet setting up NOS instruction as a dichotomy may be problematic. Highly contextualized instruction may support science-content conceptions and help connect students to science knowledge. Noncontextualized instruction may be more accessible for some teachers and students. Thus, the selection of one over the other may lessen the possible benefits of NOS instruction. A potentially helpful alternative to the either-or approach is NOS instruction along a context continuum, a combination of highly and noncontextualized NOS instruction as well as instruction with degrees of contextualization between the extremes. In a theoretical article, Clough (2006) argued for the implementation of explicit NOS instruction along a context continuum. He developed a framework for this continuum, presenting brief descriptions of four categories of different degrees of science-content contextualization. Despite laying out a framework for a continuum, he did not fully operationalize it. Part of the present study's contribution is operationalization through articulation of NOS lessons along the continuum. (See Methodology section.)

Clough (2006) considered noncontextualized (which he referred to as 'decontextualized') NOS instruction to have its place, making NOS the central focus through concrete experience. He argued that instructional movement along a context continuum decreases the likelihood that students can 'dismiss a teaching scenario as misrepresenting how authentic science works' (p. 275). In support of this idea, Herman, Clough, and Olson (2013) found that, in a science education licensure program that included much NOS instruction along the context continuum, 12 of 13 participants taught NOS in ways that were reflective of how they learned to teach NOS to varying degrees (four at high level, five at medium level, and three at low level) (Herman et al., 2013). Despite this success, the researchers acknowledged that the teachers seemed to be much less able to take advantage of potential NOS opportunities within class discussions on science content. Thus, highly contextualized NOS instruction may be more difficult to implement (Allchin et al., 2014); teachers may integrate noncontextualized instruction more readily into their lessons. Yet many promote the importance of science content and a specific disciplinary lens as context, as this may be more authentic and relevant to students (Allchin et al., 2014; Ault & Dodick, 2010).

Although Clough (2006) and Herman et al. (2013) promote the potential of NOS instruction along a NOS context continuum, neither articulated in detail what instruction along this continuum might look like. Also, Herman et al. (2013) did not investigate how instruction along a NOS context continuum, or NOS instruction with mixed contextualization, impacted teachers' NOS conceptions or rationales for NOS instruction. Before such a continuum can be fruitful for additional instructional and research applications, associated instruction needs to be described in detail.

Given the difficulty teachers have teaching highly contextualized NOS lessons and the importance of context, incorporating activities and lessons with varied degrees of context may represent an effective framework for preservice teacher NOS instruction. This may balance the apparent accessibility of noncontextualized instruction with the end goal of understanding the importance of disciplinary context. Such instruction may help to convince teachers of the importance of NOS instruction. However, very few studies (e.g. Herman et al., 2013) have examined outcomes of NOS instruction along a continuum.

The present investigation examines changes in NOS conceptions associated with one version of instruction along a science-content context continuum embedded in methods course instruction, with the primary goal of facilitating preservice teachers' instruction about NOS. The study seeks to make a contribution by addressing many of the concerns about the context of NOS instruction stemming from current research by clearly describing instruction along a context continuum and exploring NOS outcomes as a result of instruction situated within varied degrees of context to move beyond the common dichotomy. Also, the small samples of previous investigations support the need for studies utilizing larger samples, with the potential for using statistical inference and qualitative descriptions jointly to better understand how and to what extent teachers' conceptions change.

Conceptual change

Conceptual change principles associated with Vosniadou's (1994, 1999, 2003) perspective served as the theoretical framework for the present investigation. To summarize, learners commonly possess preconceptions about science prior to formalized instruction. These initial conceptions are commonly not in line with scientifically accepted conceptions and can be highly structured and change-resistant (Driver, Guesne, & Tiberghien, 1985; Ozdemir & Clark, 2007). Such alternate conceptions can either support or impede learning. For example, in NOS research, scientific theory and law conceptions have been particularly difficult to change (e.g. Morrison, Raab, & Ingram, 2009). Addressing such alternative conceptions may be a lengthy and gradual process impacted by attitudes toward learning, motivation, beliefs, and socio-cultural contexts.

A number of instructional models based on conceptual change theory emphasize the importance of conceptual conflict, or learners recognizing the need to modify their initial conception (Bransford et al., 2006; National Research Council, 2005; Posner, Strike, Hewson, & Gertzog, 1982). Such conflict provides the impetus for learners to modify or replace their initial conception with one more aligned with available data/perceptions. In this model, the instructor first assesses learners' initial conceptions that then are targeted with carefully selected activities that help the learners to confront new information that does not fit with their initial conceptions. Through substantial discussion and reflection, the instructor facilitates the recognition of the need for modification, followed by additional activities and reflection designed to facilitate the development of conceptions more aligned with current scientific thinking.

The NOS approach of the present study is consistent with modern views of conceptual change in that it requires learners to acknowledge and reflect on their current NOS conceptions. Then these conceptions are challenged through experiential learning. Learner interactions and reflection support their efforts to confront conceptual conflict and modify preexisting ideas with the goal of developing conceptions of NOS that are well aligned with currently accepted ideas.

Research questions

The purpose of this investigation was to examine the development of preservice secondary science teachers' NOS conceptions, instructional plans and rationales associated with NOS instruction along a context continuum, aligned with conceptual change theory. The following research questions guided our investigation:

(1) How did participants' conceptions of NOS change following methods course instruction that involved scaffolding along a context continuum?
(2) Did participants plan to teach NOS following the intervention and, if so, what were their rationales?

Methodology

This investigation employed a qualitative approach in which the free response survey and interview responses, focused on NOS conceptions, were translated into ordinal ratings, as described in the data analysis section below. Then the qualitative data and quantitative levels were examined jointly to provide a more complete understanding of changes in participants' conceptions of NOS. The qualitative interview responses also were examined inductively to identify which participants planned to teach NOS, how they planned to teach it, and their associated rationales.

Setting and participants

Participants comprised six entire cohorts of preservice science teachers ($n = 70$) enrolled in the first year of a two-year Master of Teaching program at a major university in the mid-Atlantic region of the USA. Of the 50 female and 20 male participants working toward a secondary science teaching certification, 13 were in earth science, 40 in biology, 15 in chemistry, and 2 in physics. Ages ranged from 21 to 54 years, with a mean age of 24.6 years. The majority of participants were Caucasian, with 11.4% from racial or ethnic backgrounds typically underrepresented in US science teaching.

The program included two secondary science methods courses, both with an explicit emphasis on NOS as an important but often neglected aspect of science instruction. See Table 2 for an overview of the program. Specific NOS instruction was completed at least six weeks prior to the end of the second course, which concluded the semester before student teaching. Although NOS emphasis was substantial in the two courses, the program included no separate NOS course. Addressing how to teach NOS in methods courses alone may be a more feasible structure for many teacher education programs.

NOS instruction

Throughout the methods course, participants were explicitly taught currently accepted conceptions of NOS (Table 1) through modeled activities that incorporated varied degrees of context (Table 3). These NOS lessons were well aligned with conceptual change theory. For example, each NOS lesson taught using this approach began with an activity that served to elicit participants' initial ideas about NOS concepts, consistent with a conceptual change approach. Activities also were used as the context for discussions that explicitly connected to the relevant aspects of NOS. In these discussions, explicit, reflective NOS portions were clearly identified and explicitly differentiated

Table 2. Organization of the Secondary Science Education Program (modified from Bell, Maeng, & Binns, 2013).

	Fall semester	Spring semester
Year 1	• Instruction and assessment (general methods)	• Classroom management (general methods)
	• **Teaching secondary science methods i with field placement**	• **Teaching secondary science methods ii with field placement**
	• Educational technology for math and science teachers	• Teaching secondary science methods lab
Year 2	• Student teaching practicum	• Capstone project (research in science education)
	• Student teaching seminar	• Contemporary issues in education

Note: The intervention took place in the bolded courses.

from inquiry-based parts of the lesson. The explicit and reflective discussions, key to conceptual change, helped learners confront their initial conceptions and modify them as needed.

The researchers operationalized the context continuum developed by Clough (2006), placing methods course NOS lessons into four categories along this continuum. We adopted the working definitions of Clough to guide this categorization. Clough defined what we refer to as *noncontextualized* NOS instruction to be 'isolated or tangent from science content and scientists, and whose primary purpose is to directly illustrate important ideas about the NOS' and 'not complicated by science content' (p. 472). Alternatively, *highly* contextualized NOS instruction is 'so tightly bound up in the science content being learned that the two are seamless, and thus conveying how the experience is *like* science is unnecessary', focused on the integration of 'historical and contemporary science examples that are tied to the fundamental ideas taught in particular science subjects' (p. 474). He articulated two categories between the extremes, with one including 'decontextualized activities linked to science content', which we refer to as *minimally* contextualized and the other contextualized category to be 'inquiry science content activities linked to NOS' (p. 476), which we call *moderately* contextualized.

Noncontextualized activities offered accessible analogies for what science is like and involved little to no science content; rather, NOS concepts were the main learning goal. These activities were used primarily at the beginning of the first science methods course to introduce and encourage reflection on NOS constructs. These activities included the Burning 'Candle', Comic Strip Inferences, and Digital Image activities (Bell, 2008). For example, in the Burning 'Candle' activity, participants first defined 'observation' in science and then listed observations of a burning 'candle' (actually a piece of string cheese with an almond sliver for the 'wick'). After the class exhausted the list of observations, the instructor ate the 'candle' with flourish. This surprise ending is followed by a discussion of inference and the role of both observation and inference in the construction of scientific knowledge.

Table 3. NOS lessons along the context continuum.

Degree of science content	Activity	Time spent on activity (min)	Science content	NOS tenets
None	Burning 'candle'	20	None	Empirical, tentative, inferential, subjective
	Comic strip inferences	60	None	Empirical, inferential, tentative, subjective
	Digital image interpretation	90	Varies	Empirical, inferential, tentative, subjective
	Gestalt images	30	Astronomy: moons of Jupiter/Saturn's rings	Empirical, tentative, role of theory, subjective, creative, social/cultural influences
Minimal	Fossil footprints	40	Predator/prey relationships	Empirical, tentative, creative, subjective
	Fossil fragments	90	Comparative anatomy Geologic time	Empirical, tentative, creative, subjective
	Mystery cans	90	Natural selection	Empirical, inferential, theory, law
	Mystery tube	90	Gas laws/kinetic molecular theory	Empirical, inferential, theory, law
Moderate	Iodine clock reaction experimental design	90	Chemical reactions	Multiple methods, creativity
	Long-term moon observation inquiry	200	Moon phases, moon rising/setting, and other patterns	Empirical, tentative, multiple methods, subjective
High	Bryson history of science readings	90	Atomic models Evolution of universe Latitude/longitude DNA and more	Empirical, tentative, creative, multiple methods, subjective, social/cultural influences
	Reading on quantum mechanics and 'the light fantastic'	20	Refraction	Empirical, characteristics of theory and its development

Minimally contextualized activities also held NOS conceptual understanding as the main lesson purpose, with specific science-content connections layered into the middle or end of a lesson to help learners make connections between NOS and content. For example, the Mystery Tube lesson began with a discussion of scientific theories and laws in general, and the gas laws in particular (Bell, 2008; National Academy of Sciences, 1998). The lesson began with students comparing and contrasting their general notions about scientific theories and laws, with most expressing the alternative conception that laws are more 'proven' than theories. Students were then asked to compare and contrast the gas laws with kinetic molecular theory. Following this discussion, students participated in the Mystery Tube, which was presented in a manner to serve as an analogy for the development of scientific theories and laws. Through this process, students learned that theories and laws are different kinds of knowledge, and that one is not more proved than the other. Further, they learned that when laws and theories exist for the same phenomena, the laws are developed prior to the theories (Maeng & Bell, 2013). Finally, they learned how this 'black box' activity could serve as a foundational experience from which students could draw during subsequent science content-focused lessons. The activity provides multiple links to substantial science content, including atomic theory, gas laws, kinetic molecular theory, and natural selection. After the lessons, participants' attention was drawn to varied contexts for NOS concepts, as recommended by Clough (2006).

For *moderately* contextualized lessons, NOS conceptual understanding remained a main lesson objective but was substantively intertwined and connected to science content in inquiry lessons. For example, a lesson on chemical reactions began with a demonstration in which two unknown, clear liquids were mixed in a flask. Then the combined liquid was poured back and forth between until it suddenly turned dark blue (iodine clock reaction). Throughout this demonstration, participants made observations and then considered what factors may have influenced the color change, based on what they knew about chemical reactions. Then, they developed testable questions and procedures to explore the potential factors they thought might influence the reaction rate. The groups shared their findings and drew conclusions of how the factors they explored changed the rate of reaction. To tie in key NOS ideas, how scientists used many methods to conduct investigations was discussed. Participants cited the role of the observational investigation (during the demonstration) and the experimental investigation they used to further explore the factors that influenced reaction rate. Participants also compared approaches across groups and discussed the role of creativity in designing investigations (e.g. even groups testing the same factors went about it in different ways).

Participants commonly discussed NOS within *highly* contextualized lessons in which content and/or the history of science were main foci. NOS was included in the lesson closures to help participants both learn NOS and learn how to teach it with science content. For example, participants read multiple chapters of Bryson's (2003) popular nonfiction book, *A history of nearly everything*. They discussed history of science examples such as the changes in the atomic model. From the ancient Greeks' idea of an atom to Dalton's consideration of the relative size and characteristics of atoms, Rutherford's model of a dense core surrounded by mostly empty space supported by experimental evidence, and so on. The examples served as the context to discuss NOS concepts such as in what ways scientific knowledge development was creative, based on evidence, tentative, accomplished through many different methods, and influenced by society and culture.

In short, the science methods NOS instruction navigated between NOS activities and instruction with varied degrees of contextualization that addressed science content through inquiry and historical examples. In this manner, the intervention provided scaffolding along a context continuum. It is important to note that since these lessons occurred in methods courses, the ultimate goal was to learn to teach science, rather than to learn science content. Even so, the researchers sought to model how the lessons should be taught in secondary science courses and thus made every effort to keep science content as the focus of the highly contextualized activities.

Data collection

Data consisted of completed pre- and post-instruction Views of NOS (VNOS-Form C) questionnaire and a post-instruction interview (Supplemental Material). On the first day of the first science methods course and on the last day of the second methods course, participants completed the VNOS questionnaire consisting of 10 open-ended questions. Content and construct validity of the VNOS are discussed in Lederman, Abd-El-Khalick, Bell, and Schwartz (2002). All participants were formally interviewed about their pre- and post-questionnaire responses during the interval that followed the second science methods course and preceded student teaching. The semi-structured interview lasted approximately one hour and explored how participants' NOS conceptions changed pre- to post-instruction, thereby serving as a member-check. Participants also were asked about their intentions to teach NOS and to what degree they considered it an important part of secondary science instruction. The interviews were audio-recorded and transcribed and all participants were assigned pseudonyms. The first author, who served as instructor for the two methods courses, did not participate in data collection or analysis.

Data analysis

For the categorization of participants' NOS conceptions, survey and interview data were analyzed following the systematic data analysis process, as described by Miles and Huberman (1994). *A priori* codes corresponding to each NOS tenet were derived from the literature (e.g. Bell & Lederman, 2003). The codes were separated into three levels of alignment with currently accepted conceptions: non-aligned, partially aligned, or fully aligned. These codes represent a judgment of the statements' level of appropriateness associated with a NOS tenet. For example, a participant's response coded 'subjective-non-aligned' represented a view of the subjective nature of scientific knowledge that reflected a skewed view indicating either that knowledge in science is completely objective or entirely subjective and not very useful. The code for 'subjective-partially aligned' was used for responses reflecting emerging conceptions of the subjective NOS. Statements coded 'subjective-fully aligned' represented statements in which a participant acknowledged that individuals' backgrounds and experiences influence observations, investigations, theories and interpretations, and that this can have both positive and negative implications for the development of scientific knowledge.

Statements within each participant's questionnaire responses and interview transcripts were coded for tenet and degree of understanding using NVivo. Each participant's conceptions on the seven targeted NOS tenets were separately and holistically categorized as one of three levels: non-aligned, partially aligned, or fully aligned for pre- and post-instruction responses. To support the validity of the findings, as suggested by Lincoln and Guba (1985), both the questionnaire and interview responses were triangulated in coding participants' responses as one of the three levels. Prior to coding the entire data set, inter-coder agreement was established by comparing independent analysis of 32% of the data ($\kappa = 0.864$). This indicated substantial to almost perfect agreement (Landis & Koch, 1977). All coding disagreements for this subset of the data set were resolved by discussion. Following this analysis, the second and third authors split the remaining data in half and independently coded. Particular attention was given to consistency of categorization as non-aligned, partially aligned, and fully aligned. After coding the entire data set, consistency of the categorizations across participants was checked through NVivo matrix queries. Labels of pre- and post-instruction were removed from participants' responses prior to the consistency check.

The qualitative categories were converted to ordinal ratings: the nonaligned category = 1, partially aligned category = 2, and fully aligned category = 3. Then the nonparametric Wilcoxon signed ranks test was conducted for each targeted NOS tenet to evaluate whether the difference in participants' pre- and post-intervention scores was statistically significant. This test is appropriate for a repeated-measures design with an intervention particularly when the data are ordinal rather than interval and the data cannot be assumed to have a normal distribution, as the test has relaxed distributional assumptions (Green & Salkind, 2008). A Bonferroni correction was made to adjust for the number of tests, resulting in the significance level at alpha = 0.00625. An effect size r also was calculated (r = Wilcoxon test statistic/$\sqrt{N}$, where N is the total number of observations, or 140; Field, 2009). The interpretation of the effect sizes followed the guidelines of Fan (2001).

Finally, researchers reviewed interview transcripts for whether participants planned to teach NOS and for what reasons. Following the guidelines of Bogdan and Biklen (1992) for analytic induction, participants' statements were first open-coded. Then common patterns were identified with the goal of characterizing participants' instructional intentions and rationales for teaching NOS. From these patterns, categories were developed and refined through comparison with the original data set, resulting in the final categories that are presented in the results below.

Results

The purpose of this study was to explore the effectiveness of NOS instruction with varied degrees of science context on the development of secondary preservice science teachers' aligned NOS conceptions and plans to teach NOS. Results indicated that participants' conceptions substantially shifted from non-aligned to partially or fully aligned following NOS instruction (Table 4). Examples of participants' pre- and post-instruction comments are presented in Table 5.

Changes in NOS conceptions

Analysis of participants' pre-instruction questionnaire responses revealed that participants held many non-aligned NOS conceptions (Table 4). None of the participants had fully aligned conceptions on all NOS tenets and many had non-aligned conceptions on most of the tenets prior to instruction. Despite the fact that they had completed their science

Table 4. Preservice teachers' views categorized by degree of alignment prior to and following instruction ($n = 70$).

	Pre-instruction			Post-instruction		
	Degree of alignment			Degree of alignment		
NOS tenet	Non	Partially	Fully	Non	Partially	Fully
Scientific knowledge is:						
Empirical	25 (36%)	43 (61%)	2 (3%)	0 (0%)	3 (4%)	67 (96%)
Tentative	42 (60%)	25 (36%)	3 (4%)	0 (0%)	13 (19%)	57 (81%)
Creative	38 (54%)	28 (40%)	4 (6%)	6 (9%)	27 (39%)	37 (53%)
Subjective, theory-laden	27 (39%)	43 (61%)	0 (0%)	1 (1%)	19 (27%)	50 (71%)
Relationship between theories, laws	64 (91%)	6 (9%)	0 (0%)	1 (1%)	11 (16%)	58 (83%)
Social and cultural influences	48 (69%)	22 (31%)	0 (0%)	5 (7%)	35 (50%)	30 (43%)
No single scientific method	45 (64%)	22 (31%)	3 (4%)	0 (0%)	14 (20%)	56 (80%)

Table 5. Representative pre- and post-intervention participant quotes organized by NOS tenet.

NOS tenet	Pre-intervention[a]	Post-intervention[a]
Scientific knowledge is:		
Empirical	Absolutely yes, the development of scientific knowledge requires experiments. … You can likely prove whatever you want. (Kate, non-aligned)	The specific evidence that scientists used to determine the structure of the atom was by making observations then inferences based on experiments that they performed. An atom cannot be seen to the naked eye or under a microscope so this is a case of scientists using experiments and making observations and inferences about what they cannot see. For example Rutherford shot rays at a piece of gold foil and based upon the scatter of the rays they could determine that there was something there. (Kate, fully aligned)
Tentative	Theories CAN change; they are not laws. … Scientific law is the notion that has advanced beyond a theory because it cannot be proven wrong. (Andrea, non-aligned)	Scientific theories change with the increased knowledge of new scientific content and facts and with changes in the perceptual framework of scientists. Scientific theories are explanations of natural phenomena that scientists propose for observations that they have made. These theories must stand up against other data. By striving to better understand the natural world, science gains a better understanding of nature, but we may never find that truth. By changing our theories when we gain additional knowledge and when we change our perceptual frameworks in order to understand something differently, we refine our understanding of nature. An example of a changing theory is the atomic theory. The structural model for the atom has changed over time as scientists gain better understandings of the way in which the atom is structured. When scientists gain more observations that necessitate a change in the theoretical understanding and explanation of the atomic structure, the model of the atom morphs. (Andrea, fully aligned)
Creative	I find science to be something concrete, something that is physical or can be applied to physical aspects, no matter how small or how large. Art, to me, is abstract and trends are always changing at a rate much faster than in science. … Many instruments today used in science were just in someone's imagination. John Fenn wanted to make 'Elephants Fly' and developed a machine to take macromolecules and get them into the gas state, which won him a Nobel Prize. (Linda, non-aligned)	In order to come up with a question, a method to answer the question, and analyze the results there has to be some creativity. When the method does not work scientists must again call on their creativity to come up with a new method to get observations and results. … When [Darwin] made observations in the Galapagos Islands he had to think outside of the box and be imaginative to realize that some species may have come from other species. The thought at the time was in creationism, and that was considered the truth, so any ideas outside of creationism would have been imaginative. … This is also true of Galileo and Copernicus and their ideas on the heliocentric universe. The idea at the time about the universe was that the Earth was at the center, so the truth was a geocentric universe. Based on their observations they realized that the Earth at the center did not make sense, so they had to come up with another model that made sense with their observations. Without their creativity (and the creativity of other natural philosophers in the past) they would not have been influential in making the heliocentric model the truth. (Linda, fully aligned)

(*Continued*)

Table 5. Continued.

NOS tenet	Pre-intervention[a]	Post-intervention[a]
Subjective, theory-laden	If scientific knowledge did not require experiments then how would one know if it is a truth or an outlandish biased idea. I could say that everything is made of water and you could say that everything is made of fire, but how would we be able to distinguish which is scientific truth/knowledge if we don't run experiments to determine that. (Tim, non-aligned)	Theories are very important because it gives scientists a framework for which they can interpret data. This perceptual framework is very important to be aware of and know that it impacts our interpretation of data. Scientific theories try to make sense of the data, so instead of just knowing how things work, theories try to get at why they work the way they do and are inferences based on data. (Tim, fully aligned)
Relationship between theories and laws	Theories that withstand extensive experimentation become scientific laws. (Emily, non-aligned)	Scientific laws and theories are different and serve different functions in the scientific community. A scientific law is a stated observation; it is describing a generalization of a process in nature, often in mathematical terms. A scientific theory explains a process that is observed in nature. For example, evolution could be considered a law based on evidence indicating similarities between species in the fossil record. Darwin's Theory of Natural Selection describes the mechanism for evolution. (Emily, fully aligned)
Social and cultural influences	Religious beliefs played a large part in the interpretation of scientific data, and it even plays a role today with ethics in relation to science, and how far people believe we should allow science to take us. (Samantha, partially aligned)	An individual's perceptual framework plays a pivotal role in the conclusions that they draw from the world around them. Some individuals may come from a very religious background, and thus these astronomers may have been highly influenced by this. In addition, individuals may have had very different educational backgrounds and prior knowledge, thus leading to significant differences in the ways that they interpreted and drew inferences from their surroundings. Furthermore, one of the key strengths of science is the creative aspect involved. Numerous different individuals can come up with and create different explanations. Then comes the collaborative NOS, because these individuals will get together and compare their thoughts and findings. Overall although, these different conclusions were possible because of these astronomers' differing perceptual frameworks and background knowledge/identity. (Samantha, fully aligned)
No single scientific method	I would argue that any type of knowledge that is not produced using experimentation is not really *scientific*. (Adam, non-aligned)	I strongly believe that any form of problem solving is fundamentally creative, and the production of a method to figure something out or test something must therefore be creative as well. … The development of scientific knowledge absolutely does not require experiments. The array of medieval and renaissance astronomers—all these people did was make and record observations. There was never any experiment to figure out whether the Earth rotated around the Sun or vice versa, or that Jupiter had lots of moons, or that Saturn had rings. All of this knowledge came about by making observations, recording data, sometimes performing mathematics, and then drawing conclusions. (Adam, fully aligned)

[a]Overall categorizations were made based on all post-VNOS and interview statements that had implications for a particular tenet. Therefore, the exemplars provided serve only as the beginning of the evidence available to conclude a participant held non-aligned, partially aligned, or fully aligned views on each NOS tenet.

coursework, none of the participants came to the methods course with conceptions that would allow them to teach a vision of NOS aligned with currently accepted conceptions.

After completing NOS instruction along a context continuum, participants made substantial gains for each of the assessed NOS tenets. The differences between participants' pre- and post-test categorizations were statistically significant ($p < .001$) for each tenet (Table 6). In addition, the effect size was large for each tenet (all *r*s >.5). Based on Fan's (2001) guidelines, the results are statistically significant and practically meaningful.

Empirical basis for scientific knowledge

Only 3% of participants fully understood the empirical nature of scientific knowledge prior to instruction. For example, most recognized that data play an important role in science but did not distinguish between data and evidence. After instruction, 96% of participants expressed a fully aligned view of the empirical nature of scientific knowledge. From pre- to post-instruction, 66 of the 70 participants increased the alignment of their conceptions of this tenet, a statistically significant and practically meaningful change ($r = .63$). All participants moved beyond a focus on experiments as providing the primary evidence for all scientific knowledge, which was characteristic of participants' responses prior to instruction. All recognized the importance of indirect evidence and 67 participants acknowledged that experiments and observations produce evidence in support of scientific knowledge. These participants recognized that not all observations that make up scientific knowledge must be or even can be within experiments.

Tentative NOS

Before instruction, 60% of participants held non-aligned conceptions, focusing on scientific knowledge, in particular scientific laws, as absolute (Tables 4 and 5). Post-instruction, 64 of the 70 participants who held less than fully aligned conceptions pre-instruction improved at least one level in their conceptions after instruction, shifting away from absolutist statements ($p < .001$, $r = .60$). All participants recognized that scientific knowledge can change, but to differing degrees. The 19% of participants with partially aligned conceptions also acknowledged that scientific knowledge changes but attributed changes in scientific knowledge to new evidence, thereby ignoring the role of different perspectives. The 81% of participants who held a fully aligned view of this tenet shifted to present a more balanced view of when and how scientific knowledge can change (Tables 4 and 5). Knowledge was seen as durable yet changeable through the addition of new data or a change in perspective. They viewed the possibility of scientific knowledge changing to

Table 6. Statistical and practical significance of improvements in participants' views of each NOS tenet, using the Wilcoxon signed ranks statistical test results and calculated effect size (*r*).

NOS tenet	*z*-Statistic	Effect size (*r*)
Scientific knowledge is:		
Empirical	−7.401*	.63
Tentative	−7.123*	.60
Creative	−6.360*	.54
Subjective, theory-laden	−7.103*	.60
Relationship between theories, laws	−7.633*	.65
Social and cultural influences	−6.669*	.56
No single scientific method	−7.083*	.60

*Statistical significance at $p < .001$.

reflect the flexibility and responsiveness of science to new data or perspectives, with a reliance on evidence.

Creative NOS

Before instruction, participants generally held the narrow view that creativity in science was associated mainly or solely with experimental design or in the interpretation of experimental results. Some focused on all scientific progress happening through experimentation even though much scientific knowledge is created using other methods. Post-instruction, 92% of participants held at least partially aligned conceptions of creativity in science, associated with a statistically significant and practically meaningful improvement in conceptions ($r = .54$). The 39% of participants with partially aligned conceptions post-instruction placed creativity within multiple aspects of experiments or within limited portions of both experimental and nonexperimental investigations. For this tenet, 53% of participants held fully aligned conceptions post-instruction, noting that creativity plays an important role in all aspects of science, from determining what questions to ask, investigation design, how to make observations, and interpretations of data. Also, 27 participants provided specific examples of scientific creativity such as creativity in thinking outside of accepted scientific knowledge such as Darwin's development of natural selection and the shift from a geocentric to heliocentric model, in addition to creativity in developing a question, method, and analysis of results (Table 5). Those with fully aligned conceptions gave creativity an essential place in science throughout investigations. Overall, participants' post-instruction conceptions reflected a substantial expansion of the role of creativity in science.

Subjective, theory-laden NOS

Before instruction, 39% of participants held a nonaligned view of subjectivity in science, expressing an overly negative view that commonly included that scientists reach different conclusions due to their own dishonesty or errors in measurement or judgment. Participants generally highlighted subjectivity in science as negative and ignored the supportive role theories can play in guiding scientists' questions as well as their observations and inferences (Table 5). From pre- to post-instruction, 60 of the 70 participants improved their understanding by at least one level for this tenet, a statistically significant improvement and large effect size ($r = .60$). After instruction, 27% of participants held partially aligned conceptions. Some highlighted the subjective NOS and positive aspects of this subjectivity yet did not acknowledge the importance of theory in shaping science investigations. These participants espousing similar conceptions were categorized as holding partially aligned conceptions of the subjectivity tenet. All but one participant moved beyond a negative-only view of subjectivity in science (at least partially aligned conceptions), and 71% of participants categorized as holding fully aligned conceptions post-instruction. Participants with fully aligned conceptions explained subjectivity in a balanced way, highlighting that theories and/or perceptual frameworks guide observations and interpretations (Table 5).

Relationship between scientific theories and laws

Prior to instruction, almost all of the participants expressed the widespread misconception that scientific theories are less important and less certain than scientific laws. Further, 20%

of participants stated that theories become laws at some point when enough supporting evidence has been collected. Participants' alternative general conceptions about scientific theories and laws commonly impacted the value they placed on specific theories and laws such as Newton's laws, gravity, and evolution by natural selection (Table 5). When talking about evolutionary theory, Andrea commented, 'It seems like it is under investigation.' This is particularly problematic with respect to these participants teaching science. For example, as theories were viewed as less certain than laws, 14% of participants saw evolution in particular as flawed or in need of improvement.

For the relationship between theories and laws tenet, 97% of participants improved their conceptions by at least one level, a statistically significant improvement associated with a large effect size of $r = .65$. Post-instruction, 83% of participants held fully aligned conceptions of this tenet. All those with fully aligned conceptions recognized that scientific theories and scientific laws serve different purposes and that it is not possible for a theory to become a scientific law with enough evidence. The hierarchical relationship between theories and laws prevalent prior to instruction was non-existent following instruction. Also, 71% of participants connected their more aligned conceptions to specific examples. Many evoked multiple examples including natural selection and Newton's laws. For example, Emily accurately identified the law or principle (evolution) and the theory (natural selection), provided evidence for this fully aligned perspective, and indicated that theories and laws have different yet very important roles in the scientific community (Table 5). In the post-instruction interview, participants recognized substantial changes in their conceptions. Those with fully aligned conceptions of this tenet clearly distinguished theories from laws. The NOS instruction resulted in particularly dramatic improvement in conceptions for this tenet.

Social and cultural influences on science

Before instruction, many participants did not consider social or cultural influences on science. Those that did acknowledge this focused on only one aspect such as the role of technology or religion in science. From pre- to post-instruction, 69% of participants articulated more aligned conceptions of the social and cultural embeddedness of science post-instruction, a statistically significant improvement associated with a large effect size ($r = .56$). Although the gains were still substantial, they were not as impressive as seen with the other tenets. Post-instruction, even the 50% of participants who held partially aligned conceptions indicated that society and culture influence science, an idea rare before instruction. The 43% of participants with fully aligned conceptions noted that society influences what scientists decide to investigate, how and what data is collected, and the way we view scientific data as well as the roles of shifting technologies and funding, individual and disciplinary differences, and collaboration in shaping how science is conducted (Table 5).

No single scientific method

All but three participants overemphasized the role of experiments underlying scientific knowledge before the intervention; most participants associated all scientific progress with experimentation even though much scientific knowledge is developed through other methods. After instruction, all participants moved beyond non-aligned conceptions, recognizing that there is more than one way to do science. Almost all participants (90%)

improved their view of this tenet. This improvement was statistically significant and associated with a large effect size ($r = .60$). The percentage of participants with fully aligned conceptions increased from 4% prior to instruction to 80% following instruction. Participants broadened scientific methods to include nonexperimental investigations such as observational studies, correlational studies, modeling and theoretical science and recognized their value (Table 5). They provided examples from various disciplines and fields, including astronomy, behavioral biology, and paleontology. They acknowledged that scientists must use nonexperimental methods to explore many topics and that those methods are rigorous.

Plans and rationale to teach the NOS

Participants' interview responses indicated that all planned to teach NOS and almost all expressed multiple reasons for this decision. NOS was deemed to be an essential component of any science instruction by 86% of participants, and 43% of participants explicitly acknowledged how little they understood NOS before experiencing NOS instruction in the science methods course sequence. They found this to be a limitation of their previous educational experiences and wanted to be sure their own students could benefit from understanding NOS:

> In high school science … I got good grades, but I don't think I understood NOS at all. It wasn't something that was explicitly taught to me and so therefore I didn't understand it. It steered me down the path of some misconceptions. But when I came into my science education courses with [the instructor], helping show us the way and really kind of bringing to light NOS, that is what got me excited about wanting to teaching it, too. (Tim, Interview)

Participants planned to use many of the activities they did in the science methods course with their own students. They envisioned integrating NOS into lectures, demonstrations, experiments, and observational investigations.

Interview responses included the following rationales for planning to teach NOS: to support doing science, to develop high-level thinking/problem solving, to increase interest in science/becoming a scientist, to entertain or engage students, to improve students' science appreciation, to support science literacy and real world applications, and to support teaching what science is and science content (Table 7). Sixteen percent of participants mentioned that teaching NOS supports students' science appreciation, again by opening a window onto the human side of doing science and providing a different way of considering the complex and varied ways that scientific knowledge is developed. Almost a quarter of participants noted that NOS is essential to science, and 33% referenced scientific literacy and/or real world science applications. For example, some discussed how NOS helps students to distinguish science from pseudoscience and inform voting choices. Others focused on the importance of preparing students to understand science articles and make education decisions in their communities.

The most common rationale, mentioned by 83% of participants, was that teaching NOS supports teaching what science is and/or teaching science content. For example, Melissa recognized NOS as helping her to better understand scientific knowledge she had learned previously. Sasha viewed NOS as a way to facilitate students' deeper understanding of evolution, an understanding greater than she had herself in high school, and she felt empowered enough to take on teaching evolution even in her 'conservative setting':

Table 7. Rationales identified by participants for planning to teach NOS.

Rationale	Expressed by % participants	Example interview quotes
To support students doing science	13	I think that [NOS] would allow them to connect with the material more if [students] could recognize where it started from and how it was gathered. That's where NOS starts to come into play because that's where we talk about scientists actually being scientists and what are they doing and how can students emulate that. (Emily)
To develop students' high level thinking, problem solving	13	Without understanding what science is, people, while they'll get scientific concepts, if they try to use scientific thinking and apply it to other situations, sometimes they will sort of overstep and make claims that aren't really justifiable based on the scientific way of looking at things. That's something I would like to prevent. Sort of to promote legitimate scientific literacy both in the sense of being able to understand science that they read about and hear about, and also being able to use science in their own lives to help solve problems and help figure things out. Sort of as a problem solving tool. (Adam)
To increase student interest in science, becoming a scientist	13	[NOS] is what attracts a lot of people to the field of science. If you're not as into reading text books and memorizing facts (where some people are into that and that's why they like science), and some people are into the innovative side or it and how it questions authority. (Ana)
To entertain, engage students	13	It's really engaging to students and it shows a whole different side of science class—it's not just about facts you have to memorize. … And it shows that science is a broader concept than most people think it is. (Ana) I think [teaching NOS] is definitely important. And I think it's important for students to really get a feel for what is science. That's what makes science so cool. The idea that there's more to it, there's a point to it. It's fun; science is fun! (Emily)
To improve students' science appreciation	16	After having all of this NOS stuff I think [teaching] it is important because it helps you learn about science in general. And I wish in high school someone had taught me all these things. I feel like it does help you to look at it differently and appreciate some things more. (Allison)
To support science literacy, real world applications	33	I think that it's important that all students know how to look at scientific things, be scientifically literate, and be able to make decisions about scientific things and issues that come up in the world. For example, 'green' and environmentally friendly things … or greenhouse gases. I think it's important for students to be able to make decisions about these issues especially when electing officials. I think they should be able to look at this and have an open mind and realize what is science and what is pseudoscience. (Bridget)
To support teaching what science is, science content	83	I liked to learn the nature of a science and, as I was learning it, I really started to understand how important it was, and how it really helped me understand the science knowledge stuff that I already had. So, I was then learning the material and I was also learning how to teach it, and, I don't know, it just really made a big impact on me and on my understanding of science. I think it will do the same for my students. (Melissa)

It has helped me to be more confident when I'm teaching, especially teaching evolution this year. I got to teach it in a way that's not, 'Oh look, here's the theory of evolution,' but, 'Let's really talk about what a theory means.' That really gave me a lot of confidence as a teacher to be able to do that in a conservative setting. And just knowing, having looked so deeply into what theories and laws are, feeling like I can give the students a more accurate description rather than what I had learned in high school. (Sasha, Interview)

Discussion and implications

The purpose of this study was to explore the effectiveness of NOS instruction along a context continuum on the development of secondary science preservice teachers' NOS conceptions and NOS instructional rationales. Explicit, reflective instruction resulted in a substantial increase in the number of participants with fully aligned conceptions of NOS on the seven tenets assessed. The sample size for this study was largely relative to previous work (e.g. Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick et al., 1998; Akerson & Hanuscin, 2007; Schwartz et al., 2004), allowing for tests of the statistical significance of outcomes. Statistical significance is an important but largely missing element of understanding the effectiveness of NOS instruction. Wilcoxon tests of the pre- and post-test scores indicated that the increases in alignment were statistically significant for each NOS tenet, supporting the substantial shifts identified in the qualitative analysis.

Improving conceptions

NOS plays an essential role in scientific literacy (NGSS Lead States, 2013). Therefore, helping preservice teachers to attain aligned conceptions of NOS is an important goal in any science education methods course. The participants in the present study made greater gains than those of Abd-El-Khalick et al. (1998). In our study, almost all the teachers expressed fully aligned NOS conceptions following NOS instruction. In contrast, the 14 preservice secondary science teachers of Abd-El-Khalick and colleague's (1998) study did not improve their conceptions for social and cultural influences. Furthermore, their participants struggled to articulate the difference between scientific theories and laws. The findings of the present study demonstrate a substantial improvement in these outcomes.

The present study demonstrates that it is possible to markedly increase the alignment of preservice teachers' NOS conceptions using a moderate number of activities spread over two semesters of coursework. This represents repeated and distributed emphasis on the assessed NOS tenets, although without the large time/human resource investment as in Akerson and Hanuscin's (2007) study of a three-year professional development. Therefore, NOS interventions similar to that of the present investigation could be adapted for use with inservice teachers for whom human-capital efficient professional development interventions are important.

Researchers also have explored the effectiveness of NOS instruction embedded in different contexts such as science content and science inquiry. Results of the present study, associated with NOS instruction along a science-content context continuum, are similar to the results of Bell et al. (2011), which compared the outcomes of NOS instruction that focused on either contextualized or noncontextualized activities. Thus, the degree of contextualization associated with NOS instruction does not appear to influence the level of teachers' NOS conceptions, as all three types of NOS intervention resulted in marked and statistically significant improvements in teachers' NOS conceptions. Instead of degree of contextualization influencing NOS conceptions, the explicit, reflective nature of NOS instruction may be more relevant when it comes to substantial gains in NOS conceptions.

Conceptual change research has documented the difficulty of modifying learners' initial alternative conceptions of scientific concepts (e.g. Morrison et al., 2009; Ozdemir & Clark, 2007). The substantial increases in the alignment of participants' conceptions in the present investigation represent clear evidence of a successful NOS intervention. Abd-El-Khalick and Akerson (2004) found that those participants who recognized the importance of NOS were much more likely to improve their NOS conceptions. Participants in the Abd-El-Khalick and Akerson study who struggled with religious conceptions that seemed incompatible with the scientific worldview did not achieve fully aligned NOS conceptions. On the other hand, those who recognized science and religion as different ways of knowing held more aligned conceptions. An important component of the present study's intervention was a specific lesson on science as one of many ways of knowing, including religion (Bell, 2008). Most participants referenced ways of knowing in their post-instruction questionnaire and/or interview. In the context of Abd-El-Khalick and Akerson's (2004) results, this lesson appears to be particularly important for supporting conceptual change for the present study's participants, helping them to reconcile seemingly opposing world conceptions. The results of the present study build upon Abd-El-Khalick and Akerson's (2004) strong results, further supporting the potential of conceptual change as a framework for NOS instruction.

Translating conceptions to instructional practice

Improving teachers' NOS conceptions is only the beginning, however. Another goal of science teacher preparation is to facilitate the teaching of aligned NOS conceptions to K-12 students. Unfortunately, many teachers do not recognize how NOS instruction fits into their content instruction, a limitation especially poignant in the present climate of high-stakes testing (Abd-El-Khalick et al., 1998; Bell et al., 2000; Gess-Newsome & Lederman, 1995; Southerland et al., 2003). In contrast to the findings of many previous investigations, the participants in the present investigation not only substantially improved their conceptions of NOS, they also viewed NOS as important and planned to teach it to their own students. This intention to teach NOS is an important outcome. The preservice teachers saw NOS as an important part of science and of their future science teaching. They recognized the methods class NOS lessons as effective in improving their own NOS conceptions and as a potentially effective way to teach NOS to their students. In fact, we followed a subset of the preservice teachers that served as participants in the present investigation into their student teaching experience and beyond to explore the extent to which and how they implemented NOS in their instruction (Bell, Mulvey, & Maeng, 2012). Thirteen of the 14 teachers explicitly planned for and taught NOS during their student teaching experience. We continued to follow 10 of these teachers into their induction year, which began 15 months after science methods courses were completed. All taught NOS in multiple lessons and seven teachers taught NOS in novel lessons not included in methods course instruction.

Previous research suggested that teachers find the translation of NOS conceptions into effective instruction to be difficult (Abd-El-Khalick et al., 1998; Akerson & Abd-El-Khalick, 2003; Lederman, 1995; Lederman & Zeidler, 1987; Mellado, 1997; Southerland et al., 2003). Thus, the approach used to teach NOS may matter most when the goal is to facilitate teachers' NOS instruction, rather than simply understand the construct. The specific framework used in the present investigation (NOS instruction along a science-content context continuum informed by conceptual change principles) builds on the positive results of previous NOS research. The present investigation's participants expressed intentions to teach NOS and expressed varied reasons for this. Many teachers saw NOS as supporting students' broader conceptions of science. Teachers recognize NOS as helpful to support the teaching of science content and/or increasing students' broader conceptions of science are important additions to reasons teachers choose to incorporate NOS instruction.

Lederman (1999) is the only other investigation to explore teachers' rationales for including NOS instruction. He found that teachers typically did not deliberately plan to teach NOS and, when they did address it, they did so for affective reasons. None of the teachers in his investigation expressed reasons that involved science content. In the present investigation, we found the opposite. Teachers expanded beyond affective justifications to indicate just how important it was for their students to understand NOS. Such content-based and conceptual justifications may support explicit planning and more detailed instruction. In addition, viewing NOS as content worth teaching in and of itself may help teachers recognize how the construct fits into their curriculum, and thus mitigate a common implementation barrier. The potential associations between certain NOS rationales and instructional implementation need to be tested.

Concerns about context

Ault and Dodick (2010) promote the importance of substantial disciplinary context for teachers and students to learn about what science is like. For them, science inquiry needs to be science discipline-specific: integrating the specific language, tools, and thinking of a particular science discipline. They caution that school science outside rich discipline-specific science leads to substantial misconceptions about the NOS disciplines. In particular, the authors speculate that learners would benefit from considering the differences in the nature of varied science disciplines over a focus on 'unity' associated with the NOS tenets promoted as important by Lederman and colleagues. In particular, Ault and Dodick warn that a focus on 'the' NOS downplays the differences in methods across sciences as well as the influence of specific theories on scientific observations and interpretations. These claims have yet to be substantiated.

On the contrary, the present investigation provides initial evidence that teaching 'the' NOS conceptions of Lederman and colleagues can promote (rather than obfuscate) the recognition of varied science methods and the important role of theory in shaping perception. Post-instruction, 80% of participants in the present investigation articulated many different ways to do science—guided by subject matter, available tools, and convention—and 71% of participants considered scientific work in all science disciplines to be theory-laden. Teachers' NOS instructional outcomes still need to be examined and compared across other science methods course instruction on NOS along a science-content context continuum to learn more about what aspects of this instruction best support teachers' NOS conceptions, rationales, and later instruction.

We do not contest that disciplinary context is essential to the work of scientists and should be integrated into K-12 students' science inquiries. However, before K-12 students can perform inquiry and reflectively discuss NOS in rich disciplinary contexts, teachers' first need to feel comfortable and be prepared to facilitate inquiry and NOS discussions.

As teachers initially learn about NOS and how to integrate inquiry and NOS instruction into their classes, there is the potential to make both seem unreachable: too difficult, too different from their current instruction, too much work, not something the teacher can do anytime soon. In the one study that investigated potential differences across the sciences, Schwartz and Lederman (2008) concluded that scientists expressed some research design differences due to the specific research context, but that there were no substantial differences in their conceptions of science inquiry or the NOS relevant for K-12 students. Lederman and Lederman (2014) argued that part of the problem is the conflation of the NOS and inquiry/science practices (e.g. Allchin, 2011; NGSS Lead States, 2013).

Initial learning in lessons embedded in rich disciplinary contexts may discourage teachers from attempting inquiry and/or NOS instruction; highly contextualized NOS instruction can be difficult for teachers to implement (Herman et al., 2013). Thus, NOS instruction along a context continuum may strike a balance between accessibility and disciplinary perspective. This may be particularly true in professional development programs that include teachers with substantial variations in science-content knowledge. When trying to reach teachers across many scientific disciplines, less-deep disciplinary context may increase the extent to which lessons reach all teachers in a professional development or science teaching methods class. This may promote transferability of how to teach NOS to other lessons. This hypothesis will need to be empirically tested.

Activities along a NOS context continuum, when informed by conceptual change principles, can help us to actively change students' nonaligned conceptions about science, including that science is done only through experimentation. This approach to NOS instruction targets those non-aligned conceptions head-on. It also is important to note that noncontextualized activities commonly are extended to address essential science content (thus categorized as minimlly contextualized) as exemplified in the present investigation. For example, the Mystery Tube activity is a great jumping off point for instruction on evolution by natural selection, kinetic molecular theory and gas laws, or Newton's laws of motion. The activity helps teachers to address the supporting concepts of hypothesis, theory and law in a less contentious way, limiting the emotions, religion and politics that sometimes accompany evolution discussions.

Before discussing important theories and laws in science, helping students to know what the terms mean and how they are used by scientists can elevate the quality of discussions about specific theories and laws. For example, the idea that scientific theories are only hypotheses yet to be proved can be detrimental to students' conceptions of natural selection. Before instruction, 14% of participants in the present investigation considered natural selection to be less certain and less valuable than laws such as gravity. This idea was absent after instruction. Post-instruction, 83% of teachers in this study recognized NOS as a way to enhance their content instruction. Some expressed that NOS helped them to better understand scientific knowledge themselves and thought it would do the same for their students. In particular, teachers recognized NOS as supporting their instruction of scientific models such as the atomic model and specific scientific theories and laws, including Newton's laws, evolution, and the theory of natural selection. Some saw teaching NOS as a way to help students be more open to learning about evolution and natural selection. The attack on teaching evolution has been well documented (e.g. Binns, 2011; Hoppe, 2012), and NOS provided these teachers with the means to frame evolution in a productive, non-threatening way. Starting with noncontextualized NOS instruction then moving to contextualized instruction may have helped teachers to broach these important issues from a less contentious place. Research is needed to determine the sequences and extent of contextualization of NOS instruction that best supports teacher and student NOS conceptions.

Limitations and future research

Although the present investigation included a moderate sample size, the participant pool was relatively homogenous, which limits its generalizability. Future research should explore the impacts of NOS instruction along a context continuum across different groups of preservice teachers and instructional settings. The data collected for the present investigation did not allow for the assessment of using different degrees of context on teachers' instruction. Future research will compare to the extent to which preservice and inservice teachers' NOS instruction emphasizes the different degrees of contextualization when they are taught through a mixed contextualization approach. Also, research is needed to explore possible correlations associated with implementation issues (length and quality of explicit NOS instruction, extent of contextualization, extent and type of scaffolding between NOS lessons), the grade and subject(s) teachers teach, and NOS conceptions and teachers' implementation of NOS instruction. Finally, while understanding how teachers learn about and teach NOS, the ultimate question is how does such instruction impact student learning? Therefore, future research should assess the impact of NOS instruction along a context continuum on K-12 students' conceptions of the scientific enterprise.

Guided by conceptual change literature, NOS instruction along a context continuum can be effective. The present study highlighted the substantial and statistically significant shift in preservice secondary science teachers' conceptions of NOS as well as their intentions to incorporate NOS instruction into their own classes. The next steps in NOS research that arose from this investigation will further refine science educators' understanding of the efficacy of variations of explicit, reflective NOS instruction.

Disclosure statement

No potential conflict of interest was reported by the authors.

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