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Teachers' Longitudinal NOS Understanding After Having Completed a Science Teacher Education Program

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Abstract The study reported here investigated experienced teachers' views on several nature of science (NOS) issues 2 to 5 years after they completed a demanding secondary science teacher education program in which the NOS was an extensive and recurring component. Both quantitative and qualitative data were collected and analyzed to determine study participants' NOS understanding. Study participant's NOS views were determined to be generally accurate and robust, suggesting that experiences in their science teacher education program had a long-lasting positive impact on NOS understanding. The preservice program that study participants completed has several unique features that may account for that long-lasting impact and has implications for preservice and inservice science teacher education professional development.

Keywords Nature of science · Science teacher education

Introduction

Accurately understanding the nature of science (NOS) is a key component of scientific literacy, a centerpiece in most all science education reform documents, and a necessity for those who teach science (American Association for the Advancement of Science [AAAS], 1989; Lederman, 2007; McComas, 1998). Mitchell (2009) provides several examples illustrating the consequences of NOS understanding on decision-making by policymakers and the general public. Science teachers, in particular, need to possess a deep and robust understanding

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of both science content and the NOS in order to effectively teach science. Abd-El-Khalick & Lederman (2000) write:

> [W]hat needs to be emphasized is that teaching about the NOS requires teachers to have *more* than a rudimentary or superficial knowledge and understanding of various aspects of the NOS …. For instance, it is not enough for teachers to 'know' that scientific knowledge is socially and culturally embedded. They should be able to use examples and/or simplified case histories from scientific practice to substantiate this claim and make it accessible and understandable for students. (p. 693)

Because teachers must understand the NOS in order to accurately teach it to students, research directed at teachers' NOS implementation must also assess and report study participants' NOS understanding (e.g., Abd-El-Khalick & Akerson, 2004; Lederman, 1999). However, almost all studies of teachers' NOS learning focus on preservice teachers' NOS views shortly after they received explicit NOS instruction. Thus, the long-term NOS understanding of teachers having experienced NOS instruction during their science teacher education program remains an important question worthy of study.

This study's objectives were to investigate (1) the extent a nature of science in science education course was successful in promoting more informed views about specific NOS ideas and (2) experienced teachers' views on several NOS issues 2 to 5 years after they completed a demanding secondary science teacher education program in which the nature of science was a reoccurring theme. The first objective, while addressed in previous studies (see Abd-El-Khalick & Lederman, 2000), is necessary to establish the impact of the participants' NOS course in order to address the second and more significant objective of determining the participants' NOS understanding long after completing their science teacher education program. To the authors' best knowledge, no prior studies have investigated and extensively detailed the NOS understanding of teachers several years after completing such a program.

The study presented here investigates one of the few science education preservice programs in the USA that require its preservice students to complete a course solely focused on the NOS and NOS pedagogy (Backhus & Thompson, 2006). While most science teacher educators value the NOS and may incorporate it in methods courses, no published studies in the last 8 years report an increase in the number of programs that *require* preservice science teachers to complete a course focusing on the NOS and NOS pedagogy. Thus, the results of the study reported here may provide important information to science teacher educators and policymakers regarding the design of teacher education programs about how to promote among science teachers accurate and durable NOS conceptions.

Methodology

Research Context

The science education component of the secondary science teacher education program that the study participants completed is unusual in that it requires both undergraduate and graduate licensure students to complete a series of secondary science methods courses (three for undergraduate students and four for graduate students) and a *Nature of Science and Science Education* course taught by a science educator. Backhus & Thompson (2006) reported that based on the 113 US institutions they surveyed, "at most perhaps 6 % of preservice teachers will have taken a [NOS] course as a requirement" (p. 74). Most preservice teachers in this program also choose to complete an elective *Restructuring Science Activities* course that addresses how to modify cookbook activities into inquiry activities. The science teacher education component of the program appears in Table 1 of the Electronic Supplementary Materials.

Promoting an accurate NOS understanding and what effective NOS pedagogy entails (Clough, 2006; Abd-El-Khalick & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002) is an important and pervasive part of the program. That said, preservice teachers in the program are taught that the NOS is one of the many important goals for science education, and teaching and learning about the NOS is always placed within the broader context of effective science teaching. For instance, deeply understanding many science ideas is often linked to understanding the NOS (Matthews, 1994; Rudolph & Stewart, 1998) and other science education goals (Clough, Berg & Olson, 2009), and students' difficulty in learning science is often linked to the counterintuitive nature of scientific processes and knowledge (Cromer, 1993; Matthews, 1994; Wolpert, 1992). Acknowledging the rarely examined values inherent in science is stressed both to understand the NOS and to help teachers understand and more effectively teach science content.

The NOS course engages students in exploring and understanding the NOS via questions (Clough, 2007) rather than tenets, the role NOS plays in science literacy (AAAS, 1989; Allchin, 2011, 2013; National Research Council, 1996; NGSS Lead States, 2013), and research-based NOS pedagogical practices. Utilizing questions regarding the NOS promotes consideration of context and complexity (Allchin, 2011; Clough, 2007) as opposed to an unintended checklist of NOS elements to be taught (Matthews, 2012). The instructor of this course overtly models research-based NOS pedagogical practices and draws extensively from his prior secondary school science classroom experience teaching the NOS. Space here does not permit a satisfactory review of the course, but see Clough (1997, 2004, 2006, 2011, and 2014) for examples illustrating what occurs in the course and the connection to the NOS ideas addressed in this study.

Study Participants

Thirteen secondary science teachers, four females and nine males, were selected to participate in this study based on geographical proximity to the researching institution. Participants were in their second to 14th year of professional teaching in schools, and none were teaching in schools that expected or encouraged NOS instruction.

All study participants completed their science teacher education program from spring/summer 2005 through spring/summer 2008 and comprise 21 % of and do not stand out from others who simultaneously completed the science teacher education program profiled above. Twelve of the 13 study participants completed their science teacher licensure program at the same large research extensive university in the upper Midwest USA. Ten participants completed the 15-month post-baccalaureate MAT program and two completed the undergraduate program. Nine of these 12 study participants completed the optional Restructuring Science Activities course. The 13th participant, a teacher in his 14th year, was in his second year of teaching after completing a Master of Science degree in science education at the same Midwestern University. That M.S. degree program included the Nature of Science and Science Education course, Advanced Pedagogy in Science Education course, and the Restructuring Science Activities course. See Table 2 in the Electronic Supplementary Materials for further information about the study participants.

Assessing NOS Understanding

This study employed a mixed methods approach that focused on data collection and analyses best suited for judiciously answering the research questions (Creswell, 2003; Feilzer, 2010). Specifically, we utilized "concurrent procedures"—collecting, triangulating, and analytically converging quantitative and qualitative survey data to achieve a robust interpretation of the participants' NOS views before and after completing a Nature of Science and Science Education course, and 2 to 5 years after they completed the secondary science teacher education program (Creswell, 2003; Hanson, Cresswell, Plano-Clark, Petska & Creswell, 2005; Patton, 2002). Important to note, the survey instruments employed in this study align with the NOS course in that both encouraged the participants' to demonstrate their views about similar NOS ideas through complex and contextual examples.

Assessing Participants' NOS Views Prior to and After the NOS Course

When study participants completed the Nature of Science and Science Education course from fall 2003 through fall 2007, selected items (see Table 3 of the Electronic Supplementary Materials) from the *Views On Science-Technology-Society* (*VOSTS*) instrument (Aikenhead, Ryan & Fleming, 1989; Aikenhead & Ryan, 1992) were administered before and after the course for the purpose of assessing and improving the impact of the course. These VOSTS items addressed NOS issues raised in this course (e.g., Influence of Society on Science and Technology; Characteristics of Scientists; Nature of Scientific Knowledge) and were completed by 11 of the 13 participants. The participants' VOSTS assessment results are profiled in this study to demonstrate the extent that participants (1) generally possessed pre-course NOS course views typically held by people with little or no formal NOS instruction and (2) expressed more informed NOS views after the NOS course.

The teachers' pre and post Nature of Science and Science Education course VOSTS responses were compared to determine the extent the course facilitated changes in the teachers' NOS views. The analysis and rating of the participating teachers' responses to the selected VOSTS items followed the procedures similar to those outlined in Rubba, Bradford & Harkness (1996). That is, each multiple-choice response to a VOSTS item was rated as "informed," "has merit," or "naive." Similar to Rubba & Harkness's (1993) analysis, the choices "I don't understand" and "I don't know enough about this subject to make a choice" were assigned to the naive category. Respondents who chose "none of these choices fits my basic viewpoint" were instructed to write their viewpoint.

Coding of VOSTS responses was accomplished by each author independently reviewing and classifying each VOSTS response into one of the three categories above based on the extent those selections and written responses reflected contemporary views regarding the NOS. Congruence was required among the authors' classifications in order for each VOSTS choice or written response to receive one of the three classifications as a final rating. The authors' independent classifications were cross compared and they discussed the remaining VOSTS selections and written responses that were discrepantly classified until an agreed upon rating and rationale was determined and justified.

The teachers' pre and post Nature of Science and Science Education course VOSTS responses were compared to determine the extent this course facilitated changes in the teachers' NOS views. To permit statistical examination, the three categories were given a numerical score (informed = 3 points, has merit = 2 points, and naive = 1 point). These VOSTS response scores were added to calculate an overall NOS understanding score for each teacher's pre-NOS course VOSTS assessment and their post-NOS course VOSTS assessment. Point totals could range from 13 to 39. A Wilcoxon signed-rank test with the ability to efficaciously detect differences among groups with lower sample sizes was then used to compare the teachers' overall NOS understanding scores derived from the pre- and post-NOS course VOSTS assessments (Cohen, 1988; Conover, 1999; Grissom & Kim, 2005).

Assessing Teachers' NOS Views 2 to 2 Years after Completing the Program

Participants' NOS understanding 2 to 5 years after completing the program was determined using six items from the Student Understanding of Science and Scientific Inquiry (SUSSI) questionnaire (Liang et al., 2008) and four additional researcher-constructed items of the same format (Clough, Herman, Smith, Kruse & Wilcox, 2010; see Table 3 in the Electronic Supplementary Materials). The SUSSI was developed after the participating teachers completed their science teacher education program. We used the SUSSI, rather than the VOSTS, to measure the participants' NOS views several years post-program for two reasons. First, a more nuanced profile of the participants' NOS views could be determined through cross comparing their quantitative and qualitative responses for each of the ten SUSSI NOS constructs. Second, triangulating each participant's qualitative and quantitative SUSSI responses provides a higher degree of credibility and trustworthiness than is achieved through VOSTS items.

For each of the ten NOS constructs, respondents first completed four Likert subscale items related to the NOS construct. Each of these four Likert scales has five choices (i.e., strongly agree, agree, undecided, disagree, strongly disagree). Immediately after completing the four Likert items associated with a particular SUSSI item, respondents then provided a written explanation of their thinking and an example illustrating their thinking. The ability to obtain, evaluate, and cross compare Likert and qualitative data makes this instrument effective with large- or small-scale studies that assess participants' NOS understanding (Liang et al., 2008).

Responses to the four Likert subitems were given numerical values from 5 (informed) to 1 (naive). Teachers scoring above 3 for all four Likert subitems were rated "informed" for that particular NOS construct. Teachers scoring below 3 for all four Likert subitems were given a rating of “naive” for that particular NOS construct. Any other combination of four Likert subitems received a rating of “has merit.”

Qualitative responses for each NOS construct were also rated “naive,” “has merit,” or “informed” based on the content of what was written. To ensure a high degree of confidence in ratings, the authors independently rated the qualitative responses until achieving a 90 % level of interrater reliability. The remaining responses with discrepant ratings were discussed until an agreed upon rating was determined and justified.

Each teacher’s qualitative and Likert response ratings for each NOS construct were then used to provide a rating of that teacher’s understanding of that NOS construct. Teachers rated naive for both the quantitative and qualitative measures were given a rating of “naive,” whereas those rated informed for both measures were given a rating of “informed.” All other rating combinations were given a rating of “has merit.”

Methodological Concerns

Three methodological concerns may arise with our study. First, that the VOSTS instrument was used to assess participants’ NOS views prior to and after Nature of Science and Science Education course, while the SUSSI instrument was used 2 to 5 years after participants completed the science teacher education program may appear problematic. However, we are not attempting to make direct comparisons between the NOS views held by study participants 2 to 5 years after having completed the program to views they held before and after the NOS course. Rather, we are investigating whether the NOS course had an impact on participants’ NOS understanding and whether the science teacher education program, of which the NOS course was one component, had a long-lasting positive impact on participants’ NOS understanding.

Second, of the 13 participants, two did not complete the VOSTS instrument when they took the Nature of Science and Science Education course. Therefore, we are left to assume they possessed NOS views similar to their peers before and immediately after the Nature of Science and Science Education course. However, the VOSTS results of the participants are reported here only to demonstrate that those entering the Nature of Science and Science Education course possessed typical NOS misconceptions and that the course was successful in improving those NOS views.

Third, while conducting an extensive post-SUSSI interview with each participant would have shed additional light on their NOS views, this was not done for a very important reason. The study presented here was part of a larger study investigating participants’ NOS instructional practices (Herman, Clough & Olson, 2013) and NOS interviews may have impacted those practices.

Results

Study participants’ expressed NOS understanding was more informed after having experienced the Nature of Science and Science Education course and remained sound 2 to 5 years after completing their science teacher education program. Specifically, notable findings that will be elaborated upon below include:

- After completing the Nature of Science and Science Education course, informed VOSTS responses increased 40 % and naive responses fell from 33 to 5 %. Participants' views about whether scientists follow a rigid method were most improved, whereas their perceptions about who should determine what scientists study and the subjectivity of scientists remained largely unchanged
- Two to 5 years after completing their secondary science teacher education program, between 38 and 77 % of the participants' responses to each of the ten SUSSI NOS constructs conveyed an informed NOS understanding. Participants' views were most informed regarding the nature of scientific observations and the stability of established scientific theories and the least informed regarding the discovery/invention character of scientific knowledge

NOS Conceptions Prior to and Immediately After the NOS Course (VOSTS)

Participants' scored significantly higher on the collection of VOSTS items after completing the Nature of Science and Science Education course ($Z = -2.94$, $p = 0.003$, $N = 11$), thus indicating that this course significantly and positively impacted their understanding of NOS ideas that are measured by the selected VOSTS items ($r = 0.89$). Out of 39 possible points, the median score for participants' responses to the VOSTS items improved from 29 before the Nature of Science and Science Education course to 37 immediately after this course. Only 42 % of the collective responses provided by participants on pre-NOS course VOSTS items were informed. Conversely, 82 % of the collective responses provided by participants on post-NOS course VOSTS items were informed. Furthermore, the percentage of naive responses fell from 33 % on pre-NOS course VOSTS items to 5 % on post-NOS course VOSTS items. Table 4 of the Electronic Supplementary Materials provides a detailed distribution of the participants' VOSTS response ratings. Appearing below are specific findings regarding each VOSTS item.

Characteristics of Scientists

After having completed the NOS course, participants had more informed views regarding characteristics of scientists conducting research (item 60211). Seven of the participants' pre-NOS course views about the extent that scientists are unbiased, logical, objective, and open-minded in their work (item 60211) were rated either "naive" or "has merit." Specifically, four participants selected the naive view that the best scientists are always open-minded, unbiased, and objective when doing science, and three participants selected the response, categorized as "has merit," that maintained the objectivity of scientists while acknowledging that scientists must also possess imagination, intelligence, and honesty. The remaining four selected the more informed view that for a variety of reasons, scientists do not necessarily display open-minded, unbiased, and objective attitudes in their work. After completing the NOS course, nine participants selected the more informed view that scientists do not necessarily display open-minded, unbiased, and objective attitudes in their work. After completing the course, only two of the participants selected naive views maintaining that the best scientists are always very open-minded, unbiased, and objective in their work.

The Role Society Should Play in Directing Science Research

Whether community or government agencies should determine what scientists investigate was the subject of VOSTS item 20121. The NOS course promoted the view that while community and government agencies should and do influence the direction of scientific investigations, scientists should have the most say because they are in a better position to know the state of current scientific knowledge and what research will likely be most fruitful. Prior to the course, nine participants selected views that gave community and government agencies much say over the direction of science research, and the course appeared to have had little impact on these views as ten of the participants expressed similar sentiments on post-course assessments.

Construction of Scientific Knowledge

Prior to the Nature of Science and Science Education course, participants largely already held informed views regarding the construction of scientific knowledge (items 70221 and 70721). For instance, prior to the course, 9 of the 11 participants selected the more informed view that scientists' decisions are not necessarily based objectively and solely on the facts of the matter (item 70221), while the remaining two participants expressed naive views that scientists decisions are or should be based objectively and solely on the facts. At the end of the course, participants' views remained the same except for one participant who moved from naive to informed and one who moved from informed to naive.

Prior to the Nature of Science and Science Education course, six of the participants expressed the more informed view that sociocultural factors, ideas, and resources will influence how scientists conduct their work (item 70721). Three participants' responses were categorized "has merit" because while acknowledging that scientists may have their own ideas and methods, they neglected the extent that sociocultural factors and ideals will influence scientists' research. The remaining two participants' responses were categorized as "naive" because they either conveyed that scientists from different countries conduct their investigations in the same way or, while scientists from different countries may use different technologies, they will still use the same scientific method.

After completing the Nature of Science and Science Education course, nine of the participants selected the informed view that sociocultural factors, ideas, and resources will influence how scientists conduct their work. One participant's post-course view was categorized as "has merit" because it accurately noted that scientists share their views and ideas with one another, but then used that sharing of ideas to maintain that scientists conduct their investigations in the same way. The remaining participant retained the same pre-NOS course view, categorized as naive, that scientists conduct their investigations in the same way all over the world because science is universal and scientists use the scientific method.

Nature of Scientific Knowledge

Participants showed the greatest improvement in their VOSTS responses related to the nature of scientific knowledge. At the beginning of the Nature of Science and Science Education course, at least three of the participants' views about any one of the nine items related to the nature of scientific knowledge were rated as "naive" or "has merit." Moreover, at least a third of the participants provided clearly naive responses to five of the items measuring this construct.

For instance, seven of the participants responded that with enough evidence a hypothesis becomes a theory, and that after a theory has been tested many times and seems to be essentially correct, it is good enough to become a law (item 90511). Nine of the participants responded that either some form of a set scientific method was followed by scientists or they did not understand enough about the subject to make a choice (item 90611). Four of the participants misunderstood the role of methodological naturalism in science (item 90921). Five of the participants denied the inventive character of scientific laws, maintaining they "are out there in nature and scientists just have to find them" (item 91011).

After having completed the Nature of Science and Science Education course, participants expressed more informed views about the nature of scientific knowledge. For instance, all 11 participants, as opposed to eight prior to the course, selected the more informed view that scientific observations may be different if scientists are working from different theoretical frameworks (item 90111). Nine participants, as opposed to two prior to the course, selected the informed view that scientists' classify the natural world according to their perceptions and accepted theories (item 90311). Ten participants, as opposed to six prior to the course, selected the informed view that either because of new evidence or reinterpretation of prior evidence, scientific knowledge may change (item 90411). All 11 participants, as opposed to four prior to the course, selected the informed view that theories do not become laws because they are different types of ideas and that theories explain laws (item 90511). All 11 participants, as opposed to only one prior to the course, expressed the informed view that no universal set scientific method is followed by all scientists (item 90611), and ten participants, as opposed to two prior to the course, selected the informed view that scientists will use any method that might get favorable results (item 90621). All 11 participants, as opposed to seven prior to the course, selected the more informed view that science does not utilize supernatural explanations to account for natural phenomena because the supernatural is beyond scientific verification (item 90921). Ten participants, as opposed to six prior to the course, selected the informed response acknowledging the inventive character of scientific laws (item 91011). All 11 participants, as opposed to ten prior to the course, acknowledged the inventive character of scientific theories (item 91013), but five of these participants' post-course views were categorized as "has merit" because their view maintained that theories are an interpretation of facts that are discovered in the same sense that a gold miner "discovers" gold.

NOS Conceptions 2 to 5 Years After the NOS Course

Summative (Likert/qualitative) modified SUSSI responses indicated that each participant's understanding of the NOS was generally congruent with contemporary science education literature 2 to 5 years after having completed the science teacher education program. Ratings for each participant's Likert and qualitative responses were highly congruent, matching almost 84 % of the time. For 15 % of the participants, their Likert and qualitative responses differed by only one level (e.g., one rated "has merit" and the other rated "informed"). On only one SUSSI item did one participant's Likert and qualitative response ratings differ by two levels (i.e., naive versus informed). A total of ten items among three participants were rated as "not classifiable" because Likert or qualitative responses were not completed. Tables 5 and 6 of the Electronic Supplementary Materials provide the distribution of the participants' SUSSI response ratings and example SUSSI qualitative responses in addition to those found below.

Nature of Scientific Observations

Ten participant's summative responses conveyed an informed view that scientists' observations and thinking are guided by their prior knowledge, theoretical commitments, and other perspectives. The following statement represents an informed view held by participants about scientific observations:

> Scientists observations and interpretations can be the same for certain events/observations but yet different as well. Significant reasons for both similarities and differences include but are not limited to personal experiences and perception, academic background, scientific training, and theoretical perspectives. An example would be when there were hotly contested debates over the steady state theory of the universe and the notion of an expanding universe. Early on, both camps were interpreting the same limited pool of evidence yet there was clear division in the scientific community over which idea best explained our observations. Despite similar academic training, scientific perspectives, and theoretical frameworks, there was a division amongst physicists and astronomers. This was likely due to our understanding of the universe being in its infancy with no reigning perspective and limited observational evidence supporting one claim over another. On the other hand, these divided scientists could view a projectile and likely examine it similarly with Newton's laws and energy perspectives that were fully established at the time with almost unequivocal agreement. Hence scientists can observe the same events with similar interpretations and yet different interpretations. (John)

Three participants' understandings regarding the nature of scientific observations were rated as "has merit" because their written responses had problematic features. For instance, Maddy's and Peter's written responses were rated as "has merit" because Maddy mixed naive statements (e.g., scientists should be unbiased) with informed statements, while Peter did not satisfactorily explain his statement about scientific observations. Mary's qualitative responses were rated "naive" because the example she gave of different observations was merely a different name for the same observation. The following are examples of qualitative responses that were rated as "has merit" and "naive," respectively:

> Most observations will be the same, but how they are interpreted, because of prior knowledge, will be different. For example, I have students complete an observation activity the first day of class to test their senses and see what they come up with. Even though their observations are the same, they have different interpretations of what the object is. (Peter)

> Observations are based on prior knowledge. For example, one person may say something is blue-green while another may say aquamarine because they may have different experiences and one may not know the color "aquamarine". Prior knowledge can also cause different interpretations if doing comparisons. For example, someone may think DNA looks like a ladder rather than a spiral staircase. (Mary)

Stability of Scientific Theories

Ten participants demonstrated an informed understanding that scientific theories may change in light of new evidence and/or reinterpretation of prior evidence. Importantly, six of these participants also alluded to the durable nature of science in their responses. The following statement represents responses about the tentativeness of scientific theories that were rated "informed":

> Science aims to examine, explore, interpret, and explain the world as humans perceive it to be. Examination, exploration, interpretation, and explanation are performed to develop the most adequate human interpretations that serve our needs. In order for the science to meet our needs we perceive that changing our ideas in the face of novel observations, interpretations and reinterpretations to be of benefit. In order for scientific theories to be a working construct they must be predictive in nature. If we can no longer make sufficient predictions then it is beneficial for us to change our explanations/or theories. Science ideas, such as spontaneous generation to cell theory and the static-land bridge geologic model to continental drift have changed over time to better serve human needs. (Sharon)

The remaining three participant's overall understandings about the stability of theories were rated "has merit" because of concerns with their qualitative responses. These written responses were trite and vague and/or attributed change in scientific thinking merely to technological advancements that permit new experiments to be done:

> Theories are based strongly on evidence and experiments, and with technology constantly changing, new experiments can be done that may not have been possible before. This can bring about new data and a change in theories based on that data. (Mary)

Scientific Laws Compared to Theories

Scientific laws are expressions of invariable relationships in nature and scientific theories are explanations for those relationships (Campbell, 1953). Scientific laws and theories are related in complex ways, but one never becomes the other (Horner & Rubba, 1979). Based on Likert and qualitative responses, nine participants demonstrated this informed understanding of the nature of laws and theories. The following statement about scientific laws and theories is representative of those that were rated "informed":

> Laws are based on invariable relationships and theories explain those relationships. The atomic theory explains why the periodic law works the way it does. In turn, each strengthens the other one, however neither is greater than the other one, and they cannot turn into one or the other. (Matthew)

Four participants overall understandings about laws and theories were rated "has merit" because their qualitative responses coupled informed views with problematic or vague/incomplete ideas. However, all participants categorized as "has merit" expressed the informed view that scientific theories explain laws. The following statement about scientific laws and theories is representative of those that were rated "has merit":

> Scientific theories are manmade and used to explain laws. Laws of nature are always out there. It is just whether or not we understand them yet. (e.g., theory of gravity is used to explain why things fall to the ground). (Thomas)

Social and Cultural Influences on Science

Of the 12 participants who responded to Likert and qualitative measures about the presence of sociocultural influences on science, eight were rated as having an "informed" understanding that social and cultural factors influence science. Qualitative statements rated as "informed" provided examples illustrating how sociocultural factors (e.g., societal needs, perceptions of science and moral, financial, and technological reasons) influence science. The following statement was rated as "informed" regarding the NOS idea that sociocultural factors influence science:

> The values of a culture will be reflected in the goals of its science. Much funding is tied to whether there seems to be some benefit for society. Also, the beliefs of a culture will affect both what science is done and how science is done and what explanations are used. Also, cultural norms will affect who does science. Yet in some ways, because of the empirical nature, science does transcend cultural influence. In today's culture, very little value is placed on basic research (understanding nature of knowledge sake). Therefore, most research has some applied or technological component. At one time in history science was only done by wealthy white men. Mostly because they had the resources and time to conduct investigations of nature. A classic example of culture's effect on science is the Lysenko affair in Russia. Lysenko's ideas were attractive to the communist government of the time for political reasons, yet his ideas were not rooted in empirical evidence so crops failed across the country. Clearly, the politics and culture affected what science was allowed, but also this episode notes that nature is the ultimate authority/judge of our ideas. (Luke)

The remaining four participants' overall NOS understanding about this construct was rated as "has merit." These participants' qualitative statements either did not provide sufficient examples of how science is influenced by sociocultural factors or focused primarily on how societies' demands for new technologies influence technological research. The following is an example of a qualitative response for this item that was rated as "has merit":

> When I think about how society can influence science, I think of something like the cell phone industry, and how the desire for more compact, more eye-catching, and faster processing devices has driven the research in that area. I also think of my college chemistry research professor who had trouble funding his research because the majority of funds available from the government had been granted to research in the biological areas. (Isaac)

Imagination and Creativity in Science

Twelve participants responded to Likert and qualitative items about the role of imagination and creativity in science. Of these, eight were rated as having an "informed" understanding of this construct. Qualitative statements rated as "informed" provided deep explanations and examples about the important role imagination and creativity plays in science. For instance, informed participants provided examples and statements regarding the role creativity and imagination play in interpreting data, devising new methodologies, and conceptualizing how natural phenomena work:

> Scientists must create ideas to account for data and observations. The explanations for why a rock looks the way it does are not discovered but created/invented and then further compared to evidence. Yet, scientists also use creativity to develop new ways to collect data and test ideas. For example, scientists have studied and made observations of distant stars for many years. Yet, when a star seems to be getting dimmer, and then brighter then dimmer, then brighter, an idea is created to account for that observation (that a planet is orbiting that star and the dimming is when the planet partially eclipses the star). Furthermore, Mendel's contribution to genetics was because of his new approach to collecting data than a revolutionary explanation of data. His idea to count the offspring types sparked a new way to consider how genes are passed from parent to offspring. (Luke)

The remaining four participants' overall understandings about this NOS construct were rated "has merit." Three of these participants' qualitative statements were rated as "has merit" and one participant's qualitative statement was rated as "naive." Statements rated "has merit" simply described that doing science entailed imagination and creativity only because scientists were human or under unexpected and extreme circumstances. In these cases, imagination and creativity *might* influence scientists' observations and data collection. The participant who was rated as "naive" limited her written statement to conveying that the primary role of creativity in science was to develop new technologies for further data collection. The following statements about the role of creativity and imagination in science represent those rated “has merit” and “naive”, respectively:

> Scientists are human and it is impossible to turn off our creativity and imagination when recording results and observations. They might try not to let it influence them, but it still might. (Philip)

> There is a difference between being creative and being biased. Creativity can bring out new technologies to help collect data that may not otherwise be possible. (Mary)

Methodology of Scientific Investigations

Twelve participants responded to Likert and qualitative items assessing their understanding regarding the nature of scientific methodologies. Six of these participants were rated “informed” about the nature of scientific methodologies. Their qualitative statements conveyed informed descriptions and examples illustrating that methodological pluralism best accounts for how scientists go about their work. Informed statements explained the lack of a single universal scientific method and referenced research and arguments from scientists. For example, written responses from many participants make reference to the work of Einstein, Watson and Crick, Mendel and Medawar’s (1963) paper, *Is the Scientific Paper a Fraud.*

> Geologists, astronomers, and field biologists (as well as other types of scientists) typically don’t experiment on the natural world. For example, understanding what the earth was like in the past would have no test or control. Similarly, if you were studying animal behavior it typically would not be experimental, but observational. Some things in the natural world are too big (astronomy), too small (atoms) or happen on a time frame that makes them unable to be tested the same way. Even when scientists conduct experiments they use creativity and imagination. Due to this, no one method could or would be used by scientists. “[As Medawar said] “Science is doing your damnedest no holds barred” (Andrew).

The remaining six participants’ overall understandings about the nature of scientific methodologies were rated “has merit.” These participants’ written statements presented hybridized views about the presence of a set of scientific method. For instance, statements rated “has merit” acknowledged the lack of a rigid scientific method, but with caveats such as research shares many common steps, research follows a series of methods, many research steps are repeated, and science begins with observation. Furthermore, all statements rated “has merit” lacked examples supporting their position. The following statement about the nature of scientific methodologies is representative of those rated “has merit”:

> They [scientists] more often than not use different types of methods. They will use whatever methodology they need to gain results. This may mean repeating steps, starting over mid-way through, or changing [methods] mid-way through. (Carey)

Social Interactions Among Scientific Researchers

Twelve participants responded to Likert and qualitative items pertaining to the social interactions among scientific researchers. Eight participants were rated "informed" about the nature of social interactions among researchers. Informed qualitative responses included accounts of peer review and/or scientists communicating to influence each other's thinking. The following statement about the nature of social interactions among scientific researchers is representative of those that were rated "informed":

> I worked in a plant pathology lab for two summers [after having completed the science teacher education program] and was involved in a different capacity for a third summer. During this experience I saw scientists collaborating with each other to discuss ideas, help troubleshoot problems, and just for personal conversation. This being said, some conversations between research groups may be reserved for "results". This may be due to competitions between the groups. Furthermore, sometimes scientists may work alone on certain aspects of research. However, science is generally collaborative and social. (Andrew)

The remaining four participants' overall understandings about this NOS construct were rated "has merit." While all four participants' Likert responses expressed an informed understanding, three of their written responses were vague or appeared to significantly limit the scope of collaboration among scientists. For example:

> I think much of the research is done collaboratively, but not every part of it. Part of your research may be performing an experiment you don't know. So, you need to ask someone else for assistance, or compare results of one test to another test by another scientist. (Mary)

Philip's written response was categorized as "naive" because while he acknowledged that some collaboration among scientists, he maintained that most scientists work alone:

> I think scientists are just like all people. Some work alone, some don't, but I think most work alone. (Philip)

Methodological Naturalism

That acceptable scientific processes and explanations must be couched in naturalistic explanations (i.e., no recourse to the supernatural) is often referred to as methodological naturalism. Seven of the 11 participants responding to this item conveyed an understanding of methodological naturalism and were thus categorized as "informed." These participants' qualitative responses noted that science cannot test for, gather evidence about, or disprove the existence of the supernatural. The following qualitative statement about the use of supernatural explanations in science is representative of those rated "informed":

> Supernatural explanations should not be characterized as credible scientific ideas. The predominant reason being they are beyond nature. Therefore, supernatural

> ideas are not subject to the laws of nature and are typically explained through means that are neither observable nor detectable in nature. If one were to suggest the seas swell with rage because Poseidon is angry, there would be no way of determining if Poseidon actually made the seas swell, or if he was actually angry. On the other hand, a scientific explanation may explain the energy transfers that led to the seas swelling and identify a chain of events responsible for the rough seas. (John)

The remaining four participants' overall understandings of methodological naturalism were rated "has merit." Three of these participants' qualitative statements about the use of supernatural explanations were rated "informed," but their overall understandings about this construct were rated "has merit" because what they wrote was at odds with their Likert responses. The remaining participant (Mary) provided a qualitative response congruent with her Likert responses but did not provide sufficient evidence of an informed view of methodological naturalism:

> Scientific ideas are research based and dependent on evidence. So, using supernatural explanations would not be scientific since they aren't based on evidence, but more of a belief. (Mary)

Time Required for the Development and Acceptance of Scientific Knowledge

The way scientific knowledge is conveyed to the public often gives the wrong impression that credible scientific knowledge is generated and accepted rather quickly. Nine of the 11 participants responding to this item conveyed an overall understanding that much time typically passes between the conception and acceptance of scientific knowledge. Informed qualitative responses indicated that the acceptance of science ideas typically requires much time to develop and included credible reasons why this is the case (e.g., type and amount of evidence, level of collaboration in developing science ideas, characteristics of prior knowledge associated with the science idea(s), people's ability to conceptualize the science idea, level of resistance against the science idea in the scientific community). An example categorized as "informed" is:

> Barbara McClintock again. Also plate tectonics, evolution, DNA and RNA structure and function—nothing proceeds in days or weeks. It may happen, and could happen, and even sometimes does. Science ideas are generally durable. They can change, but it takes a great deal of work and collaboration to change accepted ideas. Further, to have an idea be 'accepted' requires a great deal of interaction to generate consensus. And, there may still be those who disagree and work long and hard to disprove consensus ideas. Science is the slow, gradual accumulation of knowledge which builds on current knowledge. It is infrequently an earth-shattering breakthrough which turns other ideas on their heads. (Peter)

The remaining two participants' combined Likert and qualitative responses were rated "has merit." Andrew's overall categorization on this NOS construct was "has merit" because his Likert responses indicated he was undecided regarding whether credible science ideas are usually generated in a matter of days, weeks, or months. However, his qualitative response was categorized as "informed." Mary, on the other hand, was categorized as "has merit" based on her Likert responses, but "naive" based on her qualitative response because it was limited to the notion of resisting change:

> People are very resistant to change and the need to see it to believe it is often present. This can get people to stick with an idea for a long time. Spontaneous generation was believed for a long time because that was what people thought they saw. They needed to see it wasn't true many times to change their opinion. (Mary)

Discovery and Invention of Science Ideas

Five of the 12 participants responding to this item conveyed an overall understanding acknowledging the inventive character of scientific ideas and were categorized as "informed." Qualitative responses categorized as "informed" conveyed the important point that scientists do not find science ideas, but develop or invent those ideas to make sense of or account for phenomena. The following statement about the discovery and invention of science ideas is representative of those rated "informed":

> Theories and laws are invented to make sense of the natural world. For instance, the idea of atoms was invented to describe how matter behaves. Dark matter was invented to explain observations of objects travelling in deep space. (Isaac)

The remaining seven participants' overall understandings regarding this NOS construct were rated "has merit." Sharon's qualitative statement was rated "informed," but her overall understanding was rated "has merit" because her Likert responses were equivocal on this NOS issue. Interestingly, every participant whose qualitative statements were rated "has merit" appeared to acknowledge the inventive character of theories, but they either admitted the nature of laws confused them or appeared to deny the inventive character of scientific laws. The following statement about the discovery and invention of science ideas is representative of those categorized as "has merit":

> Scientific laws are simply descriptions of events or behaviors in/of nature, when these events are described in a law, this would be considered a discovery. The gas laws were discovered. Since theories describe laws & are interpretations of how the laws work, they can be considered as invented (implies creativity & process behind their development). Darwin invented the theory of evolution. (Maddy)

Discussion and Implications

Study participants' understanding of the NOS was, unsurprisingly, more accurate after having experienced a semester-long Nature of Science and Science Education course during their science teacher education program. Encouragingly, their NOS understanding remained robust 2 to 5 years after having graduated from this program. For each of the ten SUSSI items administered long after their graduation, between 38 and 77 % of the participants' responses reflected informed NOS understanding. This was the case despite our conservative criterion that in order for a participant's response to a SUSSI item to be categorized as "informed," both their Likert responses and written explanation/examples had to express an "informed" NOS view.

While none of our study participants possessed a naive understanding for any of the ten NOS constructs administered 2 to 5 years after graduation from the program, they appeared least informed about the nature of scientific methodologies (rejecting a step-by-step scientific method, but holding a variety of positions that maintained some sense of methods or steps to all science research) and the inventive character of science ideas (acknowledging the inventive character of theories, but either being uncertain of or denying an inventive aspect for scientific laws). These difficulties are interesting because the NOS course overtly and repeatedly drew students' attention to both the inventive character of scientific laws and the problematic nature of a scientific method containing common steps and made many historical references exemplifying these NOS ideas. For instance, significant attention was devoted to Galileo's ignoring observation in favor of an idealized mathematical approach to understanding pendulum motion, and students were assigned portions of Matthews (1994) book addressing this historical case.

Of course, we cannot attribute study participants' longitudinal NOS understanding solely to the NOS course they completed during their science teacher education program. A required Secondary Science Methods II course and an elective Restructuring Science Activities course that most study participants completed also advocated accurate NOS understanding and expected lesson plans and lab activities to promote informed NOS views. Moreover, after having graduated from the program, study participants may have read additional NOS material, attended NOS presentations at conferences, and sought NOS understanding in other ways. That does not detract from the apparent power of the NOS course and science teacher education program participants completed. An education, in the noblest sense of the word, should inculcate habits of mind and action that value and further pursue learning. Undoubtedly, study participants' experiences in the secondary science teacher education program they completed did contribute to their NOS understanding both after the NOS course and 2 to 5 years later.

In the past several years, criticisms have been leveled at presenting and assessing the NOS as tenets. Clough (2007) argued that NOS tenets fail to take into account the context, the ensuing important nuances and exceptions to tenets, and the very real danger that teachers and students will misinterpret NOS tenets as additional declarative statements to be taught and memorized. Matthews (2012) echoes these concerns and goes further stating that an emphasis on NOS tenets "is directly antithetical to the very goals of thoughtfulness and critical thinking that most consider the reason for having NOS (or HPS) in the curriculum" (p. 11). Allchin (2011, 2013) argues that NOS understanding is best characterized and targeted toward personal and public decision-making, not merely as general abstract statements no matter how well understood. These criticisms merit serious consideration by the science education community.

Given the context of this study addressed earlier in the paper, the SUSSI instrument we employed was the best available instrument for assessing a variety of NOS ideas that we think science teachers ought to understand and accurately convey to the students they teach. We sought to mitigate the issues raised by Clough (2007) and Matthews (2012) and accurately determine study participants' understanding of these important issues by carefully analyzing their written explanations and examples that could take into account context and nuances. Agreeing with Allchin that personal and public decision-making, in addition to abstract statements regarding the NOS, best characterize NOS understanding, we have elsewhere (Herman et al., 2013) reported the NOS instructional decision-making and practices of our study participants. Generally speaking, participants' instructional practices reflected an accurate understanding of the NOS issues assessed by the SUSSI and reported here. The most pervasive inadequate NOS understanding reflected in their classroom practice was that regarding the inventive character of scientific knowledge, and this insufficient understanding is also reflected in the SUSSI data we reported here. We urge readers to read this published work that extensively describes participants' NOS teaching practices.

The study reported here supports the contention that preservice science teacher education programs have the potential to markedly enhance teachers' NOS understanding that is long-lasting. However, as noted earlier, the science education portion (see Table 1 in the Electronic Supplementary Materials) of the teacher education program that participants completed is not typical of most efforts to prepare secondary science teachers. The program requires all its students to complete a three credit course focused solely on the NOS and NOS pedagogy, a rarity among US science teacher education programs (Backhus & Thompson, 2006). Moreover, the other science education courses in the teacher education program sustained this effort and promoted NOS teaching and learning as a crucial aspect of effective science teaching and scientific literacy. How widely programs like this can and will be created will say much about how seriously the science education community and policymakers value the preparation of science teachers and promoting scientific literacy.

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