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# Making learning last: teachers' long-term retention of improved nature of science conceptions and instructional rationales

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#### ABSTRACT

Despite successful attempts to improve learners' nature of science (NOS) conceptions through explicit, reflective approaches, retention of improved conceptions is rarely addressed in research. The issue of context for NOS instruction has implications for this retention. Whether to contextualise has been the question occupying science educators' attention. We think this question is misplaced. Instead, we build upon recent research addressing a context continuum - drawing on the strengths of both contextualised and noncontextualised NOS instruction - to improve retention. Although there are many different potential contexts for NOS instruction, this investigation focuses on science content as context. The present investigation focused on longterm retention of improved NOS conceptions and rationales for NOS instruction. Participants were all 25 teachers who completed a professional development programme (PDP) utilising a mixed contextualisation approach to NOS instruction. We classified teachers' NOS conceptions into three levels of understanding using the Views of the Nature of Science Form-C responses and interviews three times over the year: pre-, post-, and 10-month delayed post-PDP. Results indicated that initially participants held many alternative NOS conceptions. Post-instruction, responses were substantially improved across all NOS concepts. Furthermore, nearly all of the participants' conceptions were retained across the academic year following the PDP. Participants offered varied rationales for NOS instruction including its potential to improve students' scientific literacy, perceptions of the relevance of science, improve positive risk-taking, and increase tolerance for differences. These results contrast favourably with previous reports of the retention of improvements in NOS conceptions over time.

#### **ARTICLE HISTORY**

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#### **KEYWORDS**

Nature of science; conceptual change; teacher educationinservice; professional development

Nature of science (NOS) research has emphasised an either–or approach to the contextualisation of NOS: contextualised or not (Ault & Dodick, 2010; Duschl & Grandy, 2013). We think that this focus is misplaced. Contextualised NOS instruction, or instruction situated in substantial science content, offers the opportunity for increased disciplinary perspective (e.g. Allchin, Andersen, & Kielsen, 2014; Ault & Dodick, 2010). Noncontextualised NOS

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instruction offers analogies that connect the abstract to the concrete and activities accessible to most K-12 teachers (e.g. Abd-El-Khalick & Akerson, 2004; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson & Hanuscin, 2007). We believe that the emphasis on the two extremes oversimplifies the debate. NOS instruction may be most effective when these approaches are combined, with the potential to capitalise on the strengths of the two extremes and involve varied degrees of contextualisation. Beyond improving teachers' NOS conceptions, the next step is to support retention of these improved conceptions, important for teachers' teaching of appropriate NOS conceptions to students. Yet retention of improved conceptions is an issue rarely addressed in NOS research. The present investigation attempts to contribute to NOS research by exploring a mixed contextualisation approach to move past the common dichotomy and consider its potential to improve inservice teachers' retention of NOS conceptions.

The NOS is a fundamental aspect of science teaching and learning. It includes overarching understandings about the scientific endeavour and generalisations about the characteristics of scientific knowledge. These NOS conceptions are central issues linked to scientific literacy and science education (American Association for the Advancement of Science, 1993; Driver, Leach, Millar, & Scott, 1996; Lederman, 2007; Lederman & Lederman, 2014; NGSS Lead States, 2013). As such, the *Next Generation Science Standards* (*NGSS*) include NOS concepts across all grade levels, recommending that students learn about science as a way of knowing (NGSS Lead States, 2013, Appendix H). The core NOS concepts widely accepted as appropriate for K-12 students by the science education community and that are represented in the NGSS include the following:

- Scientific knowledge is based on empirical evidence; is durable yet may be revised in light of new evidence or a change in perspective; may be impacted by scientists' backgrounds, theoretical commitments, and fields of endeavour; and is a result of imagination and creativity.
- Technological advances, ethics, values, human decisions, and social and cultural contexts have influenced the progress of science and science has influenced them in return. Science and engineering are influenced by society. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.
- Scientific investigations use various methods to generate scientific knowledge.
- Science models, laws, mechanisms, and theories serve important roles in the understanding of natural phenomena.

The list represents a brief overview of the NOS concepts that are the focus of the present investigation. See Bell, Mulvey, and Maeng (2016) for alignment of these concepts with the NGSS. These concepts are not taught as a list to be memorised but instead concepts to be explored and reflected upon. Although this is not the only view of NOS held by science educators, it is a view accepted by many as appropriate for K-12 instruction (Lederman, 2007; Lederman & Lederman, 2014; McComas & Olson, 1998; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Holding these conceptions is thought to have many substantial positive outcomes, such as supporting the assessment of information from various sources and the evaluation of conclusions (Driver et al., 1996), but people need to learn how to use NOS to support this evaluation (Lederman & Lederman, 2014). In essence, understanding NOS is useful to inform everyday interactions with scientific information.

Furthermore, teaching NOS can help to shift the focus away from memorisation of scientific knowledge to understanding scientific knowledge, why scientific knowledge is reasonable, in what contexts it can be applied, and its limitations. Informed NOS conceptions can support more integrated conceptions of scientific concepts (e.g. Songer & Linn, 1991) and may increase appreciation for major scientific accomplishments. This last point is particularly important given that scientific funding relies to a large degree on the broader community recognising the cultural value of science and supporting its efforts (Driver et al., 1996; NGSS Lead States Appendix H, 2013).

#### Improvement and retention of NOS conceptions

Although NOS is widely recognised as an important instructional goal (e.g. Driver et al., 1996; McComas & Olson, 1998; Osborne et al., 2003), research indicates that few teachers hold appropriate conceptions, which limits their ability to teach this key aspect of scientific literacy (Lederman, 2007). Research on NOS instruction has identified the importance of explicit, reflective discussions in promoting appropriate NOS conceptions (e.g. Abd-El-Khalick & Akerson, 2004; Bell, Matkins, & Gansneder, Abd-El-Khalick, Bell, & Lederman, 1998;2011; Scharmann, Smith, James, & Jensen, 2005; Schwartz, Lederman, & Crawford, 2004; Yacoubian & BaouJaoude, 2010). In contrast, implicit NOS instruction has been shown to be ineffective (Abd-El-Khalick & Lederman, 2000; Bell, Blair, Crawford, & Lederman, 2003; Bell et al., 2011).

For teachers to be able to address appropriate NOS conceptions in their instruction, it follows that they must retain these conceptions over time. In much of the existing research, teachers' conceptions are assessed prior to and immediately following intensive NOS interventions, when participants are most likely to remember the complex interplay between NOS concepts (Lederman & Lederman, 2014). Such pre-/post-assessments limit our understanding of lasting changes – the type of change that is likely to result in long-term student achievement. The few investigations that have addressed the matter indicate that retention of improved NOS conceptions is challenging. For example, many elementary preservice teachers reverted to their initial conceptions five months post-intervention (Akerson, Morrison, & Roth McDuffie, 2006). Similarly, many tenth grade students in a Middle Eastern city, who improved their NOS conceptions during a six-week engineering unit, reverted to initial conceptions after four months (Khishfe, 2015). We identified only two studies, both with secondary science teacher participants, that reported mostly retained NOS conceptions five months after a six-week NOS course in the West Bank (Wahbeh & Abd-El-Khalick, 2014) and two to five years after a U.S. teacher training programme with a NOS-specific course (Herman & Clough, 2016). While these results are promising, the mixed results of existing research indicate a need to further explore retention of NOS conceptions in other contexts. Understanding retention and how conceptions change over time for different populations and different NOS interventions are important precursors to additional research on teachers' NOS instruction.

# A consideration of context

Beyond the agreement of the importance of explicit, reflective NOS instruction, what may influence retention of NOS conceptions is a consideration of context. Contextualised NOS 4 👄 B. K. MULVEY AND R. L. BELL

interventions have had some success with learners of varied ages. Potential contexts for NOS instruction include:

- historical and/or contemporary science examples (e.g. Abd-El-Khalick & Lederman, 2000; Lin & Chen, 2002; Olson & Clough, 2007; Vanderlinden, 2007; Wong, Kwan, Hodson, & Yung, 2009);
- science inquiry (e.g. Akerson & Hanuscin, 2007; Burgin & Sadler, 2016; Ozgelen, Yilmaz-Tuzun, & Hanuscin, 2013; Schussler, Bautista, Link-Perez, Solomon, & Steinly, 2013); and
- socioscientific issues and specific science content (e.g. Eastwood et al., 2012; Khishfe, 2012; Matkins & Bell, 2007; Sadler, Chambers, & Zeidler, 2004; Schalk, 2012).

These contexts for NOS instruction need not be mutually exclusive. For example, NOS instruction situated within global climate change can involve not only the socioscientific issue but also inquiry and science content. From this point on, we use the term *contextualised* to indicate instruction within some degree of science content as context.

NOS instruction without an explicit science content context is referred to as *noncontextualised*. Noncontextualised NOS instruction has produced some positive outcomes, with larger gains associated with conceptual change-informed interventions (Abd-El-Khalick & Akerson, 2004) and multi-year interventions (e.g. Akerson & Hanuscin, 2007). Yet the Next Generation Science Standards (NGSS Lead States, 2013) promote Disciplinary Core Ideas – science content – as an important context for NOS as well as Science Practices and Crosscutting Concepts. Indeed, some researchers consider science content and a specific disciplinary lens as more authentic and relevant (Allchin et al., 2014; Ault & Dodick, 2010). However, this approach has yet to be supported by empirical research as more effective than NOS instruction outside of such a context. Some research has identified that science content can act as a frame that influences students' conceptions of NOS (e.g. Brickhouse, Dagher, Letts, & Shipman, 2000; Driver et al., 1996), interpreted by Clough (2006) to support the need for contextualised NOS instruction.

A major difference among effective interventions is the degree to which NOS instruction is contextualised. Most research has examined NOS instruction the extremes: contextualised (e.g. Abd-El-Khalick & Lederman, 2000; Lin & Chen, 2002; Matkins & Bell, 2007) or noncontextualised (e.g. Akerson et al., 2000; Khishfe & Lederman, 2006). Even when studies examined outcomes of NOS instruction involving contextualised and noncontextualised NOS lessons (Akerson & Donnelly, 2010; Donnelly & Argyle, 2011), lessons were categorised as one or the other. Thus, such studies continue to emphasise an either–or dichotomy. Noncontextualised NOS instruction has produced some positive outcomes, with conceptual change-informed interventions (Abd-El-Khalick & Akerson, 2004) and multi-year interventions (e.g. Akerson & Hanuscin, 2007) associated with larger gains.

Only two empirical investigations have compared outcomes of noncontextualised to contextualised NOS interventions. Preservice elementary teachers (Bell et al., 2011) and secondary environmental science students (Khishfe & Lederman, 2006, 2007) improved their NOS conceptions to similar extents whether taught NOS within or outside of a global climate change context. Problematically, highly contextualised NOS lessons may be more difficult than noncontextualised lessons for teachers to implement (Allchin et al., 2014).

Initial research indicates that a mixed contextualisation approach holds promise. Substantial NOS conceptual gains have been associated with teaching NOS along a context continuum, involving the intentional incorporation of noncontextualised NOS instruction and lessons with varied degrees of contextualisation. When taught through this approach, 70 U.S. preservice secondary teachers made substantial, statistically significant improvements in their NOS conceptions through two semesters of science methods course instruction (Bell et al., 2016). Also, four U.S. elementary special education teachers improved their NOS conceptions, taught NOS in contextualised and noncontextualised ways, and each teacher succeeded in promoting some degree of student NOS reflection (Mulvey, Chiu, Ghosh, & Bell, 2016). Bell et al. (2016) is the only study to provide details about what instruction along a context continuum might be like, across two preservice secondary teacher science methods courses. The present investigation adapts that instruction for use with inservice middle-school science teachers in a six-day professional development programme, or PDP (Table 1). We seek to make a contribution by providing a clear description of NOS instruction along a context continuum within a relatively short inservice teacher PDP and investigating resulting NOS outcomes over time, exploring 'beyond the common dichotomy' (Bell et al., 2016, p. 499).

Additional measures of a successful teacher intervention are retention of improved conceptions and teachers' NOS instruction. The first investigation, reported here, aims to make a contribution through the examination of inservice middle-school teachers' retention of NOS conceptions and instructional intentions associated with a PDP that situated NOS instruction along a context continuum. The second paper, in preparation, explores these participants' NOS instruction.

#### **Conceptual change**

The NOS intervention in the present investigation is informed by conceptual change theory, which has been discussed and used as an effective framework for changing learners' NOS conceptions (Abd-El-Khalick & Akerson, 2004; Bell et al., 2016; Clough, 2006; Kampourakis, 2016). In this framework, learning is enhanced by constructivist instruction that encourages learners to confront their initial ideas and struggle to make sense of discrepant information (Driver & Oldham, 1986; Strike & Posner, 1992; Vosniadou, 2003). Instruction focuses on understanding concepts and interrelationships rather than memorisation through this minds-on and typically hands-on learning (Lunetta, Hofstein, & Clough, 2007), as students transition from experiences to explicit reflections on NOS. Vosniadou's perspective (e.g. Vosniadou, 1999, 2003) served as the guiding conceptual change principles for the present study:

- preconceptions commonly exist even when there has been no formal instruction;
- some preconceptions are very common, regardless of a person's background;
- preconceptions can impede learning when they differ from accepted scientific conceptions and can be resistant to change; and
- conceptual change may be gradual and time intensive.

Furthermore, our approach reflects the understanding that conceptions about scientific theories and laws are especially resistant to change (Morrison, Raab, & Ingram, 2009).

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	Degree of		Time spent		
	science		on activity		
	content	Activity	(min)	Science content	NOS tenets
$\square$	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, rings of Saturn	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
	Moderate	Mystery cans	90	Natural selection	Empirical, inferential, theory, law
		Mystery tube	90	Gas laws/kinetic molecular theory	Empirical, inferential, theory, law
		lodine clock reaction Experimental design	90	Chemical reactions	Multiple methods, creativity
	High	Moon and ocean tides simulation inquiry	200	Moon phases and ocean tidal range, and other patterns	Empirical, tentative, multiple methods
		Genetics simulation inquiry, for example	20	Inheritance of traits, variation of traits, probability	Empirical, tentative
		Lectures/discussions with astronomers, biologist, environmental scientist	260	Galaxies, stars, moon, diet, proxies, coral reefs, and more	Empirical, tentative, creative, multiple methods, subjective, social/cultural influences
Ŷ		Reading on quantum mechanics and 'the light fantastic'	20	Refraction	Empirical, characteristics of theory and its development

Table 1. NOS lessons along the context continuum (adapted from Bell et al., 2016).

In practice, this conceptual change perspective influenced the intervention employed in the present study in the following ways. Multiple instructional activities support conceptual change, starting with the assessment of learners' initial conceptions (Bransford et al., 2006; National Research Council, 2005; Posner, Strike, Hewson, & Gertzog, 1982). Activities then specifically target existing alternative conceptions to create conceptual conflict, at which point learners realise the need to revise their initial conception. Extensive discussion and reflection, with an instructor as a guide, facilitate both this recognition and the modification itself (Driver et al., 1996; Vosniadou, 2003). A series of thoughtful engagements in examining preconceptions, new information, and reflection on NOS has the potential to decrease the chance of learners returning to their preconceptions. Throughout NOS instruction, reflection is essential. Learners interact with each other in meaningful ways to recognise their alternative preconceptions and then co-construct more scientifically appropriate conceptions.

#### **Research questions**

The present investigation assessed the development and long-term retention of inservice middle-school science teachers' NOS conceptions and instructional plans/rationales

associated with NOS instruction along a context continuum. The following research questions led our investigation:

- (1) How did participants' NOS conceptions change from pre to post to delayed post-PDP instruction?
- (2) What were participants' instructional rationales for NOS immediately after the PDP and 10 months later?

## **Methods**

# Setting and participants

Participants were all 25 middle-school science teachers who completed a yearlong graduate-level NOS and inquiry PDP course. All participants taught in a public middle school, with one scheduled to teach grades 6 through 12. Two middle-school teachers were transferred to high schools for the subsequent school year. The 18 female and 7 male participants averaged 13 years of teaching experience (range of 1–32). Most participants were White, but a little more than 1/5 were from groups typically underrepresented in science teaching (3 Black, 2 Hispanic, and 1 Asian/Pacific Islander). All held a baccalaureate degree and eight also held a master's degree.

#### **NOS intervention**

NOS was integrated into a 6-day, 46-hour summer PDP. The second author and a scientist partner were the main instructors, supplemented by guest scientist talks. Throughout the PDP, instructors explicitly taught NOS lessons with varied contexts and explicitly emphasised NOS as an important aspect of science instruction. This meant that an activity elicited participants' initial ideas about NOS concepts and served as the context for explicit connections to the germane NOS aspects. Explicit, reflective NOS aspects were distinctly labelled and explicitly distinguished from inquiry-based portions of the lessons. Explicit, reflective PDP discussions - central to conceptual change - were used to assist learners to face their initial ideas and change them as needed. NOS instruction included lessons with varied degrees of science context (Table 1). Aligned with the NGSS (NGSS Lead States, 2013), NOS lessons integrated Science and Engineering Practices and Disciplinary Core Ideas such as the universe and its stars (ESS1.A). We operationalised Clough's (2006) content continuum, integrating NOS lessons from four categories 'along' this continuum: noncontextualised, minimally contextualised, moderately contextualised, and highly contextualised. Clough's (2006) working definitions guided this categorisation (see descriptions and examples below).

*Noncontextualised* lessons highlighted NOS as the primary lesson objective through activities that presented analogies for science with little or no reference to specific science content. These lessons served as introductions to NOS concepts upon which later contextualised lessons built. Examples included Digital Image and Video Clip Observation-Inference activities, Comic Strip Observation-Inference activities, and the Burning Candle (Bell, 2008). For example, in a Comic Strip activity, participants first distinguished 'observation' from 'inference' in science. Then participants noted details of images and

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related text to make inferences and 'unpack' the humour. We then discussed the importance of inferences and having evidence to support them in the development of scientific knowledge.

Minimally contextualised lessons also highlighted NOS as the main objective but added specific science content connections during or after an activity to support NOS-content learner connections. For example, we started the Fossil Fragment lesson with a discussion of 'the scientific method' (Bell, 2008; Luchessa & Lederman, 1992). Participants were asked to write down 'the method' in small groups then share with the class. Almost all expressed the alternative conception of a linear and singular science method. We then gave each student group a fossil fragment to first observe, then sketch. Next, we challenged participants to infer the rest of the organism and its habitat and sketch these in a different colour from the observations. Group discussions highlighted structure and function of organism parts as well as what kinds of body parts are more likely to be preserved in rock. Each group presented their sketch and shared their reasoning for the inferences. Participants drew substantially from their existing science content knowledge to justify inferences. In the lesson closure, we challenged participants to revisit the steps of 'the scientific method' in light of their experiences in the activity. Participants quickly commented that they did not conduct an experiment; observations and inferences are science practices, too. Participants considered the ways in which this activity was like and unlike the work of scientists, and they learned to compare their experiences to other lessons with different contexts, as suggested by Clough (2006).

*Moderately* contextualised lessons continued to involve NOS as a major lesson purpose but with science content more substantially integrated within inquiry lessons. Participants conducted online simulated inquiries on genetics, ocean tides and moon phases, gas laws, static electricity, and Doppler shift as well as performed a hands-on chemical reactions inquiry. For example, during simulated ocean tides inquiry lessons participants observed changing tidal ranges as the moon progressed through its phases. They identified the moon phase associated with greatest and least tidal range. The class cited the importance of evidence to support their conclusions. Participants also discussed the characteristics of observational investigations in contrast to scientific experiments, leading to discussions of the many methods of science.

Participants also experienced *highly* contextualised NOS lessons in which science content was the main lesson objective, emphasising contemporary science examples. Astronomers, a biologist, and an environmental scientist discussed their research and PDP instructors led reflective NOS debriefs. For example, an environmental scientist discussed his research on isotope studies of food webs in modern and fossil ecosystems, including the resolution of diet in early humans. The scientists' contemporary examples served as the context for post-presentation discussions of 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. NOS was included in the lesson closures to help participants both learn NOS and learn how to teach it within science content.

Overall, PDP NOS instruction navigated between noncontextualised NOS lessons and those with varied degrees of contextualisation that addressed science content through inquiry and historical examples as well as outside of science content. In this manner, the intervention provided scaffolding along a context continuum. Because these lessons occurred in a PDP focused on teaching NOS and inquiry, the primary focus of the instruction was on how to teach NOS and inquiry, rather than science content. Even so, the researchers modelled effective implementation of the lessons for middle-school science courses and therefore made science content the core of the highly contextualised activities.

# **Data collection**

The first author directed project research and was not a main PD instructor. To mitigate potential bias, the instructor played no role in data collection and had no knowledge of preliminary results while instruction was in progress.

To assess NOS conceptions, participants responded to the Views of the Nature of Science survey (VNOS-Form C) on the first and last days of the summer PDP and 10 months post-PDP. The survey included 10 free-response questions. See Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) for information on content and construct validity. All 25 participants were interviewed by the first author after the six-day PDP about their pre/post responses, with participants referencing their VNOS responses. The interviewer asked for clarification, examples, and further explanations of VNOS responses to serve as a member check for how participants' NOS conceptions had changed to support validity of the VNOS and associated findings. To address the second research question, the semi-structured interviews also explored participants' NOS instructional plans and associated rationales, if any. See Bell et al. (2016) for the interview protocol. All interviews were transcribed before analysis. Then 21 participants were interviewed again 10 months later, which followed a similar protocol. Each interview lasted about an hour. Four participants chose not to participate in the delayed post-assessment because they had left the teaching profession or because of family health issues.

# Data analysis

Questionnaire and interview responses were analysed following systematic data analysis process, as described by Miles and Huberman (1994). A priori codes were derived from NOS literature and corresponded to each NOS tenet (e.g. Lederman, 2007). Each code was further subdivided into three levels based on the degree of alignment with NOS conceptions currently accepted by science education researchers, as per Lederman et al. (2002) and Khishfe and Lederman (2006). Statements within each participant's questionnaire and interview responses were coded for tenet and degree of understanding. Then, each participant's conceptions on NOS tenets were holistically categorised as alternative, transitional, or informed at each of the three time points. No single statement was used to classify a participant's conceptions on a tenet. Particular attention was paid to categorisation consistency to support validity of findings. NVivo matrix queries were used to compare all statements related to participants categorised as a particular level to check consistency across conditions and participants to support validity of findings. The second author provided support for data analysis to strengthen the validity of interpretations. He reviewed the matrix queries without knowledge of the pre, post, or delayed post condition. The review resulted in only minor changes in categorisation never more than one level and for < 5% of categorisations.

Participants' post- and delayed post-PDP interview responses pertaining to their plans with respect to teaching NOS were analysed through analytic induction, following the guidelines of Bogdan and Biklen (1992). Researchers identified 28 initial codes for NOS rationales, then developed 7 overarching themes. The first author checked for confirming and disconfirming evidence, accepting the themes: increasing science literacy; critical thinking; positive risk-taking; relevance, comfort, interest, and appreciation for science; broaden ideas about science and science careers; expectations of students and makes teaching easier; and supported students academically and socio-emotionally.

# Results

This investigation explored: (1) the extent to which middle-school science teachers' NOS conceptions improved and were retained 10 months post-intervention; and (2) teachers' plans and rationale for NOS instruction. Overall results indicate that participants' conceptions were substantially more aligned following instruction, and these conceptions were retained 10 months later. Examples of participants' conceptions before instruction, after, and 10-months after instruction are presented in Table 2. Additional details are presented below, then we describe participants' ideas about their future NOS instruction.

# **NOS conceptions**

#### **Pre-instruction**

Categorisation of participants' questionnaire responses prior to instruction indicated that these teachers had many alternative conceptions of NOS (Table 3). Only 8% of participants held informed conceptions on any assessed tenets. For example, before the PDP, 68% of participants considered theories to be ideas that can become scientific laws when proven and that, with sufficient evidence, anything in science can be proven completely true with no possibility of changing. For many, creativity in science was limited to experimental design (alternative view); only 28% of participants recognised creativity in multiple aspects of experimentation, investigation design, or results interpretation but did not extend creativity to non-experimental investigations (transitional view). Before the PDP, participants overemphasised the importance of experiments for scientific knowledge development and commonly made overly negative comments about subjectivity in science. Errors or poor data were common justifications for scientists coming to different conclusions. Most participants did not recognise the importance of theories in shaping questions, observation, and inferences in science, and the role of direct observation was exaggerated. By concentrating on objectivity and verifying scientific conclusions, most participants acknowledged limited ways in which science is socially and culturally embedded (judged to be a partial understanding of the extensive interconnections, categorised as transitional conceptions). In summary, none of the middle-school science teacher participants held views that would permit them to promote current conceptions of NOS in their science instruction.

# **Post-instruction**

Post-instruction questionnaire and interview responses indicated that participants substantially improved their NOS conceptions (Table 3). Participants were rated as 'informed'

NOS tenet	Pre-summer PDP <sup>a</sup>	Post-summer PDP <sup>a</sup>	Delayed post-summer PDP <sup>a</sup>
Empirical	Photographic images of atoms and analytical measurements of elements and how they form into compounds help show the structure of the atom Biologists work in the natural habitats of the life they are studying. They may use direct observation or video observation. (Transitional, Winston)	Most scientists spend enormous hours of observing to gather data. Astronomers look through a variety of telescopes, focused of what seems like nothing to gather data on the unknown to begin comparing it to the known. Many scientists cannot observe things directly, such as space and stars or galaxies out in space, or the life or environments of millions of years ago. They compare what they have data of today to what they find in fossil evidence and use that to make inferences that are acceptable but can't be directly observed or tested with controlled variables. (Informed. Winston)	Some things are probably more susceptible to changing but they may not. I go back to the cell theory. It's still the same cell but our technology has changed so now we can make better observations, better data, and improve the model based on new evidence. Now there's a change more in explanations and small changes. Certain things have more possibility of changing than others. (Informed, Winston)
Tentative	Scientific theories will change. The world is dynamic and not static so things are constantly being changed, and with new discoveries on a daily basis no theory will last forever. (Alternative, Max)	Based on theories they [scientists] are quite certain that the structure of the atom is what it currently is, that is not to say that it may not change in the future Science is always changing so they may have to change based on changes that are occurring in science. (Transitional, VNOS Max)	Nothing is definitely true Conclusions [are] based on evidence of the time, which can change down the road. (Transitional, Max)
Creative	Science and art are both creative subjects that require patience. To conduct experiments, sometimes scientists may not have the exact equipment needed, so they have to improvise Scientists must be patient when conducting an experiment. Experiments don't take place in the blink of an eye. Experiments take hours, days, months or even years and scientists have to prepare to wait the allotted amount of time in order to get the full results. (Alternative, Monica)	Science and Art are similar because both require creativity, imagination and intuition Scientists also develop questions to test while doing another experiment and something out of the ordinary occurs They may have to improvise for certain equipment they don't have, or for experiments that are unethical to conduct. For example, Dr T. is studying the effects of smoking, but he cannot have a group of individuals to study how smoking affects the human body; therefore, he has developed a machine that smokes the cigarette and uses human lung cells as the subject. So he is observing/ measuring what happens to the lung cells based on the amount of smoke they are subjected to Scientists can read results differently from other scientists. Human brains are not all the same and they work in different directions. Just because the results are the same, doesn't mean that everyone will analyse them the exact same way in the end. (Informed, Monica)	Students can come up with the procedure themselves and figure out the solution. When students conduct an inquiry, they can come up with different questions and different answers to the same question. This can be based on their previous experiences, how they were taught to think about this topic or method before. And people are going to think differently. (Informed, Monica)

# Table 2. Representative participant statements from before, immediately after, and 10-months after summer PDP instruction.

(Continued)

Table 2. Continued.

NOS tenet	Pre-summer PDP <sup>a</sup>	Post-summer PDP <sup>a</sup>	Delayed post-summer PDP <sup>a</sup>
Subjective, theory- laden	If the experiment was not controlled (which most aren't) then the data could be interpreted differently. Information that may be crucial to a correct interpretation may not be available. (Transitional, Gale)	Scientists can interpret data differently When better instruments are invented to make measurements or more measurements are made with existing instruments then interpretations of the data can change. Not all interpretations of data are equal. The interpretation or theory that fits the data the best is usually more widely accepted. (Informed, Gale)	Scientists' personality has a lot to do with how they make an inference. I think that [subjectivity] is both positive and negative. It can be a negative thing when a scientist is trying to get certain results and they interpret their data the way they want. But it's also a good thing because so much of science is accomplished by error, accident, or just by a scientist picking up on something; maybe it's something they experienced before. Their past experiences matter. (Informed, Gale)
Relationship between theories and laws	A scientific theory is only an explanation for a certain result that occurs some of the time and only based on the circumstances surrounding the applications in which it explains A scientific law is an aspect of science that no matter what cannot be disproven, no matter what application is applied or the circumstances surrounding it. So, what goes up must always come down as long as there is gravity in play. (Alternative, James)	Scientific theories are the tools used to explain scientific laws. That is, a theory explains how the processes within the law operate. An example of this would be the Law of Conservation of Energy, which states that Energy cannot be created nor destroyed, it can only change form, and the Kinetic Theory which is used to explain how the law actually works. (Informed, James)	It may be that we find laws that are unbelievably applicable and hold up beautifully across almost the whole universe. But when we get up to light speeds or go to subatomic, they [phenomena] can change. Scientific laws describe the phenomenon but they don't explain it. Scientific theory explains it. The uncertainty of different theories and laws can be different A theory will not become a law. (Informed. James)
Social and cultural influences	First [what influences the work of scientists] would be their background knowledge and desire to investigate. Next would be the politics and funding for the experiment. (Transitional, Emma)	[Scientists] need funding and a place to work. They need background knowledge and education on that topic. Now I realise that science in colleges are not the same as industries. In school it 50% proposal writing for grants and if they cannot get the grant they do not get to work. In the other world a scientist is paid by the company to research what they want not what the scientist wants. What a company or a funding agency values can determine what research is done Technology available also plays a role. (Informed, Emma)	Science can be guided by the data but scientists still make decisions on how to work, what to work on. Budget cuts can impact this. (Transitional, Emma)
No single scientific method	Activities involve observations. Those observations can be set in a controlled environment, the lab, or in the natural world itself I only know of one scientific method. (Transitional, Cindy)	There are many scientific methods that are used by scientists. Experimental methods control a variable in order to arrive at a conclusion. Models and simulations employ a method by which a set of data is 'put into' an existing situation and is observed to see what has happened or what could happen. Scientists also observe the natural world and then make inferences based on those observations. All these methods (and more) have been utilised by scientists to reach valid conclusions. (Informed, Cindy)	From observing to the experimental method, science is done in many ways. Experiments can't always be done. Comparison, correlation, observation all can be part of developing scientific knowledge I'm thinking about the hazards of smoking and how we linked smoking to negative health effects without doing experiments on humans. There are ethics reasons as well as practical reasons to do non- experimental science research. (Informed, Cindy)

<sup>a</sup>NOS categorisations were informed by all VNOS (Form-C) and interview comments. The exemplars above represent only a portion of the evidence to support those categorisations.

	Pi	re-summer PDP	)	Post-summer PDP		
NOS tenet	Alternative	Transitional	Informed	Alternative	Transitional	Informed
Scientific knowledge is:						
Empirical	6 (24%)	18 (72%)	1 (4%)	0 (0%)	2 (8%)	23 (92%)
Tentative	16 (64%)	9 (36%)	0 (0%)	0 (0%)	14 (52%)	11 (48%)
Creative	18 (72%)	7 (28%)	0 (0%)	4 (16%)	11 (44%)	10 (40%)
Subjective, theory-laden	7 (28%)	18 (72%)	0 (0%)	0 (0%)	11 (44%)	14 (56%)
Relationship between theories, laws	17 (68%)	8 (32%)	0 (0%)	0 (0%)	5 (20%)	20 (80%)
Social, cultural influences	9 (36%)	15 (60%)	1 (4%)	4 (16%)	7 (28%)	13 (52%)
No single scientific method	12 (48%)	13 (52%)	0 (0%)	0 (0%)	2 (8%)	23 (92%)

**Table 3.** Number of participants categorised at each level of NOS understanding for each assessed tenet before instruction (n = 25).

on five out of seven tenets on average (compared to no tenets pre-instruction). In particular, all but two of the participants moved away from on the limited view of experiments as the sole source of scientific knowledge to recognising the great importance of non-experimental methods. All moved beyond the absolutist statements widespread before the PDP, acknowledging that scientific knowledge can change with either new evidence or new perspectives on existing evidence. Furthermore, the majority of participants assigned creativity a crucial role in science and extended its role considerably to include all facets of scientific investigations, indicative of informed conceptions. All participants moved beyond that the alternative hierarchical conception that scientific theories turn into laws once enough evidence is collected for them to be proven. Participants explained that it is important for scientists to both make generalisations about the natural world (laws) and develop corresponding explanations (theories). Most participants also expressed richer understandings of the complex interaction between society, culture, and science. There were substantial yet unequal improvements in participants' NOS conceptions across tenets. For example, the greatest percentage of participants (92%) developed informed conceptions of the empirical nature of scientific knowledge and multiple scientific methods and the lowest percentage developed informed conceptions of the creativity tenet (40%). All participants considered the PDP to be the source of their improved NOS conceptions.

## **Delayed post-instruction**

Near the end of the school year following the summer PDP, 21 of the 25 participants were interviewed about their NOS conceptions and instruction. There was much continuity in conceptions for most tenets from immediately after the summer PDP to 10 months later (Table 4). However, there was an unexpected substantial increase from 48% to 76% of participants with conceptions categorised as 'informed' for the tentative nature of scientific knowledge, as well as declines for the tenets of creativity (40–29%) and social and cultural embeddedness (52–29%).

*Empirical basis for scientific knowledge*. All but one participant (95%) held informed conceptions of the empirical basis of science 10 months post-summer PDP, indicating that direct and indirect observation associated with experimental and non-experimental investigations comprise empirical evidence in science. Two participants improved from transitional to informed and one moved in the opposite direction. All participants dismissed experiments as the origin of evidence supporting all knowledge in science, which characterised many pre-PDP participant responses.

	Post-summer PDP			Delayed post-summer PDP		
NOS tenet	Alternative	Transitional	Informed	Alternative	Transitional	Informed
Scientific knowledge is:						
Empirical	0 (0%)	2 (10%)	19 (90%)	0 (0%)	1 (5%)	20 (95%)
Tentative	0 (0%)	13 (52%)	8 (38%)	0 (0%)	6 (29%)	15 (71%)
Creative	4 (19%)	8 (38%)	9 (43%)	2 (10%)	13 (62%)	6 (29%)
Subjective, theory-laden	0 (0%)	10 (48%)	11(52%)	1 (5%)	8 (38%)	12 (57%)
Relationship between theories, laws and laws	0 (0%)	5 (24%)	16(80%)	0 (0%)	5 (24%)	16 (76%)
Social, cultural influences	4 (19%)	7 (33%)	10 (48%)	1 (5%)	14 (67%)	6 (29%)
No single scientific method	0 (0%)	1 (5%)	20 (92%)	0 (0%)	2 (10%)	19 (90%)

**Table 4.** Participants categorised by level of NOS understanding for each assessed tenet after summer PDP and 10 months after PDP (n = 21).

Tentative NOS. All participants continued to hold at least transitional conceptions for the tentative NOS and six participants improved from transitional to informed conceptions. The 71% with informed conceptions of the tentative NOS overcame extreme conceptions that either scientific knowledge can be absolutely proven or that scientific knowledge changes very easily and all knowledge changes with time. Conceptions were supported by examples (e.g. natural selection has much supporting evidence and therefore is accepted by scientists, yet a high degree of certainty still allows for knowledge to change). Participants noted that additional data or looking at the data in different ways could change the conclusions. All scientific participants perceived knowledge as changeable (but not necessarily easily changed), as peer review of an argument and associated evidence are needed.

*Creative NOS.* Most participants (90%) held transitional or informed conceptions of this tenet after 10 months. Two participants (10%) improved their conceptions from alternative to transitional and one from transitional to informed; four participants decreased from informed to transitional, returning to an emphasis on expressions of creativity relegated to mostly or entirely within experiments. Those with informed conceptions explained that creativity is integrated throughout science in question development, investigational design, equipment/technology selection and modification, and data analysis.

*Subjective, theory-laden NOS.* Most participants (76%) retained their conceptions of this tenet, expressing both negative and positive implications of subjectivity in science. One participant improved from transitional to informed conceptions, and two participants decreased (one from informed to transitional, one from transitional to alternative). Thirty-eight percent of participants expressed informed conceptions, referencing the possibility of an individual's and/or the larger scientific community's framework changing and many positive outcomes of subjective aspects of science. The 57% of participants holding transitional conceptions overemphasised negative aspects of subjectivity in science but acknowledged the possibility of subjectivity playing a positive role in science. References to the role of disciplinary and theoretical frameworks in science, common after the summer PDP, were rare 10 months later.

*Relationship between scientific theories and laws.* Almost all participants (90%) held informed conceptions of this tenet, noting that theories and laws have different functions. One participant improved their conceptions from transitional to informed, and one moved in the opposite direction. The misconception that theories become laws with enough evidence, common before the summer PDP, was absent 10 months afterwards.

Social and cultural influences on science. The percentage of participants with informed conceptions dropped from 52% to 29% from the PDP post to delayed post. Three participants improved from alternative to transitional, and two decreased from informed to transitional conceptions. All but one participant held at least transitional conceptions on this tenet 10 months post-summer PDP, indicating substantially more informed conceptions compared to before instruction. Participants holding informed conceptions commented on multiple ways that society impacts scientists' selection of projects and how they proceed. Despite more extreme accounts of society and culture's influences on science, those holding transitional conceptions still recognised the interplay between society, culture, and science. They indicated at least one positive and negative aspect to this relationship but commonly overemphasised a negative connotation.

#### No single scientific method

Ten months post-PDP, 90% of participants held informed conceptions and 10% held transitional conceptions, all recognising that not all science is experimental. All but two participants retained their post-PDP conceptions. One participant improved from transitional to informed and two moved in the opposite direction, a strong continuity from post to delayed post. All participants who held an informed conception of scientific methodology included non-experimental studies as important for the development of scientific knowledge.

## NOS instructional intentions and rationales

#### Post-instruction

All participants planned to teach NOS during the school year after the PDP and almost 85% expressed a strong intention to integrate NOS throughout their science instruction. Haley commented, 'I hope to not just do like one activity here and there but to actually have a theme going through the class. I am going to try to tie them together throughout the semester.'

Immediately post-summer PDP, 40% of participants expressed two or more rationales for planning to teach NOS. Twenty percent indicated that they planned to teach NOS because they now understood it. The most common rationale expressed by 52% of participants was to support science literacy development. Participants specifically highlighted how NOS can support students' understanding of science concepts as well as change misconceptions about science theories/laws and 'the' scientific method. Doug called NOS 'vital to understanding what science is'. Forty-four percent of participants thought NOS would make science more relevant for students, improving their comfort, engagement, interest, and appreciation associated with science. Almost a quarter of participants discussed how NOS could broaden students' ideas about science and opportunities for varied science careers. To a lesser extent, participants suggested that teaching NOS can improve critical thinking and positive risk-taking (16%). Although noted by only 12% of participants, one particularly interesting rationale was that teaching NOS would reduce intolerance and supporting students academically and socio-emotionally. This included increased acceptance of differences in people and perspectives. Donna explained:

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We all look at things differently.... They pick on each other a lot. A lot of times they're afraid to contribute because they're afraid the other kids are going to give them a hard time. So to maybe to be a little more tolerant of different views, different perspectives. Just because you didn't see it that way doesn't mean that your way is the right way.

These participants saw NOS discussions as supporting a more open and positive classroom environment by encouraging varied ideas and perspectives.

# **Delayed post-instruction**

All participants reported teaching NOS during the academic year and planned to continue this. Almost 85% of participants continued to express a strong intention to integrate NOS throughout their science instruction. Haley reflected that using NOS as a theme supported students' interest and science concept understandings. Emma noted, 'Teaching by inquiry and about NOS help to have more students thinking on their own. I want to reconnect to NOS after each experiment, investigation, and unit.' The other 15% of participants focused on NOS mainly during the first part of their classes.

Participants offered a variety of reasons for their decision to teach NOS, with over 70% of participants indicating two or more reasons. The emphasis on scientific literacy, including improving students' understandings of science content, decreased in prevalence from 52% to 43% of participants. There was a 44–71% increase of participants indicating they want to teach NOS because it increases student comfort, engagement, interest, and appreciation for science. Cindy shared, 'To hear the energy in my classroom ... that reaffirmed that the things I was trying to do were useful.' NOS lessons enabled students to make connections and be successful in ways that had previously eluded them. The percentage of participants who indicated critical thinking and positive risk-taking as a rationale increased from 16% to 29%. Molly commented, 'I can use NOS to help students be more OK with trying things in inquiry and being wrong; scientists learn a lot from being wrong.' The percentage of participants (24%) who considered NOS to broaden students' ideas about science and opportunities for science careers remained the same. Donna commented, 'There's more stuff to find out and they could be the ones to find it out.'

There was a small increase from 12% to 19% of participants who framed NOS as decreasing bullying and/or improving tolerance for differences, helping participants reach struggling students. Tenaya saw NOS as 'a way to introduce science as the subject where you can be wrong and it's OK. ... It gave my kids the safety net they needed.' This teacher recognised the power of more aligned NOS conceptions for shaping a more inquiry-friendly classroom environment. Doug provided a specific example to illustrate how he saw NOS draw in students who had struggled:

I have a student who is not a good traditional academic student. ... We did several activities I learned through the class. ... [Mystery tube and Mystery can lessons] were the best thing to happen to that student all year. He could make the connection between what we were doing and the differences between theories and laws. ... That student came up with his own ideas about how they worked. He was actually able to come up with a model that exactly replicated [them]. ... I've been looking for something like that for students.

New rationales emerged, indicated by 10% of participants: NOS makes teaching easier and increases expectations of students. Overall, participants found NOS to help them and/or

their students. Although many wanted to continue to teach NOS because students are engaged, all but one participant expressed additional reasons.

Regardless of their reasons, all participants planned to continue to teach about NOS to their students. The context continuum-based PDP not only increased the alignment of participants' NOS conceptions but also convinced participants that NOS is an important part of their science instruction.

# **Discussion and implications**

This investigation contributes to the NOS research base by: (1) operationalising mixed contextualisation NOS instruction for a relatively compact (six-day) inservice middleschool science teacher PDP; (2) exploring the outcomes of explicit NOS instruction along a context continuum, largely absent from the literature for this NOS instructional approach; and (3) exploring the important yet mostly ignored retention of NOS conceptions and instructional intentions and rationales. Results indicated that the middleschool teacher participants substantially improved their NOS conceptions and attributed their more aligned conceptions to the PDP. These results build on the statistically significant, substantial improvements in NOS conceptions of 70 preservice secondary science teachers who experienced similar NOS instruction along a context continuum (Bell et al., 2016). While the preservice teachers in that investigation experienced NOS instruction within two semesters of science methods coursework, the inservice teachers of the present investigation also made substantial improvements through a six-day summer PDP. Achieving strong outcomes through a short, focused intervention is important for inservice teachers in particular, for whom effective extended interventions - such as Akerson and Hanuscin's (2007) three-year PDP - are not always possible. Together, the investigations begin to build an evidentiary base for this approach to NOS instruction for teachers.

# **Consideration of context and tenets**

We agree that specific disciplinary context informs scientists' work and thus should inform K-12 inquiry and NOS lessons, as recommended by Allchin et al. (2014) and Ault and Dodick (2010). The language, tools, and thinking of a discipline may support students' learning and conceptions of the complexities of the scientific endeavour. Indeed, the present investigation's NOS instruction included lectures/discussions led by guest scientists from varied disciplines, followed by reflective NOS discussions. Yet the emphasis of some science educators solely on science discipline-specific inquiry and NOS may not be appropriate places to start with teachers who are not yet comfortable with facilitating inquiry or NOS instruction. As argued in Bell et al. (2016),

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. (p. 516)

Outcomes of a series of investigations begin to dispute the claim of Clough (2007) and others, echoed by Herman and Clough (2016), that framing NOS goals as tenets may

dangerously promote the misinterpretation of the tenets as statements to be memorised. Together, the present investigation and Bell et al. (2016), among others, offer initial empirical support for teaching NOS tenets via a mixed contextualisation approach as a way to enhance nuanced conceptions of multiple and varied science methods, as well as the critical role that theory plays in influencing perception. At least 80% of participants in these studies expressed sophisticated understandings of the ways science is done, informed by discipline-specific tools and thinking. Furthermore, at least 50% of participants explained how science work is informed by theory, supported by nuanced examples. NOS instruction was framed by explicit, reflective use of NOS tenets, but the tenets were not taught as a list. Instead, the tenets served as instructional goals to guide instruction and associated reflective questions, much as science content standards are intended to do. Neither the tenets nor the standards illustrate the complexity of associated science instruction. The NOS instruction informed by tenets involved thoughtful questions and discussions in varied contexts during and after science lessons to help teachers consider nuances of NOS concepts. Varied contexts facilitated learners' reflection on both similarities and differences in NOS across disciplines, rather than remaining 'general abstract statements' as Herman and Clough claim. The consistency of positive outcomes for both preservice and inservice teachers should serve to lessen concerns about teaching NOS guided by NOS tenets.

The present investigation also demonstrates that it is possible for inservice teachers to largely retain their substantially improved NOS conceptions for 10 months post-summer PDP using a moderate number of NOS activities over six days. This complements Herman and Clough's (2016) findings that those who completed an intensive teacher training programme still held mostly accurate NOS conceptions years post-programme. Together the studies indicate that a mixed contextualisation approach to NOS instruction can support long-term NOS conceptions for teachers when framing a teacher training programme and a short summer PDP. Conceptual change research has documented just how difficult it is to maintain conceptual change and prevent learners' reversion to initial conceptions (e.g. Morrison et al., 2009; Ozdemir & Clark, 2007).

In the context of previous research in which many participants did not retain their improved NOS conceptions (e.g. Akerson et al., 2006; Khishfe, 2015), the long-term retention of improved conceptions of most NOS tenets is a major achievement. Our findings also extend this previous research and that of Wahbeh and Abd-El-Khalick (2014) by increasing the delay between post- and delayed post-assessments and increasing participants' retention of NOS conceptions. Palestinian secondary science teacher participants in the West Bank improved their NOS conceptions from pre- to post-intervention and their conceptions remained mostly consistent five months later. Retention in the present investigation was somewhat better, with NOS conceptions remaining stable for four of the eight assessed tenets, an increase for the subjectivity and tentative tenets, and a decline only in conceptions of creativity and influences of society and culture. Furthermore, the West Bank required curriculum and assessment included NOS. It may be more difficult to retain conceptions where NOS instruction is encouraged but not required, as is the case in the present investigation, making the largely retained increases in teachers' conceptions more noteworthy.

An alternative explanation for the strong retention of NOS conceptions in the present investigation is that the inservice teacher participants may have reached higher cognitive development positions than their preservice teacher counterparts in other investigations. For example, Akerson et al. (2006) found that preservice elementary teachers ranked at higher positions within Perry's scheme retained most of their NOS conceptions, while those with assessed with lower positions on Perry's scheme largely reverted to initial NOS conceptions. Akerson et al. posited that the preservice teachers at higher levels were 'metacognitively aware of their own thinking' and this may support reflection on their improved conceptions and increase the likelihood of the retention of their improved conceptions (p. 209). The potential of adults' cognitive development to support or inhibit the retention of improved NOS conceptions within NOS interventions with inservice teachers needs to be tested.

## **Rationales for NOS instruction**

The present investigation also explored teachers' rationales for including NOS in their instruction both before the summer PDP and 10 months later, as rationales are thought to impact teachers' NOS instruction. Twenty percent noted that they now planned to teach NOS post-PDP due to their newly developed understandings. This indicates that their lack of understanding about NOS had acted as a barrier to NOS instruction, something overcome through this PDP. Many participants identified how NOS supports scientific literacy, including the development of students' science content understanding. Other rationales included increased relevance of science and broadening students' ideas about science and variation in science careers as reasons for teaching NOS. A few teachers felt that NOS improved students' critical thinking and positive risk-taking. Others considered NOS to help them reach struggling students, increase their expectations of students, and even decrease bullying and increase tolerance for differences.

These results are aligned with those of Bell et al. (2016), whose preservice teacher participants also expressed multiple rationales that moved beyond affective reasons to teach NOS. However, the inservice teachers of the present investigation presented rationales beyond those of the preservice teachers. Additional reasons to teach NOS included its support of positive risk-taking, struggling students, and tolerance of varied perspectives and differences. Some of the inservice teachers recognised NOS as a tool to help students with their social relationships in class and emotional and academic health (including willingness to take risks).

This is the first study to our knowledge that examines changes in participants' NOS instructional rationales over time. We found that markedly more teachers offered two or more rationales in the delayed post-interview compared to post-summer PDP. One rationale emerged only in the delayed post-interview: Teaching NOS made teaching easier and increased expectations of students. More rationales and viewing NOS as supportive of the rest of their science instruction in particular may support teachers' decision to teach NOS and perseverance in the face of obstacles. This assertion needs to be empirically tested. Although the specific rationales teachers offered changed quite a bit from the post- to delayed post-interview, almost all teachers considered reasons beyond student affect to teach NOS. This contrasts with Lederman (1999), who also explored this question, and concluded that teachers relied on affective reasons for teaching NOS, when they addressed NOS at all. Instead, we found that all but one participant planned to teach NOS for reasons beyond student engagement and enjoyment. These other

justifications may support' teachers' recognition of how NOS 'fits' into the curriculum, thus mitigating a common implementation barrier. This aligns with the finding of Abd-El-Khalick and Akerson (2004) that teachers were markedly more likely to increase their conceptions of NOS ideas if they considered NOS to be important for students to understand.

# Limitations and future research

The present study examined outcomes of a mixed contextualisation approach to NOS instruction for inservice teachers. The greater science backgrounds and experience teaching science of these participants warranted an examination of their NOS conceptions before considering their NOS instruction. Results indicated that inservice science teachers also benefited from a mixed contextualisation approach to NOS instruction that links the abstract NOS to engaging activities incorporating science practices. Participants of the present investigation represented a more diverse group of teachers with respect to the amount of experience and instructional settings compared to Bell et al. (2016), yet the focus on one cohort of PDP participants limits its generalisability. Additional empirical investigations of this approach need to be conducted with additional varied teacher groups, in varied instructional contexts, and with students. Future research will examine the inservice middle-school teacher participants' NOS instruction to consider whether retained conceptions and a strong valuation of NOS instruction together can support the implementation of that instruction. Future research also will explore teachers' emphasis on the varied degrees of context within their NOS instruction when teachers are taught through this mixed contextualisation approach. The potential of Perry's (1999) scheme to begin to understand why some teachers retain improved NOS conceptions and other revert to initial conceptions should be examined with inservice teacher participants. This research will then extend to consider the outcomes of this approach on K-12 students' NOS conceptions.

Overall, the present study shows the power of a NOS intervention along a context continuum to support the long-term retention of NOS conceptions. Teachers retained their substantial increases in their NOS conceptions over many months and they recognised the value of teaching NOS, planning to incorporate NOS instruction into their classes. When continued understanding is combined with valuing NOS instruction, the resulting instructional outcomes may be synergistic. Future research should compare approaches beyond the ends of the context continuum to evaluate this possibility. A mixed contextualisation approach may be an important pathway to these outcomes.

# **Disclosure statement**

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