

Pre-service Teachers' Understanding of the Nature of Science through Socio-scientific Inquiry

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Abstract

This study explored the ways in which pre-service teachers' (PSTs) understanding of the nature of science (NOS) emerged in their experience of a socio-scientific inquiry-based (SSI) experience. In this study, an undergraduate science course with structured collaboration on a SSI-based inquiry between PSTs and campus scientists was intertwined with their changing conceptions of NOS. Qualitative and quantitative data were collected and progressively analyzed to illuminate changes in twenty-four PSTs' understanding of the nature of science throughout the experience. Results indicated that that PSTs experienced substantial growth in the targeted understandings of NOS. However, findings also revealed some aspects of NOS for which several of the PSTs continued to hold uninformed conceptions. Insights from this study that add to the on-going discussions about the relationship of SSI and NOS include 1) the importance of inquiry and 2) NOS understanding as linked to PSTs perception of inclusion in the process of SSI investigations.

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Background

Contemporary reform efforts in science education emphasize the importance of the nature of science (NOS) in socio-scientific inquiry (Zeidler & Keefer, 2003). Addressing socio-scientific inquiry (SSI) in the classroom provides a convergence point for addressing multiple components of scientific literacy (Sadler, 2004) and allows learners to explore the most meaningful connections of science to their lives through topics that require dialogue, discussion, and debate. Exploring views of students within SSI has led to an increasing emphasis on NOS as a way of knowing that calls attention to the underlying, and often implicit, principles embedded in scientific knowledge. NOS is a complex and abstract construct that involves reflecting on the scientific enterprise in ways not typically encouraged by traditional curriculum. Many educators confirm the existence of several core tenets in scientific law and theory development that

describe the overarching nature of science: scientific knowledge is tentative (subject to change) yet reliable, empirically based (based on observations and inferences of the natural world), and partly the product of human subjectivity, imagination, and creativity. Additionally, science is influenced by and influences the culture in which it is practiced, which often determines where funding resources are allocated. Other aspects of NOS that are specifically resonant with SSI are the ethical and moral dimensions embedded within science and the aspect that science is one discipline among many that cannot answer all types of questions (Zeidler, Sadler, Applebaum, & Callahan, 2009). Thus, the nature of science is important as a means of underscoring the dynamic, culturally-mediated, and social dimensions of science and can help students from all backgrounds understand and challenge their positioning within the scientific discipline (Lederman, 2002).

The field of science education, however, is struggling with how to frame issues associated with the nature of science and the link between NOS and SSI. Sadler's review of recent literature (2011) focused on student understandings of NOS and offered examples of how SSI-based education can support development of more sophisticated ideas of NOS. He asserted that providing opportunities for students to consider NOS themes in the context of SSI is certainly recommended for quality SSI science instruction but not necessarily essential. Moreover, what has become the standard account of NOS with a focus on specific NOS tenets adopts a perspective in which NOS understandings are cognitive learning outcomes of science instruction (e.g., Lederman, 2002). In contrast, several scholars (e.g., Duschl et al., 2007; Sandoval, 2005) have more recently argued for the field to prioritize epistemic practice. In our opinion, this is an important and unresolved debate within the field that will likely push us to think about science teaching and learning in new ways. Current research suggests that "doing science" is not sufficient in and of itself for developing informed conceptions of NOS. We concur with researchers who suggest, and support empirically, that to be effectively taught, NOS must be viewed as a cognitive learning outcome and addressed explicitly and reflectively within the learning environment (Driver et al., 1996). As researchers have pointed out, without explicit attention afforded to relevant aspects of NOS within the context of inquiry experiences, learners' views of NOS likely remain unchanged (Bell et al., 2003; Schwartz, Lederman, & Crawford, 2004).

This study explored the ways in which pre-service teachers' (PSTs) understanding of the nature of science was showcased within the context of a socio-scientific inquiry-based experience. Our research question was: What were the ways in which PSTs' understanding of NOS emerged in their experience of SSI? We know from past research that teacher education programs involving explicit instructional attention to NOS in conjunction with the inquiry-based activities have been more successful in improving NOS views than programs that provided inquiry experiences alone (Abd-El-Khalick & Lederman, 2000). Thus, SSI that specifically centered on socio-scientific issues congruent with NOS tenets (i.e. culturally relevant, tentative, subjective, etc...) such as environmental issues on campus that were ill defined and inclusive of multiple perspectives were resonant with our goals for creating this experience. As well, PSTs were chosen for this study in response to SSI literature asserting that science teachers often marginalize SSI in their classrooms and need opportunities to reflect on their deeper values and ideals with regard to teaching SSI (Lee & Witz, 2006; Hughes, 2000). The lack of pre-service teachers' exposure to exemplary instructional strategies to contextualize NOS within SSI was a

particular impetus in this study as pre-service science teachers' inquiry experiences influence how they think of science and how they teach science in their own classrooms. As teacher educators concerned with adequately preparing pre-service teachers, it was necessary to provide opportunities for them to experience exemplary SSI teaching, particularly inclusive of NOS, that is often missing from field settings.

Literature Review

Though research in the discourse surrounding SSI is relatively new, the ways in which SSI informs NOS understanding is a burgeoning area of interest as educators attempt to meet reform goals for science education. In the following review, exemplars that incorporate investigations on how NOS conceptions shape socio-scientific decision-making are presented. A review of the research which incorporates a focus on both NOS and SSI yielded the following themes explored below: 1) SSI instruction provides students an opportunity to understand and employ NOS considerations; 2) The bridge between NOS and SSI argumentation needs to be explicitly and reflectively scaffolded over time; and 3) There is a de-privileging of both the socio-scientific components of the science curriculum and NOS.

SSI Provides Opportunity to Employ NOS Considerations

Sadler's (2004) review of research related to informal reasoning regarding socio-scientific issues highlighted the role of socio-scientific argumentation in classroom science, the influence of ideas about the nature of science on SSI decision making, and the evaluation of information pertaining to SSI including student ideas about what counts as evidence. As such, students are asked to go beyond content knowledge to incorporate an understanding of the process of developing and modifying scientific knowledge as the focus is shifted from knowledge *in* science toward knowledge *about* science. The claim is that a person's understanding about the epistemology of content knowledge will influence the application of the content knowledge. In other words, NOS conceptualizations affect the interpretation of scientific knowledge upon which decisions about SSIs are made (Sadler, 2004; Kolstø et al., 2006; Schalk, 2009).

To help explicate this SSI-NOS connection, a study by Sadler, Chambers, & Zeidler (2004) sought to explore the ways in which high school students conceptualized some aspects of NOS (creativity, empiricism, tentativeness) as demonstrated by opposing viewpoints on an SSI. As well, they wished to investigate how students interpreted and evaluated evidence in a classroom debate on global warming. The results suggested that many students appreciated the empirical nature of science, yet did not fully understand what constitutes data and how it can be used. First, social influences were noted through argumentation that incorporated economic and personal perspectives as well as societal causes and effects. Second, other students regarded global warming as having nothing to do with societal factors and that science is separate from, or in isolation of, society. Finally, myth isolation was noted when students referenced the falsity of the article titled, 'Global Warming Myth: Evidence Against Environmental Crisis' solely due to the word 'myth' in the title. This confusion about the term myth was also evident in students' conceptions about the tentative nature of science. This study, although interesting to note the students' existing continuum of conceptions using implicit NOS teaching, does not adhere to the

plethora of recommendations that NOS be taught both explicitly and reflectively (Akerson, Abd-El-Khalick, & Lederman, 2000). As well, the learning gains in NOS conceptions were not measured pre to post in an effort to showcase success of the SSI approach.

Also approaching instruction in an implicit way, Albe (2008), using an SSI about cell phone safety, found that NOS conceptions arose naturally during instruction. Students' post-conceptions were based on scientific "proof"; thus, there was heavy emphasis on empirical data and consensus among sources. Albe concluded that students lacked adequate views of the tentative NOS, as they believed that the "truth" can be discovered with enough empirical data. Furthermore, Khishfe and Lederman (2006) compared high school students' conceptualizations of NOS between two classes: one in which the content was integrated into SSI instruction versus one in which instruction was nonintegrated into SSI instruction. Both classes again centered on the controversial topic of global climate change. Researchers found that both groups employed NOS conceptions, though integration of NOS with the SSI appeared to make no difference on understanding of data. These findings suggest that despite the fact that a teacher understands and teaches the nature of science and data, students may still possess naive ideas about what data are and how they are used. The above studies merely looked at NOS concepts that were inherently embedded into SSI instruction; however, they illustrate the need for explicit instruction on NOS and data application and interpretation.

Explicit and Reflective Bridge between NOS and SSI

To explore the use of explicit NOS instruction embedded in an SSI context, Walker and Zeidler's (2007) case study examined aspects of argumentation and discourse in a classroom debate about genetically modified foods. As SSI contexts have been argued to provide a forum for informal reasoning and argumentation skills, as well as the development of NOS conceptions and content understanding (Kolstø, 2001; Kolstø et al., 2006; Sadler, 2004), this case study attempted to investigate these features employed by students in debate about an SSI using a Web-based science environment (WISE) unit which explicitly addressed the nature of science through discussions, a video covering the conflict, and online activities which allowed students to explore multiple perspectives. Results indicated that after the initial assertion of one or two points, students quickly began to use faulty reasoning, hasty generalizations, and extreme examples to evoke affective responses (for example, one's own dog could be killed by exposure to the Bt toxin). Interviews with students revealed that they did not make explicit references to conceptual understanding of the nature of science in the classroom debate, despite having learned about NOS in their Web-based unit. Interestingly, the majority of students did not invoke evidence from what they had learned in the preceding unit, though they reflected that the debate group who was most convincing utilized more facts, quoted statistics, and displayed a great deal of background knowledge of multiple perspectives.

The students' answers to online questions, however, reflected informed conceptions of the tentative, creative, subjective, and social aspects of science. Thus, students recognized potential biases in the information presented to them on-line, and they recognized that scientists cannot control for all variables and are creative, at least to some extent, in their work. Researchers concluded that it was not enough to explicitly teach NOS skills and assume those skills will naturally emerge when students make decisions (Lederman, 2007). Rather, students should also be explicitly guided in applying that knowledge when evaluating scientific claims. Researchers

also suggested that SSI move beyond developing students' nature of science conceptions to applying those conceptions within a decision-making and argumentation context.

Also incorporating an explicit teaching of NOS, Matkins and Bell (2007) tested and interviewed 15 pre-service elementary teachers enrolled in a science methods course. Participants were exposed to explicit NOS instruction combined with explicit global climate change instruction, which were both situated within the elementary science methods curriculum. Participants showed an improvement in their understanding of both NOS and global climate change, as well as their abilities to decision-make about socio-scientific issues. These studies show that curricular materials should promote NOS and argumentation discourse to an SSI through explicit instruction and scaffolded inquiry. Recommended strategies include scaffolding for students in applying the NOS concepts to SSI argumentation and teaching NOS both explicitly and reflectively within SSI contexts.

De-privileging of SSI and NOS in the Science Curriculum

To investigate the likelihood that teachers would employ NOS-SSI considerations in their classrooms, several profiles of teacher values were illuminated ranging from: teachers who embraced the notion of infusing science curricula with SSI and cited examples of using controversial topics in their classes (Profile A); Profile B participants supported SSI curricula in theory but reported significant constraints which prohibited them from actualizing these goals; Profile C described teachers who were non-committal with respect to focusing instruction on SSI and ethics; Profile D was based on the position that science and science education should be value-free; and Profile E transcended the question of ethics in science education- these teachers felt very strongly that all education should contribute to their students' ethical development (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006).

Bencze, Alsop, and Bowen's (2009) study on student-teachers' likelihood of implementing inquiry-based activism projects in their future teaching by requiring them to conduct such projects in the context of a university-based science teacher education course indicated that only half of the PSTs appeared to be highly likely to implement SSI-based inquiry projects in their future teaching. The factors that seemed to influence student-teachers' likelihood of implementing such projects in their future teaching included: explicit and self-directed research (as part of the course), prior experiences relevant to SSI issues and activism, views about the nature of science and technology, and orientation towards education. Researchers recommended that PSTs have opportunities to explore the nature of science within SSI-oriented curricula through inquiry-based activism as this may help to increase their motivation and ability to teach these issues to their future students.

Thus, some teachers have a tendency to be more interested or more likely, to incorporate SSI into their science curricula. This finding was further strengthened by Reis & Galvão (2009), whose case study showed that the implementation of discussion activities about controversial socio-scientific issues depended decisively on the teacher's convictions about the educational relevance of these activities and the knowledge needed for their design, management, and assessment. Furthermore, Lee & Witz (2009) found that teachers address SSI out of their own personal initiative, and they often developed their own materials for SSI based on their own values, ideals, philosophies, and personal concerns. These studies suggest that the current

curriculum reforms (STS, SSI, and Nature of Science) tend to suggest theoretical ideals, but do not effectively connect with teachers' deeper values and ideals.

Sadler and Zeidler's (2005) semi-structured interviews with college students participating in a genetic engineering dilemma illustrated that students demonstrated evidence of rationalistic (reason-based), emotive (care-based), and intuitive (immediate reactions) forms of informal reasoning. This suggested classrooms need to be places in which not only reasoning abilities, but also intuition and emotion are valued. However, the following research has shown that this ideal is not the case. Hughes (2000) explored the inclusion of SSI in the science curricula through use of Salter's Advanced Level Chemistry courses offered in the United Kingdom. Unlike most socio-scientific curriculum that is added-on to the existing demands of teachers, Salter's courses attempt to embed all chemistry content within socio-scientific considerations. Repositioning science into a social, economic, political, and moral context, Salter's curriculum is divided into units containing two components: a storyline which provides contexts for scientific discoveries marked by "subjective, unconstrained tales" (p.429), and activity booklets that are linked to the textbook which include technology and laboratory applications. Rather than merely critiquing the materials in the curriculum, Hughes investigated the discourse surrounding this pedagogy in two university classes over a nine-month period.

Hughes concluded that socio-scientific practice was marginalized through the structures and languages of classroom practice. She asserted that teachers were not fully vested in the promise of the curriculum, which they saw as de-privileging scientific knowledge in favor of student voice. By placing less emphasis on the socio-scientific components of the curriculum, teachers actually acted to maintain the "elitist status of physical science" (p. 435). Teachers expressed their concern that advanced students would view them as non-scientists and they should be able to handle abstract, de-contextualized science instruction so as to showcase their higher mental faculties. Additionally, the structure of the syllabus also placed socio-scientific issues as lower in status by discussing SSI and NOS considerations at the end of units or having the student do the presentations as unevaluated, marking them as "different, fun, and less serious" (p. 432). Hughes maintained that Salter's SSI curricula, noble in its attempts to incorporate SSI by restructuring course content around broader issues, in practice continues to reinforce the pedagogical hierarchies that pervade most science instruction. SSI, associated with feminine and constructivist notions, challenges the dominant masculine and elitist view on which science was constructed;

The success of curriculum reform is influenced by hierarchical gender; it requires those involved to surrender abstract science as a body of privileged knowledge, to question scientists' positions as unique authorities, and to have a serious commitment to ending reproduction of gender and other inequalities that persist in education (p.438).

Whether the placement of socio-scientific issues in the science curricula should be within the standard science classroom or as a supplementary class remains a matter of debate amidst the pressures of high-stakes testing. Though, Hughes challenges educators to fully integrate socio-scientific issues into the science curricula in both texts and practice and be cognizant of avoiding marginalizing socio-scientific material and perpetuating gender biases. If teachers support the notion that scientific literacy entails, at least in part, the ability of students to engage in active dialogue as they ponder evidence, apply critical thinking skills, and formulate positions on

various topics- then discussions and debates that challenge students to use multiple views and competing evidence in rendering decisions becomes central to a broader view of scientific literacy that explicitly includes aspects of the nature of science. Thus, educators trying to develop a scientifically literate citizenry who can make well informed decisions about societal scientific issues must pay attention to the connection between NOS and SSI.

Through the above studies, we learned that SSI instruction has potential in underscoring students' conceptions of NOS, though it needs to be explicitly centered around issues relevant to students and explicitly scaffolded with NOS in argumentation. As well, we have also noted that there needs to be a conscious privileging of SSI in the curriculum that supports student voice in science learning and allows for consideration of multiple perspectives. Though inclusion of socio-scientific issues in the classroom has been touted to also enhance student engagement in science and is necessary for active participation as citizens on our society (Driver et al., 1996), these studies have indicated that the assumption that it will make science classes more relevant and inclusive is by no means straightforward.

Methods

The first author was the instructor of record for the course. All documents were part of the requirements of the course, but only consenting students' documents were used in data analysis, which was conducted after the course and final grades were submitted.

Context & Participants

All of the twenty-four undergraduate students enrolled (15 females, 9 males; 2 African-American, 2 Hispanic or Latino, 20 White) in a Mid-western university science class voluntarily participated in this semester-long study. The class was comprised of undergraduates who had expressed an interest in becoming elementary school teachers. In early semester journal assignments, all of the students expressed their hesitation surrounding science, indicating they had taken only the required high school courses for graduation and had no experience, nor interest in science beyond that. They referenced only traditional science classes with confirmatory lab experiences as their past experience in science courses. None of the students recalled having formal instruction on the nature of science. As well, none of the PSTs planned to major or minor in science.

The overarching goal of the course was to engage students in authentic scientific inquiry with regard to socio-scientific environmental science concepts so as to provide them a basis for reflection on NOS tenets. As such, activities throughout the semester centered on inquiry, the nature of science, data analysis and interpretation, and connecting learners with both the on-and off-campus scientific community with regard to local campus environmental science issues (see Appendix A for specific course activities and how the components of NOS and SSI were linked and embedded in class lessons). PSTs conducted investigations on-campus environmental issues (i.e. transportation, water quality, energy usage, availability of healthy food options, greening computer usage, the adoption of e-books, etc...). During their inquiries, they paired with campus scientists involved in working with these issues to share data, discuss potential solutions, and collaboratively reflect upon the implications of their studies. The six participating scientists (3

female, 3 male; ranging in age from 31-60 years) were selected because of their affiliation with the Office of Sustainability's project initiatives (i.e. transportation, water quality, energy usage, availability of healthy food options, greening computer usage, the adoption of e-books, campus community gardens, etc...). The scientists had teams of affiliates also working on the project initiatives ranging from community partners to interested students. Some projects were newly adopted initiatives of the year, while others had been underway since the inception of the Office of Sustainability two years prior. The scientists attended one of our classes to brainstorm project ideas with the students as well as communicated with the PSTs through meetings and email throughout the semester duration. All projects consisted of an exploration of the scientific content and socio-political aspects of the environmental issues through both primary and secondary research.

After selecting a topic for their inquiry project from among eight environmental issues from the Office of Sustainability's projects (each spearheaded by campus scientists) underway on our campus, the PSTs' were to research the primary literature on their topic and familiarize themselves with the scientific concepts embedded in their chosen campus environmental issues, along with the economic and political dimensions of the issue. The next phase of their inquiry project involved working alongside campus scientists to develop, research, analyze, and present their research question and data interpretations. In their investigations, they paired with campus scientists several times via email as well as in class to share data, discuss potential solutions, and collaboratively reflect upon the implications of their studies. PSTs also conducted debates in class to explore multiple perspectives on their chosen issue. Finally, the PSTs' culminating project was to present their projects in a symposium held during finals week, which was attended by peers, faculty, and the participating scientists. For their final presentations, PSTs were required to display and discuss their data analysis and interpretations, as well as embed a type of educational outreach component to offer solutions to their issues (examples of educational outreach included brochures, awareness campaigns, websites, podcasts, etc...). The beginning of the semester was devoted to an explicit exploration of the PSTs views of science in relation to Cobern & Loving's views of science activity (2002) coupled with explicit and reflective instruction on the nature of science (NOS) through activities like the Mystery Tube (National Academies of Science, 1998) and Dogs and Turnips (http://www.ucmp.berkeley.edu/education/dynamic/session4/session4_act1.htm). The tenets of the NOS were then continually emphasized throughout the course in the context of their SSI projects through meta-cognitive reflections both individually and within group discussions.

Data Collection & Analysis Techniques

The data collection occurred during a semester-long period during the Fall of 2010. Classes were held twice a week for two hours each. Collaboration with the scientific community was held during class time. Specifically, the following data were collected throughout the course.

Field notes and audio-recorded observations: To document the type of instruction of scientific community over the semester. The observations involved the instructor, students, and scientific community members taking part in the study and were made each class session throughout the semester. Audio recorders were placed on each lab table in which PSTs sat. Because all of the participants signed consent forms, all audio data were usable from the

recordings. The foci of field notes and audio-recordings was to look for instances of PSTs showcasing NOS understandings within the SSI.

Pre/Post Survey: As a part of the course, students took a pre and post survey to determine their connections to science. The Views of Nature of Science Questionnaire (VNOS-B) survey (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) was used to assess student conceptions of the nature of science. This survey was administered at the beginning and end of the semester.

PST interviews: All PSTs participated in interviews (N=24) at the beginning and end of the course. Prompts were provided for informal discussion such as: Tell me your understanding of the nature of science; In what ways was the nature of science underscored in your collaboration with scientists in your inquiry? (Appendix B for pre and post interview questions).

The data from each question on the VNOS-B survey were broken down into topics and then analyzed using predetermined categories from Lederman et al. (2002). The data collected were coded based on Lederman and his colleagues coding system using apriori codes for the participants' views about NOS and they were based on the following themes: subjectivity, creativity, and tentativeness in science ...". Thus, within instances of SSI-based instruction, a record of the range of NOS conceptions for each tenet was scored. A second reading of the data allowed for grouping and combining of specific codes into broader categories for each tenet, allowing the researchers to identify increased understandings and note specific instances of the utilization of NOS tenets. We also looked for patterns of similarities and differences within and across the journals and classroom field data to note which tenets the PSTs referenced and when, and which ones they contrasted with others. PSTs' conceptions were coded as 'uninformed,' 'emerging,' and 'informed.' Both authors and a peer de-briefer separately coded the data and thoroughly discussed discrepancies until consensus was achieved. Each investigator conducted separate analyses of the data using categories of uninformed, emerging, and informed to categorize each student in the class (N=24). The two analyses were compared and degree of correspondence was noted. Any remaining differences were resolved by further consultation of the data and/or consensus. Primary data sources included the VNOS-B and interviews regarding the NOS tenets within the SSI. Secondary sources, which allowed for triangulation of data, included field notes and transcripts from audio-recordings from classroom discussions and reflective in-class activities.

Findings

Improving Conceptions of NOS through SSI-based Inquiry

With regard to their pre and post survey responses, PSTs experienced a substantial growth in their understanding of the nature of scientific processes. The pre-post semester analysis of the Views of the Nature of Science- Version B (VNOS-B) indicated that PSTs increased their understanding of each of the Nature of Science (NOS) tenets (see Table 1) from either 'uninformed' to 'emerging' or 'informed' or from 'emerging' to 'informed.' The table below indicated the overall percentage of the class that displayed an increase in their conceptions

of NOS (i.e. Calculated $\# \text{uninformed} \rightarrow \text{emerging or informed} + \# \text{emerging} \rightarrow \text{informed} / \# \text{uninformed at pre} + \# \text{emerging at pre}$; $N=23$). No students regressed in their conceptions.

Table 1
Change in NOS Conceptions as Determined by the VNOS-B

NOS Tenet	Pre-Conceptions	Post-Conceptions	Percent Improvement
Empirical	Uninformed: 15	Uninformed: 4	71%
	Emerging: 6	Emerging: 8	
	Informed: 2	Informed: 11	
Tentative, yet reliable	Uninformed: 8	Uninformed: 2	68%
	Emerging: 11	Emerging: 8	
	Informed: 4	Informed: 13	
Observations & inferences	Uninformed: 16	Uninformed: 5	77%
	Emerging: 6	Emerging: 9	
	Informed: 1	Informed: 9	
Subjectivity	Uninformed: 12	Uninformed: 5	61%
	Emerging: 6	Emerging: 6	
	Informed: 5	Informed: 12	
Creative	Uninformed: 11	Uninformed: 2	80%
	Emerging: 9	Emerging: 10	
	Informed: 3	Informed: 11	
Myth of the 'Scientific Method'	Uninformed: 12	Uninformed: 5	62%
	Emerging: 9	Emerging: 8	
	Informed: 2	Informed: 10	
Theories & laws	Uninformed: 12	Uninformed: 9	30%
	Emerging: 8	Emerging: 8	
	Informed: 3	Informed: 6	

Calculated $\# \text{uninformed} \rightarrow \text{emerging or informed} + \# \text{emerging} \rightarrow \text{informed} / \# \text{uninformed at pre} + \# \text{emerging at pre}$; $N=23$

The tenets of science being creative and based upon observations and inferences showed the greatest change, though all aspects of NOS conceptions were improved to some degree. This finding was not surprising given the explicit and reflective approach to teaching the nature of science in both a de-contextualized (prior to the inquiry projects through activities such as the Mystery Box and Tricky Tracks; National Academy Science, 1998) and contextualized fashion (during and after the inquiry projects through meta-cognitive reflections) throughout the course. The tenet of theories and laws showed the least improvement, which also was not surprising given that this tenet was not underscored in our inquiry projects to the degree of the others and thus did not allow for as much detailed and on-going reflection.

Table 2 details a representative sample of some PSTs' pre and post conceptions of the questions from the VNOS-B. As seen below, the exemplar responses to the survey illustrate the PSTs' increased understanding of the essential tenets of NOS.

Table 2
Representative Quotes of PSTs' NOS Conceptions from the VNOS-B

NOS Tenet	Representative Quote: Pre-Conceptions	Representative Quote: Post-Conceptions
Empirical	Uninformed: <i>No one has ever been able to actually see and watch a specific atom in person before, so all current information is subject to change</i> (Bonnie, Pre-Survey)	Informed: <i>Through a series of tests, observations, data collection and inferring they are able to come up with a fairly certain conclusion as to the structure of an atom, but because in science nothing can be proved we cannot be positive of the structure of an atom</i> (Bonnie, Post-Survey)

Tentative, yet reliable	Uninformed: <i>Theories are not subject to change, but new theories are then made. Perhaps an example is the theory that the Earth is flat. Galileo's theory that the Earth was round may have been the theory to disprove the first, but it was not added onto the first theory. The first theory was not altered, but just thrown out as the law</i> (Allyson, Pre-Survey)	Informed: <i>With advanced technology scientists are given the opportunity to use new methods to find new information to create or revise a theory do change because new evidence can be discovered on the subject. Many theories have enough evidence to defend the theory, and any changes would likely be minor</i> (Allyson, Pre-Survey)
Observation & inferences	Uninformed: <i>Scientists are testing this idea using many different methods, the most credible (in a "seeing-is-believing" world) would be using a high powered microscope. Scientists seem to be very confident in their ideas about the atom</i> (Bryce, Pre-Survey)	Emerging: <i>Since the atom is such a tiny particle, I am sure that scientists still have some question as to the structure of the atom, however I do believe that with new technology and research scientists are confident about their conclusion of the atom structure</i> (Bryce, Post-Survey)
Subjectivity	Uninformed: <i>One [scientist] may consider the actual size of the earth around while another may think environmental factors are what affect it. If the scientists did this study together, I think they may come up with more similar/accurate answers because they could consider more factors together</i> (Kourtney, Pre-Survey)	Informed: <i>Different conclusions are possible when looking at the same experiments and data because each individual notices different elements and their brains take them in different directions with the information they have been provided. So many factors play into one's thinking such as one's background, upbringing, and religious, political, and social views</i> (Kourtney, Post-Survey)
Creative	Uninformed: <i>Creativity is the single reason why most science is considered tentative and why different theories are formed</i> (Tim, Pre-Survey)	Informed: <i>I actually think that art and science are both very similar. They both allow room for creativity and self-expression. And I think that they both can serve a purpose. Unlike above, I think that art can serve a purpose in stirring people up and making points, whether they be political or cultural, art can make a difference</i>

		<i>just like science can (Tim, Post-Survey)</i>
Myth of the ‘Scientific Method’	Uninformed: <i>They have to use their imagination on how to conduct a certain experiment if they are trying to prove something. If a scientists wants to prove global warming they will have to be creative on ways that this is possibly true (Brian, Pre-Survey)</i>	Informed: <i>These steps are not always consistent; Normally this would surprise me considering the fact that I have gone through countless years of science with specific steps. However, during the past couple of months of this semester I have grown to realize that science is considerably more complex (Brian, Post-Survey)</i>
Theories & laws	Uninformed: <i>In a law, there has been tons of research and there is no question about whether or not it is true. Theories on the other hand, should be taken a bit more lightly. They haven’t been proven in the way a law has. There is still question about the subject, like global warming for instance, yet all the facts point toward that idea being the most valid answer on the subject (Sam, Pre-Survey)</i>	Emerging: <i>I think a scientific theory is an explanation based on related observations or events that are done by many and they all obtain the same results, and therefore they theory is deemed true. I think a scientific law is a statement of fact that people accept to be true and it is used to describe a certain thing or action, rather than explain something. This is more of a mathematical equation and describes a reaction (Sam, Post-Survey)</i>

As seen, several PSTs referenced their change in NOS understanding in the VNOS-B by linking it to their course experience. As Brian noted, “*These steps [to the scientific method] are not always consistent... during the past couple of months of this semester I have grown to realize that science is considerably more complex.*” Also, Hadley refers to knowledge she gained over the semester regarding science as a way of knowing in her post VNOS-B, “*I have also learned that science is a way of knowing, but not the only answer. The truth is; there could be many other factors that play a role in this trend. In other words, science cannot prove anything and shouldn’t be seen as the only way of knowing.*” These data point to the course curriculum’s impact on changing students’ NOS conceptions, underscoring the importance of the contextualized manner in which the NOS tenets were elucidated.

Upon deeper analysis of the curricular events that contributed to these improvements in NOS conceptions over the course of the semester, layered analysis of the PSTs’ reflections and classroom discussions indicated that PSTs were linking their conceptions of NOS to their experience within the SSI-based inquiry. The group discussions and weighing in on issues gave them a chance to explore multiple perspectives, a fundamental aspect of SSI-based instruction. As a student in the nutrition group noted, “*As a group, we all shared preconceived notions of*

healthy eating. We assumed ideas like food labeled low-fat or zero calories meant healthy. As time went on, some of our original notions were explained more thoroughly, so that we understood how to determine healthy food, rather than always choose what we used to conceive as healthy.” The various ideas the group members had on what constitutes a food as ‘healthy’ was a discussion that helped them to understand the role that subjectivity plays in science. Another member from the same group reflected on the multiple perspectives that were instrumental in their inquiry:

We also have all been raised differently and have shown multiple perspectives throughout the time we have been working on this project. An example of multiple perspectives is that some of our families eat more organic and local than the others. Being more or less aware of organic and local produce made a difference in how some ideas were formed or discussed. Not only has our group member’s ideas been expressed in this project, but the perspectives and ideas from our sources has also had a large impact on our process of inquiry.

Along with multiple perspectives in SSI supporting understanding of the subjective nature of science, another aspect of SSI that impacted NOS understanding was formulating an position based on empirical evidence. While conducting their inquiries, PSTs collected empirical evidence to build an argument. Because they were grappling with what their data meant, how it should be interpreted, and what conclusions to draw from their data, PSTs came to appreciate the aspect of the nature of science that indicates science is only one way of knowing and though it informs our understanding of the world, it is not the only way in which to view the world. As a student from the greening athletics group stated,

We have evidence that supports our question, but from what we have learned previously about the nature of science, there usually is not one correct answer. This is why we use reliable sources to help affirm our claim. We cannot necessarily claim that we know the “true” answer to our question, if there even is one “true” answer, but based on our reliable sources we consider our findings to be of valuable knowledge.

SSI-based inquiry was important in that there was no necessarily one final answer to each students’ inquiry project. Because the focus instead was on collecting and analyzing data to form a position, students were able to deeply internalize the notion that there were multiple perspectives and assumptions about data that may lead others’ to different conclusions.

The class members were asked to reflect on their basic views of science through journal prompts each week, as well as collectively through in-class discussions (see Table 3 for representative quotes for each of the NOS tenets). Overall, PSTs’ views became more specific and descriptive of NOS tenets over the course of the semester; for example, their post-views indicated that they deeply extended their perceptions of science to incorporate the NOS tenets of subjectivity and being culturally-embedded. As well, their descriptions of science became richer as they offer more detailed conceptions of the creativity in science (ie. ‘*not just about data collection, it’s about being creative and working with others*’) and the evolving nature of

knowledge (ie. ‘interesting, surprising, and constantly changing’).

Table 3
NOS Tenets Embedded in Inquiry Projects

Tenet of NOS	Example from Socioscientific Inquiry Project
Subjectivity	<i>“As a group, we all shared preconceived notions of healthy eating. We assumed ideas like food labeled low-fat or zero calories meant healthy. As time went on, some of our original notions were explained more thoroughly, so that we understood how to determine healthy food, rather than always choose what we used to conceive as healthy.”</i>
Creativity	<i>“The group was responsible for designing testable questions, choosing the materials that would be used, making controls and setting up the experiment itself. To exemplify a use of our group’s creativity, we adjusted our controls such that the temperature, time and locations were similar for each day of observation so differences in this controls would not cause dramatic changes in our collection of data.”</i>
Empirical	<i>“We can connect empirical evidence because we found solid data that shows in the past the chemicals in e-waste individually have been linked to detrimental effects on the human body, such as cancer. We also found studies that showed there are chemicals from e-waste that are being leaked into the environment at a rate that should not be acceptable and we found evidence that supports that there is a need for proper recycling methods to be done because of the increase of e-waste that is being procured.”</i>
Tentative	<i>“Scientists spent and are still spending time finding new ways to reuse this [food] waste. The tentative nature of science is shown through their continuously progressing research on new alternatives.”</i>
Observations & Inferences	<i>“In order to get our empirical evidence for the project, we had to observe specific locations. While observing we would watch an area of racks at a time and collect the data. Visually observing the area either by watching and taking notes or photographically capturing a scene helped us make inferences about where we believed would be the most areas susceptible to an overflow of bikes due to a low number of bike racks.”</i>
Cultural Influence	<i>“We also have all been raised differently and have shown multiple perspectives throughout the time we have been working on this project. An example of multiple perspectives is that some of our families eat more organic and local than the others. Being more or less aware of organic and local produce made a difference in how some ideas were formed or discussed. Not only has our group member’s ideas been expressed in this project, but the perspectives and ideas from our sources has also had a large impact on our process of inquiry.”</i>
Scientific Methods	<i>“We have evidence that supports our question, but from what we have learned previously about the nature of science, there usually is not one correct answer. This is why we use reliable sources to help affirm our claim. We cannot necessarily claim that we know the “true” answer to our question, if there even is one “true” answer, but based on our reliable sources we consider our findings to be of valuable knowledge.”</i>

With regard to the subjective nature and cultural-embeddedness of science, they referenced how their own assumptions about the environmental issues on campus were based on information they had picked up from the media or their family, rather than actual data; however, they noted how even given the data, their background played a major role in how they viewed those data. One group talked about how their varying assumptions about what it meant to eat healthy enabled them think about where these ideas originated and whether their ideas were supported by data: *“As a group, we all shared preconceived notions of healthy eating. We assumed ideas like food labeled low-fat or zero calories meant healthy. As time went on, some of our original notions were explained more thoroughly, so that we understood how to determine healthy food, rather than always choose what we used to conceive as healthy.”* These assumptions allowed for fruitful debate among the group, which illuminated multiple

perspectives of the data they were collecting. Group members were surprised by others' views of healthy eating and had interesting discussions about their relative awareness of nutrition and how their perspectives played a role in their inquiry research:

We have all been raised differently and have shown multiple perspectives throughout the time we have been working on this project...some of our families eat more organic and local than the others. Being more or less aware of organic and local produce made a difference in how some ideas were formed or discussed. Not only has our group member's ideas been expressed in this project, but the perspectives and ideas from our sources has also had a large impact on our process of inquiry.

Furthermore, when asked to reflect in her journal on the NOS tenets embedded in her inquiry projects, Hadley chose to illustrate her understanding of NOS by linking them to her research on nutrition awareness and food choice on campus. Her group researched healthy options on campus and developed a rubric to gauge the health of a variety of popular foods offered at the dining areas on campus. They posted nutrition labels on the food and collected sales reports pre and post labeling to answer their research questions, which centered on the effects of nutritional awareness on choice. The following is her account of NOS aspects of her research:

Over the course of this project I have realized that there really isn't a scientific method set in stone. Every experiment needs to be approached a different way, and there isn't necessarily a "best" way of performing the experiments either. Because I am interested in nutrition, it was difficult for me to remain completely objective throughout this inquiry project.

Hadley's contextualizing of the NOS tenets of there being no single method of doing science and the subjective influence on observations and empirical data within her inquiry project suggest that the actual process of decision-making about which data was important and how to interpret it, along with the continual revisions of her groups' inquiry plan, was the impetus for her to deeply understand these NOS aspects of science.

Also fore-grounding the NOS aspects of observations and inferences in her description of the food waste audits her group conducted at the University football arena in an effort to provide suggestions to the Office of Sustainability's effort to 'green' athletics by offering composting alternatives, Amelia noted:

We will be weighing the food that is collected in temporary composting bins. This data (empirical evidence) will hopefully help us show how much food is sent to landfills each meal and each day. This food could instead be composted and used for things like fertilizer. Our whole experiment is almost all based on observation and inference. We will be observing how much and what kinds of food are being thrown away at the dining hall. From this, we can infer whether or not a composting plan would be beneficial to the University Athletic Department.

Here, the design of the inquiry investigation itself allowed Amelia to untangle the concepts of observation and inference. Thus, the design of the inquiry projects as being based on socio-scientific issues that they could explore in their community allowed PSTs to interact with

and deeply explore the NOS tenets within context. The topical areas of research connected science to society, and because they were rooted in contemporary areas of research the topics left room for creative exploration, rather than there being one set way of researching their questions. PSTs were required to design their studies and were thus able to be involved in the processes of science and knowledge-generation. This allowed for an implementation of the NOS tenets they were learning about in class to be applied directly to their research.

Along with explicit and reflective teaching, students were able to draw those links between the tenets to their inquiries. In her description of her project on campus energy use in which her group conducted a large survey of awareness of professors and students, Macy describes the authenticity of this connection: *“Although I was not always thinking about the tenets, our group kind of naturally carried them out as we collected our data for the surveys and talked to individuals with varying opinions”* (Student Journal, 11.21.10). Thus, the tenets of NOS were underscored authentically and contextually in this classroom project. This context for teaching science led to the contextualized embedding of NOS and opportunities for explicit reflection, which allowed PSTs to integrate their understandings of NOS with their explorations of SSI.

Persistent Misconceptions

However, not all tenets of the nature of science were well understood by PSTs nor integrated authentically in the course curriculum. For example, the tenet that addresses the misconception that laws and theories describe a hierarchical relationship between the two whereby theories become laws if and when enough evidence has been accumulated in their favor was not underscored in their projects. As seen in the course activities, although the instructor did explicitly teach this tenet and students were asked to reflect on it repeatedly in their journal assignments, the inquiry projects did not touch on this tenet and thus did not allow for a contextualized understanding of it. As Sam reflected on her project on campus energy use, *“Therefore we cannot state any law or theory about behavioral change and energy, nor are we following any laws or theories”* (Student Journal, 11.21.10). During our classroom discussion at the start of the semester, the course instructor expressed concern about the ways in which PSTs were using the word ‘theory’ during a card sort activity in which students are grouped according to their views on science (Cobern & Loving, 2002):

We then discussed what a theory is and how they are based off a great deal of empirical evidence, though still subject to change in light of further evidence. [Observer Comment: Theories are difficult for students to grasp as we do not often think about them in our lived experience. As well, it is difficult for me as a teacher to find a way to incorporate theories into our discussion of everyday environmental topics] (Researcher comment on field notes, 9.1.10)

While the inquiry projects did not do an adequate job of underscoring the theory and law tenet of NOS, some other tenets were supported well and despite most PSTs coming to understand them, some students persisted in their misconceptions. For example, the existence or lack thereof of a final answer to research caused many students frustration and uncertainty. Early in the semester, students expressed their frustration with the lack of a conclusive answer in the activities we conducted to explicitly and reflectively teach the nature of science. At the end of class one day, we discussed the nature of science through the use of a mystery tube in which the

students attempted to reconstruct the inner workings of a network of strings inside a tube- a lesson designed to emphasize that scientists may never get to one right answer, but collect evidence to support or refute their continually developing hypotheses. One student said, "*Is it always going to be like this- where there isn't a right answer, cause I thought this class was going to give us a conclusion*" (Joleese, Field Notes, 9.1.10). Another student echoed her sentiment when he exclaimed, "*This is really starting to piss me off*" (John, Field Notes, 9.1.10). As PSTs reported in their journals, their having experienced science mostly as confirmatory experiments in high school science classes may have caused them to be immediately frustrated with learning about the lack of one correct and final answer in science. Even later in the semester, they returned to ask me to tell them what was in the mystery tube from the very beginning of the semester. The recognition that science does not always lead to a final conclusion was to aid PSTs in seeing science as a process, rather than an attempt at reaching a final end point.

Even towards the end of the semester, PSTs continued to grapple with their long-held misconception of this aspect of science in their inquiry projects: "*There is a website called Google where I can find this answer, right?*" (Clara, Field Notes, 11.1.10). Michelle even explicitly noted in her discussion with her group about her inquiry project results: "*If there is a right answer, then science can find it*" (Field Notes, 11.1.10). During this exchange with her group, I challenged her, "*But what if there is a right answer to why we are here or the meaning of life, does that mean that science can discover it?*" Michelle did not seem to understand that it was the issue of being based on testable data that made it available to be investigated by scientific means, not the idea that there is one final answer. Even at the end of the project, PSTs still have difficulties interpreting data when there is not a clear final answer.

Moreover, some PSTs continued to misunderstand the empirical nature of data they collected. For example, the e-waste group obtained zero donations of waste from two of the three collection sites they had set up on campus and claimed the only reason they got some donations at one site was because it was one of the groups members' fraternity and he had verbally encouraged his friends to contribute. And the nutrition group realized that they could not compare sales pre and post nutrition labels on the fried vs. rotisserie chicken because the sales reports did not break down the numbers that way. They instead had to report only the different cuts of the meat pieces. These groups asked the instructor if they should just cut out these sections and data for the final report. The instructor explained how those data are meaningful and guided them in formulating inferences from these data.

Discussion

The PSTs' improvement in understanding and applying NOS tenets supported previous research that explicit, reflective, and contextualized instruction can be effective to teaching NOS conceptions. Research on the explicit teaching of NOS has indicated that it effected the most significant conceptual change in learners when participants are provided opportunities to reflect on NOS aspects and think about them in terms of their own epistemologies (Akerson, Abd-El-Khalick, & Lederman, 2000):

Learners should be provided structured opportunities to examine the meanings

they ascribe to key NOS terms in various contexts, and assess the consistency of their ideas across these contexts with the hope of helping them reconcile these meanings into a coherent framework of ideas about NOS (Abd-El-Khalick & Akerson, 2004, p.790)

In this course, PSTs were required to continually reflect on the explicit instruction they received on NOS tenets through their weekly journal assignments, which helped them reflect meta-cognitively on the connections between SSI and NOS. As well, exploring their views of science using Cobern & Loving's card sort activity helped PSTs understand that they indeed had a view on science and reflect on how it changed throughout the course. Akerson, Morrison, & McDuffie (2006) recommend meta-cognitive teaching strategies coupled with explicit reflective NOS instruction to develop students' conceptions. The many opportunities for meta-reflection allowed PSTs to develop more sophisticated conceptions of the nature of science.

Additionally, contextualizing instruction within SSI also helped students meta-cognitively reflect on the application of NOS tenets. Clough (2006) argued that NOS instruction would be more effective if links were continually made between NOS learning experiences which he categorized along a de-contextualized to highly contextualized continuum. De-contextualizing NOS tenets in explicit instruction, such as the Mystery Tube exploration, allowed for a foundation of understanding for PSTs to then apply to contextualized instruction in which they grappled with integrating their understanding to NOS to the science content embedded their SSI-focused inquiries. However, there were some aspects of NOS for which several of the PSTs continued to hold uninformed conceptions, which was also consistent with research that claims students often increase in their understanding of certain, but not all, aspects of NOS (Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2002). For example, the lowest improvement (30% class improvement) was with regard to the NOS tenet on theories and laws. Some PSTs struggled with understanding this tenet even at the end of the semester, erroneously indicating in their reflections on the post-VNOS that laws were based on facts while theories were based on opinions. This finding was consistent with previous research suggesting that this tenet of NOS is highly resistant to change (Akerson, Morrison, & McDuffie, 2006). We posit this misunderstanding may have been related to the lack of contextualized connection between this tenet within the socio-scientific inquiries the PSTs were conducting. Thus, the curriculum did not contextualize this aspect of NOS within the content and therefore did not allow time for continual reflection throughout the semester as was the case with the other tenets.

Furthermore, despite contextualized instruction, some of the PSTs continued to grapple with data interpretation of empirical evidence, and although many showcased informed conceptions of this tenet (71% class improvement), several PSTs continued to illustrate their lack of understanding of what constitutes data and how it should be interpreted. This was seen when the e-waste group thought that their inquiry results were not meaningful and thus their experiment failed when they did not collect donations of e-waste at some of their collection sites. This finding is also consistent with prior research that suggests many students appreciate the empirical nature of science, yet do not fully understand what comprises data and how it can be used (Sadler, Chambers, & Zeidler, 2004; Khishfe & Lederman, 2006). It also highlighted the usefulness of recommendations that students should be explicitly guided in applying NOS

knowledge when evaluating scientific claims, which include scaffolding for students in applying NOS concepts to data analysis and interpretation within SSI argumentation (Walker & Zeidler, 2007; Matkins & Bell, 2007).

Moreover, our study hopes to add to the exploration of NOS-SSI by showcasing the aspects of SSI that support NOS understandings. The core aspects of SSI, such as there not being one final answer but rather multiple perspectives that can be argued using varying lines of evidence, helped the PSTs to realize that the nature of science is tentative and based upon empirical evidence. As well, the fact that solutions to socio-scientific issues are often under-determined by scientific data alone allowed PSTs to invoke their personal reflections in the data alongside uncovering the ethical, political, and/or economic implications. This holistic view of their inquiry topics allowed the PSTs to personalize the NOS tenets about cultural-embeddness and subjectivity. Thus, socio-scientific inquiry was an effective means by which to deeply explore and understand NOS conceptions and may even offer an ideal way to help learners connect with the nature of science in a way that underscores their broader view of science in society.

Thus, we came to value NOS as a foundation for including students in the process of science and underscoring their voice in the generation of knowledge in environmental socio-scientific issues. This study helped us to recognize the use of the tenets of NOS as a foundation for movement toward fuller participation in science, though this idea needs to be explored further. The valuing of different points of view, the use of creativity in conducting and designing their inquiries, the iterative approach to data collection, there not being one way to a final answer- all of these elements laid a foundation for that led students to understand science as a process not a destination and helped to empower them to understand that everyone, even non-scientists, can make a contribution to science. As suggested by Holbrook and Rannikmae (2007):

Although the nature of science is seen as an important component of science education, the over-riding target for science teaching in school, as an aspect of relevant education, is seen as responsible citizenry, based on enhancing scientific and technological literacy (p. 1352)

Thus, to be most effective, it is fundamental to incorporate NOS throughout the entirety of the course through contextualized modeling and scaffolded instruction. As such, NOS should be embedded throughout all levels of instruction on various pedagogical tools as an overarching theme, rather than as a separate topic to be covered in science instruction. We contend that these principles can be elicited from students as teachers guide them through NOS activities which are contextualized within course content (Abd-El-Khalick & Lederman, 2002; Khishfe & Abd-El-Khalick, 2002). Teachers can then explicitly highlight the connections of NOS to the content, especially with regard to data analysis and interpretation. Pre-service instruction, then, should include overt discussions about how each SSI inquiry within the curriculum illuminates NOS principles. This component of meta-cognitive reflection on epistemologies is fundamental to students' incorporation of NOS into their own ways of experiencing science.

Another insight from this study to add to the on-going discussions about the relationship of SSI and NOS included the importance of open forms of inquiry. PSTs were scaffolded

through a more guided approach to inquiry before their development of their own open inquiry projects in which they designed, implemented, and analyzed their own investigations; the experience of actually conducting an open inquiry was important in developing students' conceptions of NOS. Many referenced their open inquiry experience when describing their NOS views at the end of the course. The tenets of creativity, subjectivity, inferences, and lack of one scientific method were underscored and easily drawn upon to describe their experience. NOS understandings were in fact most connected to the open-ended inquiry aspects of the SSI. Specifically, the PSTs talked about how their 1) exposure to primary & secondary research challenged the assumptions they brought into the course that stemmed from their family and media-influenced exposure to socio-scientific issues, 2) collaboration with other group members who held multiple perspectives helped them understand the subjective influence of data interpretation, & 3) experimental designs that were flexed and negotiated as they explored their SSI underscored the lack of one single scientific method. The more open-ended aspects of their inquiries, then, were continually referenced when the PSTs were asked to reflect on NOS tenets.

Many SSI contexts, however, center around research for the development of an argument (Khishfe & Lederman, 2006; Bell & Lederman, 2003; Albe, 2008), rather than engaging students in the *process* of open inquiry. We believe it is here that the relationship between NOS and SSI is better evidenced. In this study, data suggested that open inquiry of SSI may be a fruitful way to encourage students to apply their understanding of NOS. Teachers should draw upon scaffolding students toward open inquiry experiences to explicitly steer students towards a comprehensive understanding of NOS principles as foundational for participating in the process of scientific inquiry. Thus, we contend that inquiry should be leveraged more in SSI to promote NOS conceptions and more focus should be on the process of exploring socio-scientific issues rather than argumentation alone.

It is important to note, however, that research in the field of NOS indicates that inquiry experiences may not necessarily lead to improved NOS conceptions (Schwartz et al., 2004); our findings indicate that the movement toward more open forms of socio-scientific inquiry actually enhanced understanding of NOS. What would seem like a contradiction may actually be explained by the nature of SSI itself. In essence, the socio-scientific aspects of the inquiry were themselves what led students to improving their understandings. Here, the connection the PSTs had to their campus community and the ownership they took over the data interpretation and analysis allowed them to feel as though they had unique perspectives to add to the discussions of the socio-scientific issue. Had the PSTs been conducting an open inquiry on an issue in science that did not explore multiple perspectives nor holistically investigate the political, economic, or social dimensions of the issues, the PSTs may not have showcased as many gains in their understandings of NOS. We believe that the personal resonance of the inquiry in PSTs lives enabled them to more fully embody the core aspects of NOS.

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Appendix A: Sample of Course Activities

Classroom Activities	Connections to NOS	Connections to SSI	Student Artifacts
Introduction to Nature of Science (Dogs & Turnips Activity) & The Mystery Tube Activity Prof. Xargle Children's Book Powerpoint of NOS	Aspects of NOS presented explicitly & reflectively Aspects of NOS presented implicitly Aspects of NOS presented explicitly & reflectively	<ul style="list-style-type: none"> • Presentation of ill-structured problems • Connection of science to society, relevancy 	<ul style="list-style-type: none"> • Student Journals • VNOS-B pre-survey
The Card Sort Activity Youtube clips of scientists' views Newborn Blood Draw Article	Exploration of NOS views Exploration of NOS views Socio-cultural dimensions of NOS	<ul style="list-style-type: none"> • Ethical, political, and/or economic implications of science • Multiple Perspectives 	<ul style="list-style-type: none"> • Student Journals • Card Sort Activity • Posters
Top Inquiry Activity Phylogenic Tree Activity	No single scientific method Tentative aspects of NOS	<ul style="list-style-type: none"> • Exploring Different types of Scientific Inquiry 	<ul style="list-style-type: none"> • Student Journals
Data Analysis of Controversial Issues	Using data as evidence for building an argument Subjective aspects of NOS explored reflectively	<ul style="list-style-type: none"> • Presentation of ill-structured problems • Data Analysis & Interpretation • Argumentation 	<ul style="list-style-type: none"> • Student Journals • Looking Deeper into Data • Data Analysis & Interpretation

Appendix B: Interview Protocols
PRE-SERVICE TEACHER INTERVIEW QUESTIONS

1. Do you feel included in the process of science? How?
2. A section of the survey asked about your connections to environmental issues. What reactions did you have here?
3. What kind of role do students play in the processes of science?
4. How would you describe the relationship you have with science?
5. Are students' ideas and opinions incorporated into science? If so, in what way?
6. What questions should have been asked by this research project, but weren't?
7. Tell me your understanding of the nature of science.
8. In what ways was the nature of science underscored in your collaboration with scientists?
In what ways was it not?
9. Imagine an ideal experience of being involved in science. What does it look like?
10. In what ways was the nature of science underscored in your collaboration with scientists in your inquiry?