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Jessica McClain, Claire Cesljarev, Qiu Zhong, Shukufe Rahman, Conghui Liu, Andrea Phillips, Tulana Ariyaratne, Valarie L. Akerson
Indiana University , United States

To cite this article:

McClain, J., Cesljarev, C., Zhong, Q., Rahman, S., Liu, C., Phillips, A., Ariyaratne, T., & Akerson, V. L. (2022). Developing nature of science ideas and orientations at the graduate level: Better late than never. *International Journal on Studies in Education (IJonSE), 4*(2), 155-170. https://doi.org/10.46328/ijonse.82

International Journal on Studies in Education

2022, Vol. 4, No. 2, 155-170 https://doi.org/10.46328/ijonse.82

Developing Nature of Science Ideas and Orientations at the Graduate Level: Better Late Than Never

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Article Info

Article History

Received:
31 November 2021
Accepted:
30 March 2022

Keywords

Graduate education
Nature of science
Professional development

Abstract

This paper describes the improved science conceptions and orientations for teaching about Nature of Science that resulted in a group of doctoral students who took a Nature of Science graduate course. This paper was a result of a panel discussion at the 2021 International Conference on Social and Education Sciences (IConSES) in Chicago, IL. The format took a reflective view on the past course, and how the doctoral students made changes in their ideas about NOS and their teaching practices. Reflections were made across themes that included Early ideas about NOS, our orientations to teaching about NOS, the world outside our window, and teaching NOS, and teaching NOS, past, present and future. Recommendations are made for beginning NOS instruction as early as kindergarten and embedding it in science content throughout all science education, making it a part of instruction similar to how scientific practices are similar to instruction.

Introduction

Teaching and learning the Nature of Science (NOS) in science education is the key to accessing content knowledge through engagement with authentic current and historical science practices. It is through this understanding of how scientists amass new knowledge and discoveries along with the sustained uptake of science educational content that we can move towards a more scientifically literate society (Ryder, 2001). Science teachers experience many constraints to planning and teaching NOS including beliefs that teaching NOS is not as important as instruction for other science content outcomes and a lack of knowledge and resources for teaching NOS (Abd-El-Khalick, et al., 1997; Akerson, Elcan Kaynak, & Avsar Erumit, 2019; Avsar Erumit, Fouad, & Akerson, 2019; Bilican, 2018; Elcan Kaynak, Akerson, & Cevik, 2020). While there is a wide range of NOS literature that focuses on preservice and in-service teachers, research about how graduate students develop the NOS knowledge is very rare.

Moreover, little research has been conducted to examine development of the conceptions of the Nature of Science of science education doctoral students and its impact on their teaching pre-service teachers. Therefore, it becomes a need for researchers in science education to examine what the science education doctoral students perceive as NOS and their role in supporting pre-service teachers' NOS conceptions as well as science

education reformation. Using an explicit and reflective approach, (Celik, 2020; Adıbelli-Sahin & Deniz, 2017; Khishfe, 2013; Akerson, et.al., 2007), we looked at how graduate science educators develop their NOS knowledge and what factors would affect their NOS knowledge development. More specifically, we wanted to take a closer look at how our beliefs, cultures, academic background and previous teaching experience reflected in our experience in developing NOS knowledge during a graduate seminar.

We used a collaborative self-study approach to explore how we developed our NOS conceptions during a semester-long course two years before this panel took place. The course is designed for science education doctoral students focused on NOS, its role in science education, and the associated research in NOS. The class met weekly for three hours, and all class members and the class instructor are included as both authors and participants in this reflective process.

The primary data source for this study included recorded discussions of weekly readings about NOS and how participants' views and understandings of NOS were changing as a result of engagement in an explicit and reflective NOS seminar. Initial findings from the study included growth in conceptualizing and applying instructional strategies for NOS teaching and learning. Several and varied strategies for NOS instruction were discussed and brainstormed during class discussions, the primary strategy discussed being the implementation of inquiry instruction in the science classroom.

Through the existing literature on NOS, we were able to progress from having a little to no understanding of NOS to feeling confident in being able to effectively implement it into our own instruction. The data also highlighted a lack of NOS assessment ideas and tools as well as very limited availability of curricular resources intended to support NOS instruction. The panel enabled us to reflect on any changes in our NOS ideas and teaching practices over the past two years.

Participants

The following section provides a description of each panel participant. The panel was composed of 7 doctoral students and 1 professor in the curriculum and instruction department part of the school of education at Indiana University in the United States. To emphasize the intersectionality of identities represented, each panelist description details career experiences, cultural and gender identifications, and highlights diverse global perspectives:

Jessica

Jessica is an African American female from the southeastern United States. Prior to her entering the doctoral program, she obtained an MS in biology and taught middle school science for four years. Now in her second year of the program, she has gained additional classroom experience teaching both an elementary science methods and field experience course.

Claire

Claire is a white female from the midwestern United States. Before entering the doctoral program, she was a middle school science teacher for seven years with experience in urban and suburban schools, in a mid-sized city and suburban town respectively. Claire also has experience teaching in informal science educational settings across the US. She is currently in her 4th year of the program and has gained experience in teaching elementary and middle school science education methods classes.

Andrea

Andrea is a white female from the western United States. She entered the doctoral program directly from an undergraduate degree in biological science education, so her experience in the classroom was limited to teaching undergraduate lab courses and student teaching for one semester in a high school biology class. Now in her second year of the doctoral program, she entered the NOS course with some additional experience teaching pre-service teachers in elementary science field experience courses.

Qiu

Qiu is a female doctoral student from China. Prior to starting her PhD, she obtained an undergraduate degree in applied chemistry and a master's degree in environmental science. She has taught in public and private high schools as a chemistry teacher for 5 years successively in Wuhan and Beijing, China. Now in her second year of the program, she has gained additional classroom experience teaching a scientific inquiry course.

Shukufe

Shukufe is a female from Bangladesh, a developing country in South Asia. Prior to starting her PhD, Shukufe gained five years of professional experience in Non-profit organizations in the education sector. She started her professional career as a material developer for a non-profit organization in Bangladesh and developed two science textbooks. She also worked in India promoting inquiry-based science, and in China teaching English.

Conghui

Conghui is a female from China. Prior to her doctoral program in science education, she obtained a master's degree in ecology in China and worked for 3 years in the field of informal education, including MOOC and a popular science magazine. She also taught middle school students in outdoor scientific activities for six months during her master's program. She is in the first year of the doctoral program.

Tulli

Tulli is a queer male PhD student from Sri Lanka. Before his PhD studies, he completed his MS in chemistry in

the Midwest, USA. He did his bachelor's degree in chemistry and physics in Sri Lanka. After his bachelors, he taught chemistry and physics to community college level students in Sri Lanka, and chemistry to freshman/sophomore undergraduate students in Illinois (Midwest), USA.

Valarie

Valarie is a white female professor of science education and has 20 years of experience teaching elementary science methods and doctoral courses. She has previously been an elementary teacher. She has a bachelor's degree in psychology, master's degree in elementary education, and a Ph.D. in science education.

Graduate Students Conceptions of the Nature of Science Panel Discussion

The International Conference on Social and Education Sciences panel provided a platform for us to revisit NOS teaching and learning with explicit and reflective discourse, and share insights into practices that influenced our understanding and teaching methods. In preparation for the conference, we reconvened to engage in conversation around our current understandings and applications of NOS concepts in our various university teaching positions. Questions and considerations around teaching and learning NOS were developed and with further individual reflection, we were able to have a meaningful panel discussion about our contemporary beliefs and understandings of teaching and learning NOS ideas as developing graduate students. The panel discussion is divided into the following sections:

- Early ideas about NOS,
- Our orientations to teaching about NOS,
- the world outside our window, and
- teaching NOS, and teaching NOS, past, present and future.

Valarie: Thank you so much for inviting us, and we are excited to be here. I'm Valarie Akerson, and I was an instructor of a course on the Nature of Science that included these doctoral students; and we are sharing some ideas and changes in practice that took place as a result of the course.

Claire: So, hello, I'm Claire, and I'm a graduate student who was part of the course. And before we started, we wanted to ask [to Valarie] why is the nature of science or NOS your research area? And why are you interested in teaching a graduate-level course about the nature of science practices?

Valarie: When I was an elementary teacher, way back when, there were very few teachers that actually liked teaching science or that even taught science, and I think it's because they didn't realize what science actually was. So, they thought it was information to memorize and text that their students would find boring. But, if they understood the kind of knowledge that science was, they might enjoy it. If they understood the nature of science, I felt like they would have a better understanding of science and a better attitude toward it and be more willing to teach it to their students.

I ended up focusing on the nature of science because I do prepare elementary teachers to teach science. The reason I wanted to teach a graduate class on the nature of science is that I knew for myself that when I came to my doctoral program, I didn't know what the nature of science was, and that is where I learned it, and wished I had discovered it sooner. So, I thought maybe that might be the case for other people. So now I have a few questions for the panel.

Early Ideas on the Nature of Science

Valarie: Did you experience shifts and ideas around teaching and learning about the nature of science? And if so, how did you experience these changes, and how did they affect your opinions of science education? Claire, would you answer that one for us first?

Claire: Sure. So, in my position, I used to be a middle school science teacher, and I was lucky enough to find the nature of science teaching ideas in my curricular searches and research. I often applied the nature of science in my classroom and found that teaching about it taught the nature of science helped my students learn about science practices. Furthermore, I noticed that my students were more readily able to build schema and understandings around scientific concepts and phenomena after they understood how science went about finding out about the scientific phenomena and these concepts, what context science resides to do that.

So, I enjoyed the nature of science. I'm happy to have taught it in my middle school classroom and then come to graduate school and reinforce the power that the nature of science has in the science classroom for positive conceptual change and understanding.

Valarie: Great. And Jessica, how about you?

Jessica: Sure. So, my background is similar to Claire's. I was also a middle and high school science teacher before starting my Ph.D. program. Before that, I have a degree in science. So, Masters and bachelor's in biology. So, the nature of science was something completely new that I did not learn until I took Dr. Akerson's class. For me, it made sense how we learned about the nature of science and how it should be taught. What I taught my students was the scientific method down to a tee. But now, after learning the nature of science, and of course, I feel like I failed my students a little bit, but I didn't know what I know now. So, I'm glad I took the class to be a little bit more conscious about how we should really teach and impact students as far as understanding science in a better way.

Valarie: Hey Tulli, how have your perspectives of teaching experiences changed after being exposed to the nature of science?

Tulli: Hi, I'm Tulli. Well, actually, I was born and raised in Sri Lanka, so I did my bachelor's in chemistry and also a Master's in chemistry in the United States before I started learning the nature of science. Professor Akerson, I was looking at things from science. After I enrolled in my Ph.D. program, I started learning NOS.

So, after learning NOS, I was able to see the world and see things from non-science and social science. Thank you.

Valarie: Shukufe, can you answer the same question?

Shukufe: Sure. Before I start answering my question, I'm Shukufe Rahman, a graduate student at Indiana University, and I'm also from Bangladesh. Before starting my Ph.D. program, I worked as a curriculum developer in Bangladesh, India, and China. I have done my bachelor's and master's in applied physics. So, before my Ph.D. program and the course with Dr. Akerson, I hadn't been introduced to the nature of science, though I have spent a lot of time in my science career.

So, what I interpret from this course is that now I understand how science works, how scientists work, and how the scientific community functions.

And I want to instill that understanding and attitude towards science in my students. So, I want to implement that nature of science into my teaching experiences to see science from various perspectives and multiple understandings. I also want my students to know that science is not only a body of knowledge, but a part of your own experiences and social and natural life.

Valarie: Great. And as you can see, we are fortunate to have students from a few different countries, so we're going to see if they can tell us a bit of how the nature of science is positioned in their country. Tulli, do you want to start?

Tulli: Sure. Well, actually, in Sri Lanka, when I was doing my bachelor's in chemistry, I didn't know what the nature of science was. I was taking a few classes in science education. I was teaching, but not the nature of science from its name itself. But I learned bits and pieces of the nature of science, but not as the nature of science.

Valarie: Qiu, would you like to share your ideas?

Qiu: Sure. Hi. My name is Qiu. I'm from China. In China in the past, we didn't have the nature of science in the curriculum, but in 2017, we issued the new Standard for elementary science that includes some new concepts such as engineering, STEM. Part of the new curriculum reform also included the nature of science, so we are starting to do it. But there is a long way to go.

Valarie: Conghui, do you want to add to that?

Conghui: Yeah, I'm also from China. So that's what we are doing for the policies. In my personal experience, I hadn't heard about the nature of science before I came here. Still, after I learned the nature of science, I talked to some of my friends working in China, and they are working on implementing the nature of science into science

classrooms.

Shukufe: So again, I'm from Bangladesh. And though science has its priority in our country as a low economic country and South-East Asian country, we haven't thought or learned the nature of science while doing our science. I don't think it is still there. And as an educational researcher, I also believe that if I want to implement that in my country's curriculum or science material or science textbooks, I need some viable reason to address this nature of science to the policymakers and curriculum developers, and the teachers in our context.

Our Orientations on Teaching Nature of Science

Valarie: So, how has your experience teaching the nature of science changed since taking the class? Andrea?

Andrea: My name is Andrea. I'm from the Western United States, but I've had the chance to teach elementary science methods again since taking the course. So, I was teaching it when we were taking the course, and now I'm teaching it again. Now I've spent a lot more time introducing and framing all the activities in terms of NOS and encouraging my students to find opportunities to implement the nature of science instruction into their lessons. I'm not an expert at it yet. I will say that I feel like I miss many opportunities, and in retrospect, I'll see lots more opportunities to connect with NOS. But I'm feeling better about my teaching, knowing that I'm trying to implement this and aiming for better literacy for my pre-service teachers and their future students as well.

Valarie: Shukufe, how about you?

Shukufe: So, as I have said before, that nature of science was new to me and a new addition to my learning and my teaching experiences. Also, after learning that, I was trying my best to implement in every teaching material that I'm using or activities that I'm trying to do with my students. I want my students to reflect on what they have learned from that nature of science tenets and find opportunities to use the nature of science in their learning.

Valarie: Great. So, I know that all of you teach at the university as well through your graduate assistantships. Do you find any constraints as a graduate assistant in teaching the nature of science? Jessica, how about you share?

Jessica: Absolutely. So, while we were taking a class, I was teaching the science methods course, which was perfect because I felt like it was an excellent time to implement what I was learning in Dr. Akerson's class. My big issue was taking the theory into practice. So, I felt some difficulty when I took what I was learning into the actual classrooms for my students.

So, for me, I see value in the nature of science and the need for my students to understand it. But how can we take it from this concept into something useful for students pre-service and both in-service teachers to use? I know that different universities and school systems will have other curricula that students will use in their

classrooms. So, my issue was making sure that it's something that pre-service teachers can take and implement on top of the other ideas and things they have to do. So that was my significant constraint.

Valarie: Andrea. Same question.

Andrea: Yeah. So, I'll say that especially starting graduate work, who you're supervised by plays a big role in what you teach. So, at the time, I was taking this course; it was my first time teaching a methods class. So, I was given a lot of instruction and guidance on how to structure that class, what to teach, and what to focus on. And the person I was supervised by didn't necessarily forefront NOS. And so, I didn't end up teaching NOS as something that my pre-service teachers should implement in their instruction.

But now that I'm in my later years of grad work teaching methods, I have a little more freedom, I guess, a lot more freedom. But those constraints were there the first time. And this time, I'm feeling a lot less constrained because I can choose what I want to focus on. So, I wanted to teach it. Taking the NOS course at the time, I wished that I was implementing more of NOS into my instruction. So, I'm glad that now that I have a little more freedom, I can do that and try to forefront NOS a little more.

The World outside Our Window and Nature of Science

Valarie: Great. That's good to hear from my perspective. Does learning about the nature of science change your perspective of how you interact with science in your own personal and student life? How about you, Qiu?

Qiu: Sure. So personally, after learning the nature of science, I became more critical about what I hear from the TV, the news, and the newspaper. So, whenever I read the news, I want to know what kind of method you are using to know those kinds of things and how to provide evidence best? Also, I began to look at things from other perspectives, not just science, but also social perspectives because scientific knowledge is also socially embedded. I also had several interesting conversations with my friends because some said they believed in science, and then I challenged them. Do you know what science is? And then, they all paused and said, "I don't know." It's pretty interesting because most of them come from a substantial science background and they feel challenged about- oh, I don't know what science is, but I claim myself as a scientist. So that's pretty interesting. When I teach my students, I also encourage them to challenge my ideas. So, I think that's pretty interesting for my personal life and teaching.

Valarie: Great. How about you, Jessica?

Jessica: Yes. So, in a world full of miscommunication and misinformation, I feel that now more than ever, NOS has entered my life in an extraordinary way, similar to Qiu having conversations with friends, and the response has not been so forthcoming. However, I'm still here working on them. I have seen a need for it as far as my personal life. In my research focus on equity in STEM, I had an opportunity to create a curriculum for a summer bridge program this summer. A part of the curriculum, I made sure to have NOS embedded in their lessons to

make sure that they work closely with NOS early in their learning. So, for me, I see fit. But it's also essential that we have that when we think about equity and that social embeddedness and make sure that everyone is exposed at the same time and have the opportunity to understand the concepts they might have been exposed to before.

Valarie: Sounds good. So, do you find that the social and cultural embeddedness of NOS helped you bridge cultural and geographical gaps between how we understand and interact with science? Tulli?

Tulli: That's my favorite tenet in the nature of science. I would say that even a few of us have learned in Asian countries. I'm from South Asia. We have all learned Western science, not an insult, but that's a stream of science that we have all learned. But we know that some different types of sciences are there, like Indigenous medicines, in other countries, such as Sri Lanka and China, and Native American people have their own Sciences. We cannot ignore these things, but I think we can understand how they are thinking and how they were constructed by using the nature of science, I would guess.

Valarie: Great. How about you, Shukufe?

Shukufe: Yeah, that's also my favorite one. We understand and value this cultural thing because we are from different cultures but pursue the nature of science concepts in the Western style. So that is why we can understand the difference between how we pursue science in our context and how they pursue this Western context. One of the crucial things now in this century is globalization and mobilization. Our students need to be informed by different world perspectives. We need to instill that they have to see ways of knowing or interacting with the nature of science in different contexts and ways. So, it is the social and cultural embeddedness of the nature of science that will help us create that lens to see the world from multiple perspectives. Also, it allows us to reduce the gaps to see and interact with the size from different geographical or dimensions. So, it is important to instill that while we are teaching or learning the nature of science. Also, I believe we should explicitly mention this tenet in every activity.

Teaching and Learning Nature of Science: Past, Present, and Future

Valarie: Great. Awesome. So, did you find that there were better materials and activities that aided you in teaching the nature of science? Conghui?

Conghui: Yeah. We have a lot of materials for the course. We have read the book *What is this thing called science,* and the books Valarie brought to us that her undergraduate students created are wonderful. We also have activities and lesson plans. My favorite is the peer teaching, and activities allowed me to see how others teach the nature of science because I hadn't taught the nature of science before I came here. I didn't have enough teaching experience in formal school settings. So, I didn't know how to teach that. So even though we had learned and agreed that the nature of science should be taught explicitly, what does that mean? So, the opportunities for us to witness how other people teach the nature of science help. I love that.

Valarie: That's great. Awesome. Jessica.

Jessica: I feel like the lesson plans were phenomenal and a great resource. I loved working with my colleagues because we all have different perspectives when processing NOS during class. So, each lesson plan was unique and brought different perspectives that I didn't think of when we thought about it. So, I felt that we were our best-kept secret in understanding NOS.

Valarie: I learned a lot too. When you're thinking about different perspectives. How about you, Shukufe?

Shukufe: Okay. So, I believe also because of Dr. Akerson and her work on the nature of science, you will find plenty of scholarly articles in Google scholar everywhere and helps me to understand the nature of science. Now I see myself and have a better understanding of the nature of science. But, honestly, to say that there are not enough materials out there when it comes to teaching or helping out the teacher or supporting the teachers to teaching the nature of science. And my big fear is that whatever the material is available, that's in English. So, when I'm thinking about other countries, maybe in China or for my country, that will be not enough material that is translated or that would be enough material that teachers can use [to teach NOS to their students]. So, we, as researchers, maybe have a lot of opportunities to do with that material and the textbooks, everything regarding the nature of science.

Valarie: I agree with you. So, when you're learning about the nature of science as a graduate student, do you think you could have been better prepared in your undergraduate studies? How about you, Andrea?

Andrea: Well, I would say definitely. Yes, it's what we could all say because none of us, except for Claire, had heard of NOS before starting this course. So that's a starter. And I think we talked a lot and learned a lot in this course about teaching NOS explicitly and reflectively and making sure that NOS is explicit in those types and also explicit. My undergraduate was in biology education, and so much of my coursework was in biology. But I think the biggest thing was I wasn't taught about science as a way of knowing how science works and what science is. But it said it was left implicitly. I was sent an alumni survey from my undergraduate university, and the department asked me. A portion of the survey asked me if I felt confident in my understanding of the nature of science, and I was stunned to see that question because I knew for a fact, they hadn't taught me the nature of science. After all, I've never heard of it before starting my graduate work. So, I think that goes back to the importance of making sure that it's explicit. If you intend to teach it and with the learning outcome, you need to make sure that you're talking about it explicitly.

Valarie: How about you, Conghui?

Conghui: Yes, of course. I will give my own experience as an example. When I was in my master's program, I did scientific research. But I was confused when I got some results. I don't know if I did it right. Is my result the fact, and is there any other thing that could make my theory perfect? There are always flaws. I can see the flaws. So, I was not confident with the result. But after I learned the nature of science, I think now I can better

understand that this is what science is. It is science. It's not because of me. So, if I'm going to do the same research now, I think I will be much more comfortable with the result and how we interpret the data. Same to my undergraduate studies, although I didn't question myself about those things. When I think back to the things I learned in undergraduate studies, all the concepts, theories, laws, I just take them and memorize the terms. But do I really know what the terms mean? I didn't. So, I think if I learned the nature of science by that time, I might be better prepared for a deeper understanding of all of those concepts, theories, and laws, and I feel it helped.

Valarie: Great. So, let's think about future plans for incorporating the nature of science in teaching and research. Let's have a couple of people share ideas about that. How about you, Qiu?

Qiu: Yeah, sure. So, taking Valarie's classes inspired me. I found myself becoming interested in learning the nature of science. I further took several courses in the philosophy department of Indiana University, including several science philosophy courses. I found there is a lot to explore about the nature of science, especially in education settings. For example, I would like to explore more about the nature of science in specific discipline learning in the future. For example, when you are learning chemistry, physics, or environmental science, you can embed the learning nature of science in your single discipline learning and different single discipline learning. They focus on various aspects of the nature of science. For example, there's a lot of evidence-based observation in physics, while for environmental science, especially for toxicology, there's a lot of uncertainty in this area. I find that it's pretty interesting, and we need to do a lot of research in this area and my future research. I'm pretty interested in the philosophy of modeling and especially climate modeling. My questions consist of how we know of the past and future, what kind of evidence we have, and how robust is the evidence to make informed decisions for the climate.

Valarie: How about you, Claire? Because you've taught it before. Do you have future plans for what you would do now?

Claire: So, I'm currently teaching secondary science pre-service teachers in a methods course. So, as part of the course, they develop lessons and teach them to the class. As a result, we have mock experiences of creating lessons and teaching them. I have different considerations for one of our lessons that they need to do for their other classes. And from one of them, I did have them focus on the nature of science. It was exciting and very successful because they were able to take different parts and different tenets of the nature of science. Some of them are interested in the tentativeness of it. Some of them were interested in subjectivity, and we talked a lot about theory and law and what that is. And so, it was interesting that in teaching these nature of science lessons for us, we were able to talk about what science is and why it is so important to teach the nature of science. And since I focus on being explicit and reflective with them and in their reflections, I can notice that they're at least starting to incorporate the nature of science into their pedagogies. They're seeing the power that it has to understand how science works, how theory works, which is so important for secondary science teachers to understand how scientists develop scientific theories so that we can talk about them and break misconceptions for their future students about science and what it can tell us and what it cannot. That was exciting, and I was encouraged by that.

So, my research interests are exploring the intersection of ecological and social justice specifically, on how it is discussed and positioned in the science classroom. I'm also very interested in the power that the nature of science has. This construct has to help facilitate shifts in teacher beliefs about how science should be constructed in the classroom, moving towards a more equitable science classroom for science learners. I'm also interested in how explicit teaching and learning the nature of science can promote conceptual change for students and how this can assist in helping them create a deeper understanding of the interconnectedness science has with society, with the environment, really, with all thing's planet Earth. I think the nature of science has the potential to be a mighty vehicle for helping our students. Our science students in science education see these big connections that we need to recognize to move to a more equitable and just science classroom. So yeah, I'm really excited about it.

Valarie: Sounds excellent. How about you, Andrea?

Andrea: Yeah. I hope to incorporate it into all my future teaching, whether that be in teacher education or science content courses of any age. I believe that it's important and underlies and informs the practice of science and how science functions in our society. So, I think it's imperative to bring that into education for everyone for those reasons. As for research, I'm interested in opportunities to explore NOS further, teaching it effectively, and how NOS understanding influences other aspects of science learning.

I'm also interested in NOS related to identity development and science, and specifically how intersectionality sort of influences NOS learning and NOS understanding. I was interested in looking at how people perceive NOS as a way of knowing and as an epistemology compared to something like religion. So how does religious identity influence the development of science identity? For example, and things like that, so I'm interested in helping people embrace and look at the development of science identities coming from various backgrounds, something I'm definitely interested in looking into.

Valarie: Sounds interesting. All right. So finally, we all have been teaching during the emergency remote learning during COVID-19, and we still are experiencing it to some degree. Does it change the way you approach teaching the nature of science?

Qiu: I taught the nature of science during the pandemic for two semesters. One of the most important things is we need to consider students' emotions because people conduct science and people have emotions, and so do we when learning science. If students are experiencing difficulty in their families, such as during covid, it's challenging for them to focus on what they learn in a class. So as an instructor, we should acknowledge their experiences at difficult times and do whatever we can to support them, be successful, or let them know that it's okay not to feel okay and it's okay to feel difficult. But here is the instructor to support you.

The second important thing is because it's a difficult time, we should help students connect what they are learning during the class to the society they are experiencing. They see a society with such chaos and why we're learning the nature of science in class. So, they need to use what they're learning to interpret what happened in

society and help them be good citizens.

Valarie: How about you, Tulli?

Tulli: I totally agree with Qiu, and I have a little addition to her comment. Yes. I also taught many times during the last two semesters about the nature of science. So, the first thing is that we need to understand the students' emotions and feelings. For example, when I started teaching on zoom, I was not very happy to teach them on blank screens, but we have learned so many things about the students' background and how they are attending zoom and that kind of thing. So now I'm fine with that because they have their own problems. I'm glad that they are in the class and learning the nature of science.

The other thing is that the pandemic alerted us about things happening in society and worldwide. When I was answerless, the nature of science helped me understand things for myself, how science and society are working, and the connections between them. So that kind of thing makes it easy to understand the nature of science for me. So those are things that helped teach the nature of science through the pandemic.

Valarie: Yes. The pandemic was quite a "fun" year, and it keeps going. We want to share with you some implications, and we're each going to say a sentence of what we think is most important about teaching the nature of science. So, should we start with Qiu?

Qiu: Sure, so my one sentence is we cannot learn science content knowledge well unless we learn what science is and how science works.

Claire: So, my takeaway is that the nature of science has great potential for shifting our perspectives in science education to move towards more equitable teaching and learning in the science classroom.

Tulli: My take-home message is interdisciplinary collaboration. Collaboration would include scientists, social science professionals, non-science professionals, etc. So, the nature of science is a kind of a good linkage for interdisciplinary collaboration.

Andrea: I would say that my big takeaway is that we should continue to make NOS the norm in science education just like we've made scientific practices a norm. I think that the nature of science should be the same, and that means continuing to emphasize it in teacher education, but also improving on things like curriculum development, including NOS, and making sure that NOS is clearly embedded throughout the science standards.

Valarie: For me, the big takeaway is we need to start teaching it when we begin teaching science, right? When kids are in school, throughout their school careers, into their college careers, into their graduate careers. If we really want people to be scientifically literate, it has to be part of what we do when we teach science.

Shukufe: For me, there is no doubt that teaching and learning the nature of science is fundamental. Discovering

the nature of science provides knowledge on understanding science and how it works. It is also time for us to look into how the nature of science can be integrated into science curriculum and textbooks.

Conghui: I strongly feel that the nature of science should not be limited to science teachers and educators. We should spread it out for general scientific literacy.

Jessica: So, I'll wrap this up. My takeaway is to think outside the box with the nature of science. This class has reminded me that we don't have to NOS to just one subject, but other areas where NOS would be useful for students and teachers.

Valarie: Great. Thanks, everybody.

Conclusion

It is clear from the continuing discussion that the NOS seminar had an overall and lasting positive impact on graduate students' understanding about what it means to learn science through the NOS lens. What we also realized through the discourse was that NOS conceptual development is divergent and can be affected by an individual's cultural and academic backgrounds as well as previous career experiences. The cultural diversity of the study participants allowed for an international perspective which underscored the lack of NOS education in many educational settings around the world. Thus, the group concluded that the teaching and learning of NOS is important and should be included in primary, secondary, and tertiary educational systems globally.

As part of the panel discussion, each study participant provided an outcome that was personally gained through the reflection and continuing discourse of ideas conceptualized in the NOS seminar. These *takeaways* were diverse in thought and inclusive of many considerations of NOS teaching and learning. One panelist found NOS teaching to be critical for science content acquisition while another conceptualized NOS as a vehicle for equity promotion in the science classroom. Two graduate students agreed that NOS can promote interdisciplinary collaboration. Two more participants looked to normalize NOS teaching in science education, making it an integral part of educational programming starting in the early years and lasting throughout science educational experiences. One graduate student highlighted the need to analyze current curricula for the incorporation of NOS content as well as the development of new textbooks and other resources that effectively address the teaching and learning of NOS.

Implications

This self-study and panel discussion point to several areas of growth that can help in the promotion of NOS instruction in science education. Science education graduate programs should consistently incorporate NOS instruction in learning and applications of NOS instruction in teaching. In primary and secondary education, explicit and reflective teaching of NOS should be supported by ongoing professional development (Quigley et al., 2010).

Additionally, the development and introduction of appropriate NOS related curricular materials will enhance the incorporation of NOS into K-12 science programming. Future research could look at the level of graduate assistants' knowledge of NOS instruction and how that affects the uptake of NOS understandings and knowledge of instructional strategies in preservice science teacher programs. It is critical that we understand how NOS is conceptualized by teachers and learners of science as we move toward a goal of complete incorporation of NOS in science education.

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Author Information

Jessica McClain
https://orcid.org/0000-0003-3376-3226
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States
Contact e-mail: *mcclaijr@iu.edu*

Claire Cesljarev
https://orcid.org/0000-0002-1160-5377
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States

Qiu Zhong
https://orcid.org/0000-0001-6751-4661
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States

Shukufe Rahman
https://orcid.org/0000-0002-8040-0797
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States

Conghui Liu
https://orcid.org/0000-0002-3218-4460
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States

Andrea Phillips
https://orcid.org/0000-0001-5886-7772
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States

Tulana Ariyaratne
https://orcid.org/0000-0003-3099-3464
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States

Valarie L. Akerson
https://orcid.org/0000-0002-0945-6149
Indiana University
201 North Rose Avenue
Bloomington, IN 47405
United States