TEACHING NATURE OF SCIENCE

ACROSS CONTEXTS AND GRADE LEVELS: EXPLORATIONS THROUGH ACTION RESEARCH AND SELF STUDY

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INTRODUCTION

It has long been determined to be important to teach NOS as a component of scientific literacy, from the youngest ages (e.g. Michaels, Shouse, & Schweingruber, 2008; NSTA 2020). Additionally, it is also known that to teach Nature of Science (NOS) effectively it has to be taught explicitly and reflectively (e.g., Akerson, Abd-El-Khalick, & Lederman, 2000), and teachers need more than a good understanding about NOS, but also need to teach NOS (e.g. Akerson & Abd-El-Khalick, But what ideas about NOS should be taught, and learned Pre-K-16 (and beyond)? In the United States we have the Next Generation Science Standards that include eight aspects of NOS, four within the Science and Engineering Practices and four within the Cross-Cutting Concepts.

Within the Science and Engineering Practices section there are four aspects of NOS to be found that K-12 students should know by the end of high school. First, scientific investigations use a variety of methods. One can still often times see a poster of the steps of "The Scientific Method" posted on a classroom wall, when in reality scientists do not use one simple method. In fact, many investigations are descriptive and/or correlational, and simply do not fit "the scientific method." Second, scientific knowledge is based on empirical evidence. For something to be a scientific way of knowing, there needs to exist empirical data that supports the idea. All scientific knowledge is at least partially based on observations of the natural world. In addition, all theories and laws can be checked against what actually occurs in the natural world, which will substantiate the scientific knowledge, as well as allow for predictions. Third, scientific knowledge, though robust, is open to revision in light of new evidence. If new evidence is found, the scientific knowledge can be changed or modified. Similarly, reinterpreting existing scientific knowledge can also allow for changes in scientific knowledge. Fourth, scientific models, laws, mechanisms, and theories, explain natural phenomena. These are different types of scientific knowledge, but all help explain phenomena, and all arise from interpretation of empirical evidence. Laws describe relationships among observable phenomena and theories are inferred explanations for observable phenomena.

There are also four aspects of NOS to be found within the Cross-Cutting Concepts section that students K-12 should conceptualize. The first is that science is a way of knowing, that is different from other ways of knowing, such as history, art, philosophy, and religion. Scientists attempt to explain natural phenomena, and are not involved in questions that cannot be answered by science, such as whether God exists. Third, science address questions about the natural and material world. It does not seek to answer questions outside the natural world. Those questions are important, but cannot be answered by science. Third, scientific knowledge assumes an order and consistency in natural systems. By assuming this order we can search for patterns in data and empirical evidence, and then make predictions and form generalizations to explain the natural world. And fourth, science is a human endeavor, meaning data are subject to human interpretation and creativity, as well as being theory-laden and subjective, and socially and culturally embedded. These ideas are in line with the National Science Teachers Association (NSTA) position statement for teaching the Next Generation Science Standards ([NGSS], Lead States, 2013) and are derived from years of research on teaching NOS (e.g. Lederman & Lederman 2014). NSTA recommends that by the time they graduate from high school, students should understand the following concepts related to NOS:

- Scientific Investigations Use a Variety of Methods;
- Scientific Knowledge Is Based on Empirical Evidence;
- Scientific Knowledge Is Open to Revision in Light of New Evidence;
- Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena;
- Science Is a Way of Knowing;
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems;
- Science Is a Human Endeavor; and
- Science Addresses Questions about the Natural and Material World.

So how do we get instructors of all grade levels to not only understand these ideas NOS, but to teach it in ways that their students can learn, and in various contexts? The group of chapter authors in this book enrolled in a doctoral level NOS class where they learned about NOS, and explored NOS research in their various settings, from kindergarten to college level. They subsequently enrolled in a self-study and action research in science education methodology course taught by the same instructor (Dr. Valarie Akerson). In the methodology course we decided to each design an action research or self-study (or both!) to help us not only explore what it means for instructors to learn about teaching NOS (self-study), but to also determine the understandings that students of various grade levels could learn in various contexts. These studies were carried out, and the resulting work is published in this book. The instructional approaches used are described in each chapter, but align with the explicit-reflective approach shared in various research studies, and especially in the current review of NOS literature (Bubingo et al, 2022).

We have structured the book into two sections: Action Research and Self-Studies. Within the Action Research section there are two subsections: In person and Online teaching. In the action research section, teachers describe how they embedded NOS into their instruction and examine students' conceptions of NOS as a result of that instruction. The Action Research Studies on In-Person Nature of Science Teaching and Learning section contains four chapters. The first chapter is a study of integrating NOS (in particular, observation and inference) into kindergarten curriculum by using fairy tales and a mock crime scene. The second chapter in this section describes a study that explores high school chemistry students' conceptions of NOS embedded in a unit on The Gas Laws and Kinetic Molecular Theory that is grounded in the NGSS. The third chapter examines how NOS can be highlighted in a unit about evolution, focusing on Darwin's life and work. The fourth and final chapter in this section examined the NOS views of students at a Christian high school.

The second section in this book, which contains three chapters, focuses on Action Research Studies on Online Nature of Science Teaching and Learning. The first chapter explored the results of embedded NOS into a unit of fingerprinting within a fully asynchronous online college-level forensic science course. The second and third chapters both examined NOS within fully asynchronous online college-level life science courses.

The self-study section contains four chapters, with the first being in a fourth-grade classroom as a former high school science teacher strives to remind herself how to teach elementary science as well as embed NOS into her teaching. In the second chapter a high school chemistry teacher shares how she used Appendix H from NGSS as exemplars to teach her chemistry students about NOS. The third chapter highlights how an online college biology instructor incorporated NOS into her courses, and the struggles and resolutions she encountered. In the fourth chapter, an in-person college biology instructor shared her endeavors in incorporating NOS into her instruction, and how she made changes and improved her teaching about NOS.

We hope you enjoy this book as much as we have enjoyed conducting the research and putting it together. We hope it adds to the field, and we hope it will prompt others to explore teaching NOS in various contexts and sharing their outcomes as well. Enjoy the book!

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SECTION I - ACTION RESEARCH STUDIES ON IN-PERSON NATURE OF SCIENCE TEACHING AND LEARNING

Chapter 1 - The Influence of Engaging Texts and Immersive Experiences on Kindergarten Students' Conceptions of Observations and Inferences

Kristen A. Poindexter

Chapter Highlights

- Increasing kindergarten students' use of observation and inference
- Engaging experiences can help students engage with NOS aspects
- Fairy tales can provide a basis for teaching explicit-reflective NOS lessons
- Kindergarten students can increase their use of NOS aspects such as observation and inference
- Kindergarten students can effectively use observation and inference to make informed decisions

Introduction

It was long thought that developmentally, young children could not learn about scientific ideas. Metz (1995) critiqued three developmental assumptions that had been made and found that they were not supported by Piagetian and non-Piagetian literatures. Young children can learn about scientific ideas and although they might not have a deep understanding, they are able to engage in posing questions, gathering, and interpreting data, and revising their theories (Metz, 1995). In terms of learning about nature of science (NOS), children as young as kindergarten age are capable of learning NOS through appropriate science instruction (Akerson et al. 2011).

The focus for this study is to determine whether fairy tales that are commonly known to many elementary students can help to effectively teach them about nature of science, specifically inference and observation, when paired with an engaging experience, such as a mock crime scene investigation. Will these students be better able to communicate how inference and observation are used in developing scientific knowledge?
There has been much research done to determine that children even as young as kindergarten can learn about nature of science aspects and communicate their ideas and understandings about nature of science (Akerson, Buck, Donnelly, Nargund-Joshi, & Weiland, 2011; Akerson & Donnelly, 2010). Kindergarten students can grow their understandings around nature of science through explicit-reflexive teaching and learning along with other evidence-based strategies including the use of children's literature (Akerson, Weiland, Khemmawadee, & Nargund, 2010).

A gap exists in the literature that has been published about the use of fairy tales when teaching about nature of science. Several studies offer nonfiction texts or texts specifically written about science content, however, to the knowledge of the author there is no research currently published about the use of fairy tales. Similarly, there is no found research about immersive experiences such as the mock crime scene investigation when paired with a fairy tale text (Brunner & Abd-El-Khalick, 2020; Ford 2006; Zarnowski & Turkel 2013).

Many teachers have begun to turn to children's literature to teach their students about nature of science, as children's trade books have become more widely available. Often the chosen texts are inaccurate or do not effectively teach nature of science (Brunner & Abd-El-Khalick, 2020; Ford 2006; Zarnowski & Turkel 2013). Ford (2006) found that trade books that were not explicitly tied to science curricula, tended to imply that science is fact, that it cannot be changed, and that there was little evidence that showed areas about what scientists do not know. If children's trade books are used in a classroom where the teacher used the text in a way that asked students to question the facts, they could be used in a manner in which to teach nature of science effectively. Linking these texts with an immersive experience, such as the mock crime scene investigation, that is explicitly designed to increase students understanding of inference and observation, could help to open the door to the use of more children's fairy tales being used to teach young children about nature of science. Could fairy tales be an exception to what has been studied about children's science literature when they are paired with an activity purposefully designed to enhance student understanding of nature of science?

Research Question

How do engaging texts, such as fairy tales, when combined with an immersive experience, help to increase Kindergarten student understanding of inference and observation?

Theoretical Background

There is existing research about ensuring that NOS is taught early on in a child's educational career, as early as Kindergarten. There is also research regarding the use of children's literature as a vehicle to teach NOS in a more effective manner. Much of that literature focuses on children's literature written for a specific scientific topic or purpose or literature that is tied back to science in some way (Brunner & Abd-El-Khalick, 2020; Ford 2006; Zarnowski & Turkel 2013).

Science instruction should begin as soon as science starts in a classroom (Akerson et al. 2011). Waiting to include NOS ideas in science instruction impacts the students' ability to change their thinking about science and NOS in the future (Akerson et al. 2011).Young children can begin to build ideas about NOS as early as Kindergarten, and although they cannot yet fully understand NOS, they can begin to develop some ideas about all areas of NOS. Introducing the ideas of observation and inference to kindergarten students in each science lesson can help a young child begin to develop ideas about NOS. Metz (1995) argues that educators often look to developmental psychologists to determine developmental constraints that children might have in learning stages. Using these learning stages can constrict educators thinking regarding what is actually developmentally appropriate for their students to learn. Educators should look beyond the learning stages and use them as a guide, knowing that children enter school with differing background knowledge and focus on providing appropriate science instruction to increase background knowledge and understandings of NOS. When children are taught about NOS using explicit-reflective strategies along with other evidence-based strategies, they can increase their understanding of NOS as early as Kindergarten (Akerson et al., 2011, Akerson et al., 2010, Akerson et al., 2019).

When children are taught using explicit-reflective strategies that allow them to try out their thinking and then reflect upon it, they begin to develop an understanding of basic aspects of NOS. It is not sufficient to teach NOS in an inquiry setting, the explicit-reflective portion is key to increasing NOS understandings. Through an extensive literature review, explicit and evidence-based strategies were shared to help educators intentionally include them in their teaching (Akerson et al., 2019).

First, including NOS terms in existing curricular materials can help students make connections to NOS terminology. Educators doing this will need to make sure they are explicitly pointing out connections to NOS as well as including ways for students to reflect on their NOS understandings at the end of the lesson. In using explicit-reflective science instruction, students can connect NOS ideas with activities they engage with in their classrooms. The teacher begins by introducing the NOS tenets to students and then works to incorporate them into hands-on lessons. One way to collect data about what students know and want to know about a topic is by using a KWL chart or another anchor chart to record this information. A KWL chart is a graphic organizer that is used to find out what children already know (K), want to know (W), before engaging in a new topic, and as new learning occurs, the learning (L) is collected in that column on the chart. It is important to note that the most effective teaching of NOS happens when NOS concepts are taught within a lesson and the teacher cycles back to them in the lesson (Akerson et al. 2019).

Students need time to share their new learning, reflect on what it means and how it ties to NOS, and what their data means. Many curricular materials based on the Next Generation Science Standards (NGSS) allow for a clearer connection to NOS, as NOS are associated with the included crosscutting concepts (NGSS Lead States, 2013). The Matrix, set forth in the *Next Generation Science Standards : For States, By States* (2013), allows teacher a to find NOS understandings more appropriate for their age band, however this does not mean that educators cannot venture into other age bands to include more aspects of NOS in their lessons. Additionally, utilizing classroom discussions to help students reflect upon their NOS understanding can be a useful tool to encourage students to engage in meaningful discourse about NOS and science (Akerson et al., 2019). Discussions can happen at any point in the lesson but are especially meaningful when they happen at the end of a lesson, where students are able to debrief the learning and connect back to NOS terms. Teacher questioning can also guide students into connections with NOS. Asking questions such as, “What did you observe?”, or “What did you infer from that data?”, helps students to dig more deeply into NOS ideas and allow educators to find out informally how many NOS aspects their students are understanding. Engaging learners in these discussions, particularly with young students, helps to also cultivate an interest in science as well as values and attitudes (Carey & Smith, 1993).

Children’s literature is another strategy that teachers can use to engage students in learning about or reinforcing NOS aspects. Beginning in pre-service teacher preparation programs, future educators can learn how to use children’s literature to teach ideas about NOS using a context that is appealing to young children. Using carefully selected trade books, teachers can use specific questions to teach students about NOS. Asking students to make observations and inferences as they read a book together can strengthen students' NOS understanding. Teachers can elicit student help in creating a t-chart for each book, aligning observations with inferences and any other NOS aspects within. Books chosen about dinosaurs, for example, can help students to understand how scientists use bones as clues to observe and to make inferences about the appearance of dinosaurs, resulting in the recreations we currently have. Connecting student interests with children’s literature is a wonderful way to increase engagement and interest in NOS. The reviewed literature indicated that using children’s literature was an effective strategy in the teaching of nature of science to early childhood children. As children’s literature is highly engaging and is written at a level that makes topics accessible to young children, educators are able to carefully select and use children’s literature along with explicit-reflective instruction to enhance nature of science teaching.

Children’s literature is an exciting way for teachers and students to learn about a new scientific topic, however, much of the literature that has been published is either inaccurate or does not cover specific NOS aspects. Akerson et al. (2022) and Erumit (2021) tasked their pre-service teachers with developing children’s books that would enable them to leave their course with an accurately written NOS book to use in their future classrooms. Erumit and Akerson (2021) additionally asked middle school pre-service teachers to create a 5E lesson plan to accompany their children's books so that those pre-service teachers would be able to implement NOS activities into their first classroom experiences. Akerson et. al (2019) used explicit-reflective teaching strategies with pre-service teachers about each NOS aspect throughout the semester long class. The pre-service teachers were tasked with writing a children's book that covered all NOS aspects, excluding theories and laws as they are difficult for young children to understand. As the pre-service teachers learned more about NOS aspects themselves, they were readily able to include most NOS aspects into their own children's books and use the NOS aspects correctly, enabling them to pass on accurate NOS ideas to their students. The idea of asking pre- and in-service teachers to help fill the gaps in the lack of accurate NOS related children's books was also used by Erumit and Akerson (2021) with middle school pre-service teachers in Turkey. In both instances, the pre-service course instructors used explicit-reflective strategies to engage pre-service teachers in learning about NOS aspects. In-class activities included reading of specific children's literature that was effective in teaching one or more aspects of NOS coupled with a NOS related activity. Participating in activities such as these gave the pre-service teachers contextualized experiences from which to draw when writing their own children's books. Ford (2006) reviewed 44 children's books that were randomly selected off the shelf at her local public library. Books were chosen to represent all disciplines of science and were representative of what a parent or child could check out from their local public library. Ford concluded that children's books should be selected carefully, as some misrepresent scientific concepts, some would need an educator to use them in conjunction with an in-class inquiry, and some would be suitable for classroom use with explanations and discussions carefully designed by the classroom teacher.

Research is lacking around linking children's literature to mock activities/experiences. There is an opening in the research for studies on incorporating more children's literature into inquiry units and engaging, hands-on experiences (Brunner & Abd-El-Khalick, 2020; Ford 2006). Buck, Akerson, Quigley, & Weiland (2014) explored the use of contextualized and decontextualized approaches to teaching first grade African American students, in a low socio-economic status (SES) school, as a way to increase student understanding of NOS aspects, specifically observation, inference, and evidence. During the two phases of instruction, students participated in explicit-reflective units, the first was decontextualized and allowed the instructors to introduce students to observation, inference, and evidence through various age-appropriate experiences. The second, contextualized unit, introduced the students to a unit about the contributions and methods of past scientists. NOS aspects were referred to frequently during this second, contextualized unit so that the first-grade students could make connections between the NOS aspects and them in practice within the concepts of the unit. The first-grade students in this classroom did increase their understanding of observation, inference, and evidence, although the research team wondered if the highly engaging activities in the contextualized unit took away from a more complete understanding of NOS aspects by these first-grade students. Buck et al (2014), reflected that the use of the social sciences in the contextualized unit was a possible distraction for the students in this lower SES school setting. The students focused more on the diverse scientists and the culturally relevant topics that were presented to them and less on the scientific content, distracting them from fully engaging with NOS.

Method

The setting for this study was in a Kindergarten classroom composed of 22 five- and six-year-old students. The elementary school is in a suburban setting, 15 minutes outside a major city and has a very diverse student population. It also has varied socio-economic status levels represented and over 19 different languages being spoken. The class is taught by a 21-year veteran in the Kindergarten classroom (author). Students completed an inferring sheet as well as a sheet where they can draw the mock crime scene and circle any clues that helped them observe or infer clues to solve the case.

Intervention

Using explicit-reflective instruction, students engaged in a NOS lesson based on the children's book The Little Red Hen (Galdone, 1985). They have previously read this text and have studied the words within it extensively as part of their reading instruction. During the lesson, students will examine an age appropriate "crime scene" staged to look as though someone stole the loaf of bread that the Little Red Hen baked. Students will learn to use observation and inference to find clues to lead them to the thief.

Lessons

Day 1: The instructor asked students what they knew about the word observation and created a t-chart (see Figure 1) with the student responses on one side. The instructor repeated the same activity using the word inference. If students had difficulty responding, the instructor provided some examples between observation and inference at an age-appropriate level. For example, when students were not initially able to describe was observation looked like in action, the instructor reminded students that they can observe with their senses. The instructor also reminded students that inferring was a skill they had previously used when reading children's literature together during past literacy lessons. This chart was used throughout the next activities so that the children were able to refer to it as needed to clarify their understanding about these two aspects of NOS.

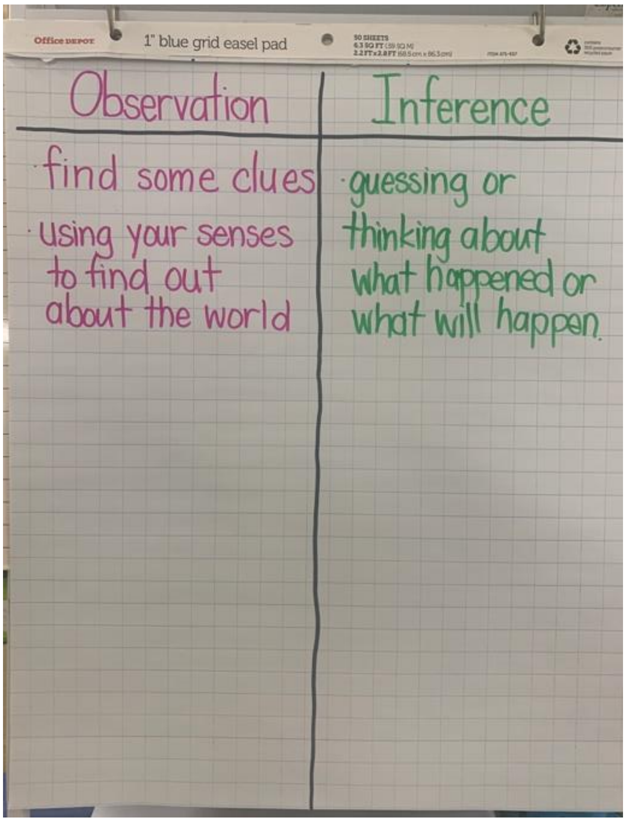

Figure 1

Day 2: Students gathered on the floor and the teacher read to them the chosen version of The Little Red Hen. After reading the story, students used observation and inference to help solve the case of the missing loaf of bread. The teacher lead a discussion reminding children (and gave examples as needed) of what observation is (the evidence we can see in front of us) and what inference is (what we can figure out from the evidence in front of us). The teacher also reminded students that they can refer to the t- chart as they try to determine who the thief of the loaf of bread is.

Day 3: The teacher invited students to gather around the crime scene (Figure 2). and asked them to observe what they saw and to share their observations with the group as a whole. The teacher wrote down their observations on a large chart paper (Figure 3). Once all observations had been collected, the teacher asked students to make inferences about what happened in the crime scene. Inferences were also recorded on the large chart paper. Finally, the teacher followed up this discussion by asking students to share what evidence they had from their observations that helped to make their inferences accurate.

Figure 2

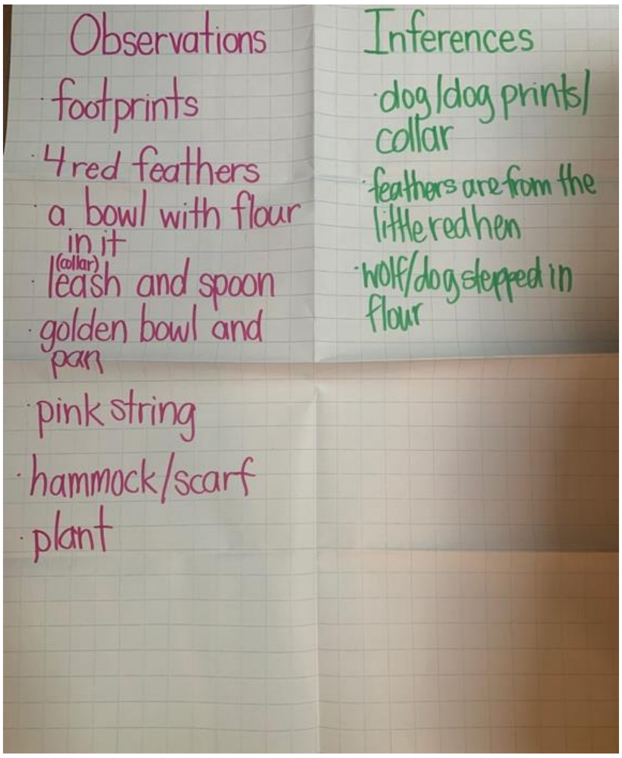

Figure 3

Day 4: Students gathered back as a large group to review and debrief the case files on each animal. They used the case files along with the observations and inferences to determine who the thief was. The teacher asked students to support their claims with evidence from their observations and inferences, using productive talk moves. The instructor asked questions such as, “What did you observe?”, or “What did you infer from that data?” Additionally, on day 4, students were given 3 more clues to help narrow down which suspect may have taken the loaf of bread.

Day 5: Students completed a recording sheet designed by their instructor where the students had the opportunity to draw who they thought took the loaf of bread and the reasons for inferring this.

Data

This is a mixed methods research study. The VNOS-E was administered as a validated pre/post assessment, as it is designed for use with young children. The study took place over a week with the VNOS-E being administered the week before the lesson takes place as well as immediately after the lesson takes place. The VNOS-E is an open-ended instrument designed initially by Lederman and O'Malley, to determine what students know about NOS before and after instruction has taken place (Abd-El-Khalick, Lederman, Bell, & Schwartz, 2001; Ayala-Villamil & García-Martínez, 2021). It is also used in conjunction with individual interviews, to find out more about the subjects' thinking and understanding. The VNOS-E was created for use with very young students.

Information collected from the VNOS-E is coded into three categories of understanding: adequate, inadequate, or informed, Voice recordings were taken while administering the VNOS-E so that all ideas I may have missed scribing during the initial administration and final administrations could be captured. Additionally, I used student data, specifically a teacher-created recording sheet that allowed students to record information about their inferences along with a second recording sheet where students drew the mock crime scene and circled evidence/clues that were helpful to them in solving the case. These recording sheets were handed out and collected on day 4 and day 5 of the lesson. Following the conclusion of the lessons, the VNOS-E was again administered as a post assessment to determine growth specifically in the areas of observation and inference. This research took approximately three weeks to complete.

Data Analysis

Students were asked to write their names on any recording sheets and names were translated into numbers to ensure anonymity. Names were added to the VNOS-E each time it was administered, and those names were also translated into numbers to match those on recording sheets. VNOS-E pre/post responses were coded (adequate, inadequate, or informed) and then tabulated. Once the responses are tabulated, pre/post assessments were compared to determine any change in understanding. Student recording sheets were coded as well, in similar fashion to the VNOS-E (adequate, inadequate, or informed). Recording sheets were used to inform future instruction as well as to show the current ideas of students after participating in the mock crime scene activity.

Sample responses given by students in response to VNOS-E question 4b
(How certain are scientists about the way dinosaurs looked?)

Inadequate: "They make movies, they look like real life dinosaurs."
Adequate: "Because they put the bone puzzle pieces together."
Informed: "They are probably sure because they can look at the footprints and the skin that dinosaurs left behind from when they died."

Results

Although students overall shifted their thinking from inadequate to adequate/informed views of NOS, the greatest gains were shown in questions specifically about observation and inference. As student responses were scored, it was evident that there were better-quality responses after the intervention occurred. Explicit-reflective instruction, as it was used in these lessons, specifically targeted the NOS aspects of observation and inference as they are the most developmentally appropriate for kindergarten students and easiest for them to access Akerson et al (2011). Young children can learn about scientific ideas and although they might not have a deep understanding, they are able to engage in posing questions, gathering, and interpreting data, and revising their theories (Metz, 1995).

Children engaged in these explicit-reflective lessons over five consecutive days, and in the teaching of each lesson the students became more adept at pointing out observations and inferences they noticed with the information they were given. During each of these lessons, students were given the opportunity to think aloud with the whole group and to think-pair-share with a partner.

Prior to the intervention more than half of the students in this class had inadequate views of most aspects of NOS (Table 1), with the exception of question 5b, where students are asked to infer what might happen as the snowboarder continues his or her journey down the snow-covered hill. Inferring is a skill that is very appropriate for children at this age as they are exploring the world around them and discovering through experiences how things work. They can use the information they are taking in through those experiences to talk about how things happen (Berk, 2019).

Table 1. Kindergarten VNOS-E Pre-assessment

n=number of students

Question	Inadequate	Adequate	Informed
1.	*n*=8	9	3
2.	14	3	1
3.	14	4	1
4a*	12	2	5
4b	14	5	0
4c	16	2	1
5a*	2	9	8
5b*	0	14	5

*denotes questions specifically about observation and inference aspects

In responding to that question, most students were able to give adequate ideas about what may happen using what they could infer from the picture they were shown, for example:

S1: He could fall because there's a lot of snow dust

S2: He could get hurt and fall on the snow, but he is holding his hand out in the snow, so he doesn't fall

S14: Maybe he's going to be hurt after falling

It was interesting to note that many students were emphatic that science in books would and could not change as books are permanent objects and that it would be wrong to write in books to change the information within them. Developmentally, they do not yet understand how information is constantly changing and that books and other texts can change and be revised as well. This was especially interesting as the author had worked with as class numerous times previously to rewrite the endings to books we found within our classroom. Thus, it was important in teaching these lessons to be explicit about new information, point it out to students, capture it on our anchor chart, and talk about it with the students to help them to integrate the new information into their existing schema and to help introduce the idea that science can change with new information.

Table 2. Kindergarten VNOS-E Post-assessment

n=number of students

Question	Inadequate	Adequate	Informed
1.	*n*=6	9	4
2.	11	5	2
3.	6	6	7
4a*	9	4	6
4b	9	9	2
4c	11	3	4
5a*	1	6	12
5b*	1	6	12

*denotes questions specifically about observation and inference aspects

The post intervention assessment indicated that students increased their use of observation and inference (Table 2) when compared to their use before the intervention. The responses collected using the VNOS-E and the teacher-created reflection sheets indicated that students used all the information they collected through observation, conversation, and inferring, helping them to give informed responses. Students gave more explicit details in their responses that aligned with informed thinking in response to the VNOS-E questions and were able to give specific examples as to who they think took The Little Red Hen's loaf of bread.

Example student responses on teacher created inferring reflection sheet:

S: I think it was the dog because he likes to sniff and take food away.

S: I am inferring it was the dog because I've heard that he has been sniffing some tasty things

S: I think the cat did it because he was the smallest.

S: I think the dog took the loaf of bread because the dog had on a collar and had footprints.

S: I saw dog prints and I didn't see anything about the cat or pig

S: I think all three might be working together because of all the clues

Students were also asked to draw the mock crime scene and circle any clues or information that helped them solve the crime and to place question marks next to any clues they still had questions about. The responses on this sheet were similar to those on the inferring reflection sheet, indicating that they held true to their beliefs about the main suspect across two days and while assimilating new information into what they had already deduced. Many students circled the footprints indicating that those were a clue that helped them infer that the dog took the loaf of bread. Several students also circled the red feathers that were included in the mock crime scene, and one indicated that the dog prints walked towards where the feathers were. One student noticed the dog collar in the crime scene and circled that along with the footprints indicating that these two pieces of evidence pointed to the dog being the culprit. Yet another student agreed with this student by circling the footprints and collar, and adding in arrows pointing to each of these clues indicating these were the most important clues in solving this case. A student who indicated that the dog was also the culprit noticed that the footprints in the crime scene walked away from the loaf pan and towards the feathers. This student circled the footprints, loaf pan, feathers, and drew arrows to indicate the direction in which they think the dog went. Interestingly, this student paid no attention to the dog collar.

In designing these lessons, the author intended for them to be open-ended with no clear answer so that students could use observation and inference to determine their main suspect. Several clues that were given leaned more towards the dog being the main suspect, however, there was other information that countered those facts. In the end, regardless of which suspect students chose, they all nearly gave adequate or informed responses for choosing the suspect they did.

Final tabulation of suspects

Dog	Cat	Pig	All 3	Dog/cat
15	1	0	1	1

Discussion

Prior research has shown that young children are able to increase their understandings of NOS aspects with explicit-reflective instruction that includes the use of children's literature and various strategies to give students opportunities to use them in practice (Akerson et al., 2011, Akerson & Donnelly 2010). As evidenced by Buck et al. (2014), young children can effectively learn about NOS aspects through an explicit-reflective decontextualized approach. Students need the explicit instruction of the NOS aspects as a precursor to implementing them in their own science practices. When Buck et al. (2014), analyzed the data from the decontextualized and contextualized units, they found that although the first-grade students grew in their understanding of NOS aspects, but within the decontextualized unit, where observation, inference, and evidence were explicitly taught, the growth appeared to be greater and students had an easier time including them in their science journals, interviews, and whole group discussions.

One area that the author did not consider was how valuable the whole group discussions would be in increasing student use of observation and inference. Allowing students to talk with one another and hear from each other about alternate viewpoints enriched the students use of inferring and, through productive talk moves (Doubler, McWilliams & Michaels (2011), students were able to consider new ideas about the mock crime scene and who the suspect was. Using a fairy tale that students were familiar with along with a mock crime scene proved to be an effective way to engage students in the use of observation and inference. Throughout the lesson, the students were highly engaged in finding out who had taken the Little Red Hen's (Galdone, 1985), loaf of bread, allowing for them to become caught up in the excitement of finding the thief. The literature has shown that engaging scenarios and children's literature are excellent vehicles for teaching young children about NOS aspects, however, there was nothing in the literature that discussed combining the two approaches. It is the author's belief that because the students had already come to know The Little Red Hen through repeated readings, they were invested in finding out who had taken her loaf of bread. The instructor set up the mock crime scene after school so that it would be the first thing the students saw when they entered the classroom the next morning, engaging them immediately in wanting to help solve the crime. The lessons were written to provide explicit-reflective instruction, where students would be able to hear, learn, and think about observation and inference and the put them into practice each day to reinforce and use new learning (Akerson et al, 2010; Akerson et al, 2011; Akerson et. al 2019).

The Little Red Hen text was chosen by the author as the students had just completed an extensive literacy unit learning about fairy tales. Students had previously considered the emotions of each character within the text and how those changed throughout. This fairy tale was also selected because it provided a way to extend the story into another area of learning (i.e., observation and inference) when the dog, cat, and pig expressed their remorse about not helping the Little Red Hen to be able to enjoy the loaf of bread. Although this text does not specifically focus on scientific ideas, there was no incorrect presentation of science within it and it provided for an extension activity which allowed the author to develop lessons aligned with explicit-reflection teaching. As the author worked to develop lessons that would explicitly teach students about observation and inference, the Little Red Hen was selected as its ending (i.e., The Little Red Hen baking a loaf of bread and not offering any to her friends who would not help her) provided a situation that the students could investigate further. During a classroom literacy lesson, the author used the feelings of the friends (cat, dog, mouse), when they were not able to enjoy the loaf of bread, as potential cause for a crime to happen.

It is important to note that in the lessons that were taught related to The Little Red Hen (Galdone, 1985), the author explicitly returned each day to a quick discussion about observation and inference to ensure that students were able to assimilate new learning with existing schema. At the end of each day's lesson, the author asked students to share out any new learning they had that day with their peers as a way to think and sift through new information and clues learned. Through these discussions, the author facilitated conversations between students to help them make sense of new information or clues that may help them solve the crime and to connect new learning with previous learning. In any explicit-reflective NOS lessons, returning to the focus question, objectives, or research question after the lesson is complete, ensures that young children will begin to make important assimilations.

Conclusion

Explicit-reflective instruction in this way allowed students to hear the thinking of their peers as observations and inferences were shared aloud with the group. Many students commented that after hearing a peer's idea, they looked at the crime scene in a different way, considering a new idea or making a new inference. Using this method of explicit-reflective instruction by connecting a fairy-tale to a mock crime scene allowed students to take their existing schema and change their thinking as new information was given to them. Specifically, students increased their use of observation and inference, using the information they took in from the mock crime scene and discussions with peers. The use of these highly engaging lessons and mock crime scene allowed students to develop and use observation and inference to determine who took The Little Red Hen's loaf of bread. The author can infer from the gains in observation and inference during these lessons, that the combination of an engaging scenario (mock crime scene) and a familiar fairy tale (The Little Red Hen) is an effective strategy in which to explicitly teach NOS aspects. The hands-on nature of the crime scene and the fact that it was present in the classroom for children to actively observe and make inferences from provided a real-life way for students to practice the use of observation and inference. Additionally, as mentioned above, the author set up the mock crime scene when the students were not in the classroom, further exciting students and drawing them in to help investigate the crime that had taken place. After engaging in these lessons, students had increased their use of observation and inference and were able to better articulate their thoughts behind their inferences.

Recommendations

More formal research needs to be done about the use of engaging experiences and fairy tales to increase NOS aspects, specifically observation and inference. There is a current movement in education to use engaging experiences in classrooms (i.e., room flips, room transformations), however, there little formal research that can be found to indicate the effectiveness in the use of these experiences. Over the past ten years, the author has attended several professional development conferences (Ron Clark Academy & Get Your Teach On) where the idea of engaging students with immersive, engaging scenarios has been shared and explained in detail as to how to replicate this strategy in one's classroom, however, the use of engaging scenarios and the outcome of the strategy needs to be formalized. Additionally, no research could be found that examined combining engaging experiences with fairy tales. Data regarding the use of fairy tales and other science related stories, as long as they are scientifically accurate, has been shown to be a promising way to introduce or review scientific content with students (Ford 2006) . Using the combination of a fairy tale and a mock crime scene was a highly engaging way for these Kindergarten students to be immersed in the action of solving this crime, thus making it a powerful way for them to experience the use of observation and inference as they worked together to find the thief. Appealing to their sense of wonder and curiosity, the mock crime scene brought to life a book the class had enjoyed together many times and allowed the students to be part of the action. Being able to have the crime scene in the classroom allowed rich discussions to take place, where the author was able to facilitate discussions that helped students to constantly revisit their observations and inferences, leading to growth in their use not only in this setting, but in the ability to apply observation and inference to other situations.

The author could not find any research about both the use of fairy tales and engaging experiences together in the way they were used in this study, specifically, creating a mock crime scene, creating a gap in the NOS research that needs to be examined further.

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Chapter 2: Nature of Science in an NGSS Chemistry Classroom

Mary F. Johnston, Valarie L. Akerson

Chapter Highlights

- Nature of Science (NOS) within a Next Generation Science classroom.
- Transition from common NOS aspects to Appendix H exemplars.
- NOS embedded within a Chemistry Classroom unit on The Gas Laws.

Introduction

Nature of Science (NOS) is described as a critical aspect of a student's development into an informed citizen, capable of making educated and scientifically based choices in personal and societal contexts. NOS comprehension is considered an essential concept to learn in science classes (Lederman, 2010; National Science Teacher Association [NSTA], 2021). The educational research published referencing NOS comprehension is frequently focused on pre-service teacher training or elementary school level classrooms. There are a minimal studies referencing NOS delivery at the secondary school level and even fewer conducted on NOS comprehension within a Next Generation Science Standards (NGSS) classroom. It is important to analyze the incorporation of NOS within an NGSS classroom. More specifically, it is important to understand pedagogical strategies utilized to explicitly and reflectively embed NOS via Appendix H: *Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards* (NGSS Lead States, 2013a) in a secondary science classroom.

Purpose

There were two purposes for this action research study. The first objective was to connect the commonly accepted NOS target aspects with categorical characterizations and grade level exemplars located on pages 5 and 6 of the NGSS Appendix H. The exemplars, grade level guidelines which are reflected in each of eight categories are listed in *Appendix A* of this publication. The categories, extrapolated from the NGSS Science and Engineering Practices (SEP's) and Cross Cutting Concepts (CCC's) include: "Scientific Investigations Use a Variety of Methods; Scientific Knowledge Is Based on Empirical Evidence; Scientific Knowledge Is Open to Revision in Light of New Evidence; Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena; Science is a Way of Knowing; Scientific Knowledge Assumes an Order and Consistency in Natural Systems; Science is a Human Endeavor; and Science Addresses Questions about the Natural and Material World" (NGSS Lead States, 2013b). The second and main objective of the study was to explicate the modified Appendix H and accompanying exemplars in a reflective manner, within a specific science content. The specific context was a high school chemistry classroom embedding NOS within unit lessons on The Gas Laws and Kinetic Molecular Theory. An initial emphasis was placed upon the identification of each Boyle's, Charles' and Gay-Lussac Laws as laws, reinforcing the concepts of observation versus theory. During the unit lessons, each of the categories or NOS tenets were reviewed. These included science as a human endeavor, the theory laden or tentative nature of science, creativity and imagination as it relates to science, and social and cultural impact on science.

Background

While NOS is not described using a single agreed upon definition, an overall consensus of its characteristics and values exist with which educators and scientists are able to describe the concept. These characteristics may be summarized in eight to ten target aspects such as: observation versus inference, distinction between laws and theories, scientific knowledge is partly empirical, scientific knowledge is subjective (theory laden), science is a human enterprise and scientists are a product of culture, scientific knowledge is tentative, and finally, NOS is not to be conflated with scientific process or inquiry (Lederman, 2007,. pp. 833 – 835).

The literature suggests that explicit and reflective incorporation of NOS is more effective than implicit instructional strategies to improve understanding. That is, the incorporation of inquiry based laboratory activities and analysis of data or discussions about the history of content observed in these activities may not be as effective as connecting the science experienced by either the scientists or the students themselves to the activities (Akerson, Abd-El-Khalick, &Lederman, 2000; Khishfe & Abd-El-Khalick 2002; & Lederman, 2007). More recent research by Eymur (2019) has demonstrated the lack of growth in NOS comprehension for chemistry students receiving implicit instructional strategies compared to those receiving explicit instructional strategies embedded within argumentation driven inquiry. The importance of introducing NOS concepts in earlier grades has been demonstrated, as has the additional time required to correct misconceptions and form new NOS understandings (Ağlarcı, 2016; Demirdöğen & Uzuntiryaki-Kondakçı, 2016). As many science educators themselves have inadequate or partial levels of NOS comprehension (Akerson & Hanuscin, 2007), transfer to students may be difficult. Those educators who do receive instruction on NOS are not readily able to transfer this understanding into their lesson plans nor classroom instructional strategies (Lederman, 2007). In their recent publication, Nouri et al. (2021) reviewed teacher competencies in both comprehension and instructional strategies for the delivery of NOS within the classroom. The authors reiterate the pre-existing scholarship which indicates the need to comprehend the NOS aspects, student misconceptions and appropriate instructional strategies (Nouri et al., 2021).

The Next Generation Science Standards (NGSS) were created to enhance science instruction and the application of scientific epistemology for students to make informed sense of global issues and for the United States to continue to lead, innovate or create jobs in the future (NGSS Lead States, 2013b). The NGSS is a three dimensional instructional framework intended to connect disciplinary core ideas (DCI's), science and engineering practices (SEP's) and cross cutting concepts (CCC's) within each lesson. The first edition of the standards included very little reference to NOS (Lead States, 2013b). In the revision to the NGSS, in order to present and launch *The Framework* in participating states, many of the adjustments were relegated to an additional appendix. Appendix H (*Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards*) does not include a separate list of target aspects but characterizes NOS from the SEP's (Appendix F) and CCC's (Appendix G).

The intent of the NGSS framework may have been to explicitly incorporate Appendix H and NOS within classrooms, yet many educators fail to do so (McComas & Nouri, 2016). Recent publications list 20 states and the District of Columbia have adopted NGSS standards and another 24 states have adopted standards which are based upon *The Framework* (Judson, 2022). At the time this paper was being prepared at least one more state (Indiana) had adopted the NGSS framework. Limited publications which include sample unit lessons include explicit and reflective NOS embedded within NGSS classrooms (Fanning & Adams, 2015; Griffin, 2021; NGSS Lead States, 2013b).

Educational research on the *explicit* (NOS tenets intentionally included in lessons) and *reflective* (independent, group and class considerations of NOS) within NGSS classrooms, specifically via the *exemplars* (grade level statements exemplifying each of the eight categories) located on pages five and six of Appendix H was needed. In addition, appropriate pre-service and in-service educator training in both NOS comprehension and instructional strategies would also be suggested. Finally, previous research has demonstrated a connection between both improved NOS and content comprehension compared to implicit instructional strategies following explicit and reflective delivery (Peters, 2012).

Research Questions

Q1. What is the impact of explicit and reflective NOS embedded within a unit lesson on The Gas Laws and Kinetic Molecular Theory upon secondary school students' understanding of NOS?

Q2. Are students able to identify transition NOS target aspects on categories and specific grade level exemplars of Appendix H of NGSS?

Methods

Interventions

This research was conducted in a secondary school chemistry classroom. Pedagogical strategies and methods for the explicit and reflective delivery of NOS aspects in NGSS classrooms were incorporated. The methods were modeled in a number of studies (Akerson et al., 2000; Lederman et al., 2007) here, the adjustment of incorporating pages five and six of the NGSS Appendix H was added. In this action research study, ten (10) participants anonymous to the researcher, consented to include their pre-test and post-test data for review. The students represent a heterogeneous sampling of their course level population with three sophomores (two female and one male), six juniors (one female and five male), and one senior (male) participant. As the study coincided with multiple day field trips, single day field trips and state testing make-ups, participants may have missed pertinent instruction. The criteria for participating including fewer than four absences during instruction for the study, and completion of a pre- questionnaire earlier in the year. One participant was absent five days; however the fifth day was when the post- questionnaire was administered and his data will be included in this paper.

The inclusion of explicit discourse on the CCC's and SEP's has been established within my classrooms since the implementation of *The Framework* within the district beginning in 2014 and fully adopted by 2015, excluding adjusted instruction during the previous two academic years due to the Covid-19 adjusted learning platforms. In New Jersey, the NGSS based standards were renamed New Jersey State Learning Standards for Science (NJSLS-S, NJ.gov). Generally, students are asked to identify the SEP's or CCC's within unit lessons or laboratories. Students may also be asked where they observed a specific CCC or SEP. In recent units student groups or partnerships have also been asked to identify the science aspects or tentets. These reflections were stressed during units such as The Atomic Theory and The Dual Nature of the Electron.

During the study, students were asked to reflect individually and then within groups, directly from Appendix H grade level exemplars. These reflections included exemplars which described their responses to specific content related questions about activities and / or diagrams. Their reflections were then discussed as a whole class. Students were also asked to complete practice problems, incorporating the equations derived from The Combined Gas Law, respond to questions about Teflon, and create visual display which served as a review of the content. The visual display was an electronic poster created using a Canva™. Student were also asked to complete a post-intervention VNOS-B questionnaire (Lederman et al., 2002) as well as a unit assessment. The instructional timeline (Table 1) included below outlines the plan of instruction for this action research study. A general overview of a few lessons follows.

Table 1. Instructional Timeline

Week	Content
Week 1	Connecting NOS Aspects with Appendix H; Kinetic Molecular Theory and Nature of Gases. Gas Laws – Boyles's Law Syringe and Graphing Lab; Reflection Questions (Independent, Group and Whole Class); Diagram System (Observation) and Inferences (Particles); WS1 Calculations
Week 2	Gas Laws - Charles's Law Charles's Activity (Balloon Activity); Reflection (Independent, Group and Whole Class); Diagram System (Observation) and Inferences (Particles); WS1 Calculations Gay-Lussac's Law Gay-Lussac Demo (Video); Relate to KMT and theory supported by law; WS1 Calculations
Week 3	Visual Display Review: Connecting The Gas Laws and KMT with NOS via Appendix H Completed prior to summative assessment (content) and Post-assessment (VNOS-B)

Introducing Appendix H and Gas Behavior

Students were first asked to explore the exemplars and annotate a modified handout representing the Appendix H categories and their corresponding high school level exemplars (See *Appendix A*) with corresponding NOS tenets. The annotation required a few definitions and explanations of terms. For instance, the term "probabalistic." The students were then introduced to concept of "pressure" (P = F/A) and an overview of Torricelli's manometer. In this lesson, reflection questions included *"Was Torricelli able to see atmospheric pressure?"* or "*Provide an exemplar which explains the development of the barometer following the manometer."*

Figure 1. Flask within Vacuum

The first demonstrations incorporated as an introductory "phenomenon" is depicted in Figure 1. Here, an Erlynmeyer flask containing water was placed within a vacuum and students observed the water as it appeared to boil. Studdents inferred that there had been a change in the kinetic energy of the water, yet were confused about why the flask did not feel warm, as well as the appearance of condensation on the flask which had not been boiling. Whole class review reinforced the student comprehension of atmospheric pressure as well as the concept of gases expanding in volume when held under less pressure. A follow up demonstration is described later in this section.

The next lesson in this part of the unit introduced gas behavior or *The Kinetic Molecular Theory of Gases* (KMT). Following the description of how an Ideal Gas behaves, students were asked to determine if the description fit the example of a law or a theory. Again, they responded independently and then within groups. Emphasis was placed upon the equal importance of both scientific theories and scientific laws, and that one did not become the other. Prior to moving into the specific gas laws, the Combined Gas Law ($P_1V_1/T_1= P_2V_2/T_2$) equation was displayed and variables were identified. Without naming the law itself, students utilized it to create each of its three gas laws during subsequent unit lessons.

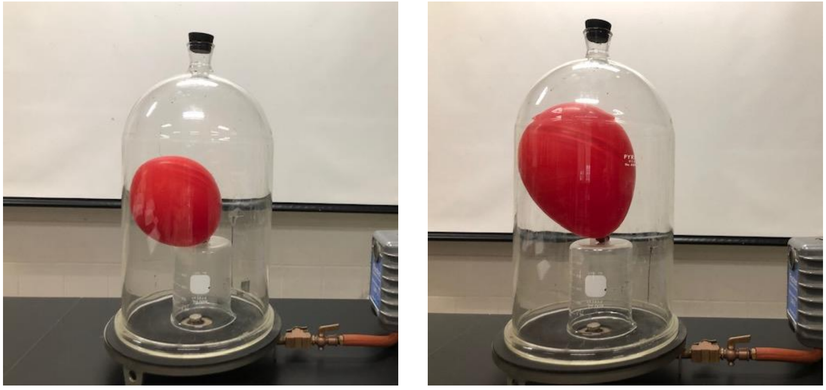
Boyle's Law Lessons

Students started the section on Boyle's Law with an activity. They added a sereis of masses to a closed system (syringe) suspended on a ring stand. The masses under gravitational pull over the same area represented "pressure." Changes involume were obtained by reading the graduations on the syringe. After the data was collected, students followed the same sequence of independent and then group reflections on questions such as: "*What would you need to do to decrease the volume of a closed system such as a syringe? Do you believe this would happen in nature? Would it be the same in most cases"* and "*Which exemplars would relate to this activity?"* Students also created a graphical display of the data and responded to activity related analysis questions. A copy of the quick activity is found in *Appendix B*.

Figure 2. Boyle's Activity

A brief introduction of Boyle as perhaps the "first modern chemist" and his historical contribution to science preceded our review the content for student notes. Students discussed the controversy surrounding Boyle's experimentation and use of empirical data rather than logic and reason. Students were asked to place the statements into a historical context. They were asked how they might respond to a similar situation today. Would they risk their reputations or employment? Here, the exemplars from Appendix H were reviewed to determine which described societal impact upon science. One of the exemplars selected was "*Science and* *engineering are influenced by society, and society is influenced by science and engineering*" (Lead States, 2013a).

As mentioned above, a formative assessment was included prior to moving onto calculations of volume or pressure. Students were asked to predict what would happen to a balloon placed within the vacuum chamber, to check for transfer of understanding from reduced atmospheric pressure upon water molecules (*Figure 1*) to the reduced atmospheric pressure upon the balloon, and the air (N_2 and O_2) within the balloon.



Figures 3a and 3b. Before and after Balloon in Vacuum Pump

To emphasize creativity and imagination within science and the impact of one's prior experience and knowledge, a quick lesson was added. Students were asked to read a section of an online commemoration (Tefloncoat, 2018) of the discovery of Teflon by Roy Plunkett (Appendix C) and following identify terms which they felt demonstrated science. No students recognized terms such as "observe" or "curious" reflect science. For this reason, students were instructed on the impact of our experience and prior knowledge on our observation as outlined by Chalmers' (2013) description of how relevant knowledge may impact experimental conclusions and observations made (Chalmers, 2013). Prior knowledge as well as creativity and imagination were incorporated to notice and then recreate the anomaly and finally the need to communicate this discovery to others. Here, communicating results was also emphasized as part of creativity and imagination.

Charles' Law Lessons

Again, students first completed an activity prior to learning about the next gas law, Charles'

Law. The first part (Appendix C) of the laboratory activity was to demonstrate the impact of temperature upon the observed volume of a balloon and the second part reinforced the impact of temperature upon density of air particles within the flask. Lesson reflections were focused upon the impact of an observed temperature upon the observed volume of a balloon as well as the impact temperature upon the inferred water molecules and or air particles within the system.

Figures 4a through 4d. Temperature's Impact upon Volume

The same method was followed for this laboratory activity. Students made an initial prediction about the activity, then responded to reflection questions independently and within groups. Questions included: "*What happened to the volume of the balloon as the temperature increased*?", "*What happened to the volume of the balloon as the temperature decreased*?", "*What two substances inside of the balloon may have been changing its volume? Are you able to see both of them at the molecular level? What makes you believe they are there*?"

Students created a diagram of the system to include the observed variables and the inferred molecules. Finally, students used their modified Appendix H handouts to provide appropriate exemplars to describe their responses. In addition, a historical perspective of Jacques Charles was discussed in a historical context and his experiment was described. The diagrams were reviewed as a whole class. Students were again able to identify the variables as observable (and they were able to change the size of the V and the T to reflect and increase or decrease), they were also able to demonstrate the change in motion of the gas particles (O_2 or N_2) as well as liquid H_2O increasing motion and vaporizing. Students also demonstrated the vaporized water molecules within the flask. Transfer of understanding was later checked when students were asked to predict, diagrammatically, how a hot air balloon is able to fly.

Similar to the previous section, we turned to the student chapter study guides. Students were readily able to describe the impact of temperature upon volume (as the temperature was increased the volume increased, and as the temperature was decreased the volume decreased). They considered this to be a law due to their inability to provide an example from nature which opposed this observation for gases. When asked if they observed or inferred the O_2 or N_2 expand the students stated this was an inferred aspect of the Kinetic Molecular Theory. Students were able to extrapolate Charles' Equation readily from the Combined Gas Law. We then added the graph to their notes.

Gay-Lussac Lessons

In this lesson, students were asked to predict what would happen to a sample of gas held within a rigid container when heat was added. Here, a YouTube video was incorporated as a demonstration, where hairspray was placed into a fire. Most students had predicted that the result would be explosive, however they were not all able to explain the reason at the molecular level. We returned to the discussion of pressure and that the pressure of a gas is caused by collisions with other gases or its container. As the instructor discussed the gas particles within the rigid container, a steady tapping of her hand on the whiteboard increased as the temperature increased, representing gas particles colliding with their container. The instructor asked students what happened to the pressure as the kinetic energy caused more collisions on the container. The instructor then asked students "Until when?" Students generally responded that the collisions increased the pressure within the container until the pressure exceeded the constraints of the can.

Whole class discussion included which aspects of the law were observed, and where the kinetic motion was inferred and therefore, theoretical. This part of the chapter was a third iteration and students quickly responded to the law versus theory, they quickly described the behavior of the gases as temperature went up or down, and the impact upon pressure. They readily identified Gay-Lussac's Equation ($P_1/T_1= P_2/T_2$). Here, students transcribed the common misconceptions in mathematical calculations soliving for temperature as delineated in the previous section and began working on a practice problems within cluster groups. We reviewed the first problem as a whole class, and students were then given time to complete the remaining practice within groups.

Visual Display

Students were provided with a handout describing a review poster to be created within their groups. The display had eight prompts for students to complete within their groups. This was both an assignment and an opportunity for bonus points. The minimum expectation was to include the Combined Gas Law and then at least one of the three gas laws (Boyle's Law, Charles' Law and / or Gay-Lussac's Law) we had discussed. Many groups addressed more than one gas law to win the competition. The prompts included:

a. Provide a historical perspective of the person responsible for the Gas Law(s)
b. Provide an example of how the Gas Law was used as the result of this history
c. Provide an example of the Gas Law in a laboratory setting
d. Provide a calculation for the Gas Law
e. Demonstrate KMT as it relates to the Gas Law This may include any theoretical aspect of gases which you have discussed, see me if you have questions,
f. Provide and explain where you observed science in prompts 1, 2 and 4. Include the exemplars and explanation as they apply to each question. Then list one SEP and CCC which applies and
g. Predict where you might encounter Gas Laws during your summer vacation.

Students were allowed to begin the visual display prior to the one laboratory period which was allowed for its completion, as long as they worked while they were in class. The platform (Canva™) had been utilized in prior classes. In this assignment, the students demonstrated the ability to respond to each of the prompts correctly for both the content and the science. The group whose display was posted had included with minimal error an example for each prompt using each of the three gas laws.

Summative Assessment

Students generally complete error analysis following summation, where they identify and revise errors in their responses. Points may be awarded to students after they have completed the analysis. In the case of the gas laws quiz, students scored above average and precluded the need for error analysis. Many students mentioned that the reflections completed as we moved through each section of the chapter reinforced their understanding of the content itself. Adding that the independent reflection and explanations of selected exemplars had them think about the content more than usual, and they felt they understood it more.

Data Collection

Data collection consisted of instructor teacher/researcher log which included an overview of attendance, the lesson, student successes (for example, the ability to identify specific concepts as a theory as a law and select appropriate exemplar), any apparent challenges or clarifications that might be needed in future lessons, and other pertinent observations or reflections. Student work was monitored for overall correctness and growth as students first incorporated grade level exemplars into their reflections (written and verbal). The test instrument was the Views on the Nature of Science Form B, or "VNOS-B" (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002) consisting of six questions (the sixth question of seven had been omitted from the initial pre-interventional questionnaire and for consistency was administered for the post-interventional questionnaire).

The VNOS-B is a questionnaire which has been administered and found to be a reliable measure of science epistemology. Construct validity was established by Lederman et al., (2002) and in multiple subsequent analyses. Although the questionnaire may be followed by a percentage of semi-structured interviews, permissions precluded the inclusion of such interviews for the ten participants in this action research study. A post-intervention questionnaire (VNOS-B) was administered following the unit lessons, just prior to the discussion of the Ideal Gas Law. The pre- intervention questionnaire (VNOS-B) was administered prior to the study and remained unanalyzed until the end of the post-test.

Data Analysis

The data analysis included the coded review of pre-intervention versus post-interventional responses on VNOS-B questionnaires. The data was analyzed using previously published coding (Akerson et al., 2019). A minimum of 50% of the participant responses coded by the primary author underwent expert to establish inter-rater reliability. Inter-rater reliability was very good, and 100% consensus was reached upon a collaborative review of the data.

The student participant's academic standing or need for resources such as individual educational plans (IEPs) or 504 modifications were not indicated. All students (participants or not) were administered the same assessment, without modifications. The instructor chose to administer the questionnaire in this manner to ensure that the student was responding without interference or without the instructor reading a potential participant's work. Future iterations of this work would allow an alternative test administrator or modifications. Regardless of their educational status, students who needed extra time to complete the questionnaire would have been allowed to do so with a gatekeeper, as the assessment was reduced to 40-minute periods. One student (who may or may not have been a participant) approached to state they had not completed one response. The student was assured that their work would not impact their grade and that if they wanted to speak with a gatekeeper about completing the question they may, yet it would be fine if they left the questionnaire "as is."

Rating

The participant responses were distributed for analysis from the gatekeeper. Each participant's work was numbered with their assigned numerical identity; the pre-interventional responses were identified in pencil, while the post-interventional responses were numbered in marker and separated from the initial questionnaires. A Google document was created onto which each of the participant responses was dictated using voice recorder. The document was reviewed, comparing the transcription to the written hard copies. Adjustments to the transcriptions were made when apparent errors were noticed. In a few cases, words were illegible and the intent was inferred. These inferences did not appear to impact the overall rating of any specific responses.

#	Yr	M/F	Abs Year /Sstudy	Pre 1	Post 1	Pre 2	Post 2	Pre 3	Post 3	Pre 4	Post 4	Pre 5	Post 5	Pre 6	Post 6
1	10	F	0 and 0	Ad	I	Ad	I	In	Ad	In A	Ad	Ad	Ad	In A	Ad A
2	11	M	6 and 2	In	Ad A	In	I	In	Ad	Ad	Ad	In	In	In A	Ad A
3	11	M	5 and 2	In A	Ad A	A In	In A	In	Ad	In	Ad	Ad	Ad A	In A	Ad A
4	10	F	1 and 0	Ad	I	Ad	Ad A	In	In A	Ad	Ad A	Ad	I	Ad	I
5	11	M	20 and *4	Ad	Ad	In A	In A	In	In	A In	In A	A In	In A	In	Ad
6	11	M	3 and 2	In	Ad A	In	In A	In	In A	In	Ad	Ad	Ad	In	Ad A
7	10	M	1 and 0	In	I	In	Ad	In	In A	In	In A	Ad	Ad A	In	Ad A
8	12	M	2 and 0	In A	Ad	In	Ad	In	I	In	In A	In	Ad	A In	Ad A
9	11	F	4 and 1	In	Ad	In	In A	In	In	In	Ad	Ad	Ad A	In	Ad A
10	11	M	8 and 0	In A	Ad	In	Ad A	In	Ad	In	In A	Ad	Ad A	In	In

Figure 5. Student Ratings

Student responses were rated according to a coding chart created by Akerson et al. (2019). Initially, students were rated as approaching inadequate (A In), inadequate (In), approaching adequate (In A), adequate (Ad), approaching informed (Ad A) and informed (I). These ratings were performed to gain an overall understanding of improvements made by the participants. The analysis was then completed combining the categories into simply the three listed (Inadequate, Adequate and Informed). To distinguish written responses from blank responses, an additional rating of “approaching inadequate” was applied to limited responses such as “I don’t know.”

Due to the anonymous nature of student participants, the analysis of teacher/researcher notes was a qualitative review of instruction and student responses. The teacher-researcher sought patterns in the notes to determine influences on student understandings, and to ensure the teacher was delivering NOS instruction as intended. The data included a daily overview of attendance, instructor reflections on the lesson, successes and challenges for either students or the instructor, specific adjustments needed in future lessons, and other pertinent observations or reflections related to the unit lesson. Daily reflections following each lesson are the practice of the instructor, and in this case enabled the instructor to note the interactions between students, instructor, and content. These reflections were more detailed during the action research and included a general overview of student work (written and verbal) which had been monitored for both correctness and growth in conceptions. In addition to the daily reflections from the instructor’s journal, reflections were also maintained in an electronic journal specific to the action research and concurrent self-study, or as voice memoranum. All notes were transcribed into a common electronic document, where patterns were noted and will be presented in the results section.

Results

The purpose of this action research study was to examine the impact of explicit and reflective embedding of nature of science (NOS) within a chapter on The Gas Laws. Table 3 below will demonstrate the results of student pre and post VNOS-B questionnaires. The table includes the overall percentage of student participant scores when using a previously developed coding chart for responses to the six question VNOS-B questionnaire. Each of the ten participants’ data was included in the analysis, including participant 5 who was absent five (5) times, with the fifth absence occurring on the day of the post assessment. Table 3 reflects the pre-interventional and post-interventional responses of VNOS-B responses coded using the coding table located in Appendix E.

Table 3. Pre and Post VNOS-B Questionnaire

Question	Pre Intervention %	Post Intervention %
1: *Tentative Nature*		
Inadequate	70	0
Adequate	30	70
Informed	0	30
2: *Obs. v Inference*		
Approach Inadequate	10	0
Inadequate	70	40
Adequate	20	40
Informed	0	20
3: *Theory v Law*		
Inadequate	100	50
Adequate	0	40
Informed	0	10
4: *Creativity and Imagination within Science.*		
Approach Inadequate	10	0
Inadequate	70	40
Adequate	20	60
Informed	0	0
5: *Creativity and Imagination within Scientific Method*		
Approach Inadequate	10	0
Inadequate	20	20
Adequate	70	70
Informed	0	10
6: *Social and Cultural Influences on Science.*		
Approach Inadequate	10	0
Inadequate	80	10
Adequate	10	80
Informed	0	10

Tentative Nature of Science

The first question on the VNOS-B questionnaire asks: “After scientists have developed a theory (e.g., atomic theory, kinetic molecular theory, cell theory), does the theory ever change? If you believe that scientific theories do not change, explain why and defend you answer with examples. If you believe that theories do change: (a) Explain why. (b) Explain why we bother to teach theories. Defend your answer with examples.”

When reviewing the data, prior to intervention the majority of students (70%) had inadequate views on the tentative nature of science, and the remainder (30%) appeared to have adequate views. A few students appeared to conflate the term theory with that of a hypothesis. Post intervention demonstrated growth in most students, with the majority (70%) demonstrating adequate understanding. The remaining students (30%) demonstrated informed understanding.

> Examples of *inadequate* statements include:
> A student conflating the term theory with that of a hypothesis “... if there is a theory on micro-plastics in the ocean this can change depending on if there are more or less micro-plastics in the ocean.”
> Examples of *adequate* statements include:
> “The theory can and should only change when new evidence has been presented in a new light that has contradicted or contrast with previous evidence.”
> Examples of *informed* statements include:
> ” ... theories can possibly change over the course of time because of science advances technology also advances. With these ever and improving inventions scientists will be able to see and understand more about what they theorized. And with new discoveries older theories could be replaced or built upon... it creates a purpose to grow and expand in scientific knowledge.”

In the examples we see an inadequate understanding in which as student response conflates the term theory with that of a hypothesis. In the adequate statement the student has indicated new evidence may prompt changes in science. Finally, the informed statement has progressed to indicating new evidence may change science, rather the theories may be reinterpreted.

Observation versus Inference

In the second question "Science textbooks often represent the atom as a central nucleus composed of positively charged particles (protons) and neutral particles (neutrons) with negatively charged particles (electrons) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine the structure of the atom?"

Prior to the intervention, the majority of students were inadequate (70 %), with approaching inadequate (10%) views regarding observation and inference, and the remainder (20%) appeared to have adequate views. Following the intervention most students demonstrated growth. The majority of participants (60%) demonstrated either adequate (40%) or informed (20%) understanding and only (40 %) remaining at or improving to inadequate understanding.

> Examples of *inadequate* statements include:
> "They have been able to see an atom with an unbelievably powerful microscope..."
> Examples of *adequate* statements include:
> "...evidence that scientists use to determine the structure of the atom came from compiling results from a variety of tests regarding subject matter an example of this would be the gold foil experiment.." and from the next question "...inference based on visual evidence from nature experiment etc., to explain what is happening even if it is not visible to the naked eye."
> Examples of *informed* statements include:
> "I think that the specific evidence that scientists have found is very little but in fact most of their views come from inference. This subject leads back to the previous question where we believe we know what it [the atom] looks like we have not actually seen it however there is new evidence for a new way to see a scientist may change their views and make a new permanent model of the atom"

In the example, the student's inadequate statement suggests that a powerful microscope may allow scientists to observe that which is inferred. They do not appear to understand that the atomic model is inferred. The next statement suggests an understanding of both the inferred nature and changes to the model based upon continued experimentation. In the informed statement, the student has suggested that experimentation has resulted in a level of certainty, despite the model being inferred not observed. They also suggest that new evidence might lead to reinterpretation of existing models of the atom.

Theory versus Law

The third question "Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer "reflects the participants' knowledge regarding theory versus law. The literature suggests that theory versus law is a commonly misunderstood aspect of science and for this reason it was stressed during the study. When reviewing the data, prior to intervention the majority of students (100%) had inadequate views regarding theory versus law. Post intervention demonstrated growth in most students, with (50%) demonstrating either adequate (40%) or informed (10%) understanding and the (50 %) remaining at an inadequate understanding demonstrated growth as well.

> Examples of *inadequate* statements include:
> "A theory would be you would test it out in an experiment to see how accurate the theory is... It is ... what can happen. A law is what will happen."
> Examples of *adequate* statements include:
> "An example of this is the atom versus the gas laws. There are multiple theories about the atom throughout time that were changed and built upon such as the addition of electrons, protons and neutrons or the fact that there is a nucleus. This is different from the gas laws because while the gas laws has reacted the same way and in experiments and has variables that can be observed what an atom looks like cannot be observed."
> Examples of *informed* statements include:
> "...the scientific theory is an inference based on visual evidence from nature experiment etc., to explain what is happening even if it is not visible to the naked eye...A scientific law is an explanation for a natural phenomenon that will remain true and always happen with the assumption that it will remain the same in the future."

In the example, the student's inadequate statement the student has used the term theory as a hypothesis, while suggesting when the theory occurs it is called a law. In an adequate response, although the student has indicated that theories and laws represent a different form of knowledge, for instance observed versus inferred, they have not indicated that a theory may be used to reinforce a law. In the informed sample, the student suggests that the theory is an inference based upon observed behaviors and that a law is an explanation of phenomenon. They also suggest a law may change in the future.

Creativity and Imagination as it relates to Human Endeavor or Science

The fourth question, "How are science and art similar? How are they different? "may be used to establish an understanding of creativity and imagination as it relates to science.

When reviewing the data, prior to intervention the majority of students, (70%) had inadequate views regarding creativity and imagination; (10%) were approaching inadequate, and the remainder (20%) appeared to have adequate views. Although post intervention demonstrated growth in most students, the majority demonstrated adequate understanding (60%), the remainder (40 %) either remains at (30%) or improved to (10%) inadequate understanding.

> Examples of *inadequate* statements include:
> "Science and art are similar because both use ways to show life in different ways. Science uses experiments to prove or theorize about the world or specific things in the world. Art shows life in more creative ways by expressing life through different things like painting, writing and making music."
> Examples of *adequate* statements include:
> "Science and art can be similar and different they are similar because they both require creativity and thinking outside of the box. They also are a way to express or show how things are. They are different because science you have to come up with explanations and data, in art you usually just explain what happened by the painting, drawing, creation you make.."
> Examples of a student *approaching informed* statements include:
> "Science and art are very similar in relation to creativity trial-and-error experimentation and expressing ideas, even if they're not in the same way. With the common process of thinking outside of the box and creating unique ways to complete or prove something, art and science can be seen as similar... (on) the other hand, science and art can be different in the ways of communicating. While an artist is prone to allowing the viewer to interpret the piece as they please, scientists are strict about details and making sure to communicate exactly [what] went on in an experiment so that another may be able to repeat it exactly."

In the inadequate example, although the student is expressing the creative nature of experimentation, they are remiss in a description of gathering evidence or communication to others. The second student is adequately including the evidence or data gathered when conducting science. The final statement has included the creative nature of both art and science, while indicating the need to communicate the findings, interperate and replicate the work.

Creativity and Imagination (Myth of the Scientific Method)

The fifth question "Scientists perform experiments/investigations when trying to solve problems. Other than in the stage of planning and design, do scientists use their creativity and imagination in the process of performing these experiments/investigations? Please explain your answer and provide appropriate examples" will again reflect the participant's awareness of human endeavor, yet in this question the emphasis is upon the need for creativity within the scientific process goes beyond experimental design. The scientific method, when viewed through the lens of creativity and imagination did not appear to change significantly when reviewing participant responses.

When reviewing the data, prior to intervention the majority of students, approaching inadequate (10%) and inadequate (20%) views were coded with respect to the creativity and imagination aspect of the scientific process, and many (70%) were at the adequate level. Post intervention demonstrated growth in most students, with the majority (70%) were still demonstrating adequate understanding, with growth to inadequate (10%) and to informed (10%). Most students within the adequate rating had improved to approaching informed (40%).

> Examples of *inadequate* statements include:
> Here the student appeared to confuse being a student working with a specific laboratory procedure to that of an investigative scientist "...a scientist have the option to be creative [in the] process they would... if scientists do as they please on an experiment they could seriously mess up the experiment and create dangerous chemical reactions..."
> Examples of *adequate* statements include:
> "Scientists have to be creative when doing or conducting experiments. The way an experiment is made in the first place is creativity and Imagining the future outcome of something while making it. For Boyle's Gas Law formulating all the necessary steps

and procedures to see the outcome consistently requires a lot of planning, trial and error and creativity. Not every person can just come up with an experiment that will help prove something. It takes a specific kind of person with a combination of endurance to try again and reimagine."

Examples of *informed* statements include:

"Absolutely, when something is discovered in the experiment a scientist must go back and find the exact point that something not predicted occurred and then use their creativity and imagination to explain happened. With something new in science there is little to nothing that a scientist can fall back on when trying to understand what happened and with the use of creativity in human endeavor the scientist could think of new experiments new technology that could explain the occurrence."

The student's inadequate statement has incorrectly suggested that scientists are confined to a specific procedure. While the next statement adequately demonstrates the student is aware scientists include creativity and imagination in all stages of investigations, they have not discussed interpretation or collection of data. The final statement demonstrated an understanding that each part of the scientific process requires creativity and imagination. In addition, the student explains observations may provide novel insights from which scientific knowledge may be discovered.

Social and Cultural Impact or Theory Laden Nature of Science

The sixth and final question of this VNOS-B "In the recent past, astronomers differed greatly in their predictions of the ultimate fate of the universe. Some astronomers believed that the universe is expanding while others believed that it is shrinking, still others believed that the universe is in a static state without any expansion or shrinkage. How were these different conclusions possible if the astronomers were all looking at the same experiments and data?" provides the participants with an opportunity to demonstrate an understanding of societal and cultural impacts, or the theory laden nature of science.

When reviewing the data, prior to interventions the participant sample was predominantly inadequate (80 %) with (10%) approaching inadequate and the remainder (10%) coded at adequate. Post interventional responses demonstrated improvement, with only 10% of the responses inadequate, 80% growing to adequate and 10% scored informed understanding.

Examples of *inadequate* statements include:

"They all believe that something is happening to the universe we all think that the size of the universe is going to be different in size."

Examples of *adequate* statements include:

"..there is more than one way to explain how something work..."

Examples of *informed* statements include:

"This conclusion could vary by interpretation of the data and the background / histories of the astronomers. While others may know different information from past experiments and others understand other information then data can be taken differently."

In the examples we see an inadequate understanding where the student is suggesting that the scientists agree there is something happening in the universe and dismiss the different opinions. An adequate statement is simple, yet suggests that data may be interpreted differently. Finally, the informed statement has demonstrated an understanding that diverse cultural backgrounds may result in data being interpreted differently historically, impacting current interpretations.

Field Notes

Instructor field notes taken during lessons in reference to both the aforementioned science tenets and content comprehension were either aligned with or demonstrated an underestimation of understanding in the VNOS-B responses of the student participants. The instructor did observe growth regarding both the method employed and the use of exemplars selected in responses during the unit lesson. Additionally, the benefit of discussing independent reflections within their groups and then as a whole class was evident.

For example, during the first lesson when asked *"Was Torricelli able to see atmospheric pressure?"* A student may have responded that he (Torricelli) was able to see the atmospheric pressure and he would use the equation P = Force / Area to do so. The same student may then revise their response during the group reflection to indicate that he could not see it (atmospheric pressure) but that he saw the effects of it.

Field notes suggested that students had more difficulty locating an exemplar which described *observation versus inference* in this part of the unit lesson. They may have deferred to the category here "Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena" or they may have simply described inference in their own words. Students generally were more successful locating the second exemplar *"Provide an exemplar which explains the development of the barometer following the manometer."* Here, the majority of students and their groups selected "*Technological advances have influenced the progress of science, and science has influenced advances in technology*" or "*Scientific investigations use diverse methods and do not always use the same set of procedures to obtain data*", a few of the groups cited the exemplar "*New technologies advance scientific knowledge*" (Lead States, 2013a).

During the discussion of The Kinetic Molecular Theory (KMT) students were again asked to respond to reflection questions corresponding to gas behaviors. When asked specifically if the gas behavior was a law or a theory, those students who described the behavior as a law when working independently (about 20 % of those observed) were able to adjust their reflections when reviewing within cluster groups. For example, some students described the gas behavior as a law when working independently and then adjusted their reflections to suggest the behavior was a theory because "the particles are not observed." The most common exemplar cited here was "*A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that a theory does not accommodate, the theory is generally modified in light of new evidence*" abbreviated to "*A scientific theory is an explanation of some aspect of the natural world*" (Lead States, 2013a).

As students responded to the reflection questions following Boyle's Activity and subsequent lessons on Boyle, the majority of students were able it identify Boyle's Law as a law and not a theory, citing similar exemplars. Students who were asked to describe the first activity (Boyle's Activity or the syringe activity), the majority of students readily expressed that as the pressure was increased the volume of the closed system would decrease. When asked to provide an exemplar from Appendix H which described the work they had completed in the laboratories, there were a variety of exemplars selected. An example of a student adjusting their exemplars included to describe their activity may have started with *"Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and will continue to do so in the future"* and adjusted this to "*Scientific investigations use a variety of methods, tools, and* *techniques to revise and produce new knowledge"* (Lead States, 2013a). Students located and described subsequent lessons on Charles' and Gay Lussac's Law's correctly.

Field notes also indicated that students were readily able to both identify each gas law equation as well as label the gas law as "a law." In addition, students were able to verbally describe or provide a written prediction of what happened with one variable as the other changed, for each gas law. During class observations, most students were able to distinguish between observed changes versus those which were inferred (gases within a balloon, for example) on diagrams created both independently and following group collaboration.

When asked to identify relevant exemplars for lessons which included either historical perspectives, such as the experimentation completed by Jaque Boyle, students generally included "*Science and engineering are influenced by society, and society is influenced by science and engineering*." as well as "*Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues*."

Overall, students demonstrated an advanced ease of use and locating appropriate exemplars which reflected various aspects of science observed in activities, equations or content. Notes on the ability to complete practice problems while observing student work would reflect strong comprehension of the Gas Laws, and the ability to solve problems. The common issues which accompanied a small group of students were the lack of units of measure when completing calculations. Visual displays and summation were also evidence of student comprehension of both the science and the content reviewed. The majority of the displays scored in the high B to A range, and the majority of student groups correctly incorporated Gas Laws, History, Sample Calculations, CCC's, SEP's, NOS, and even where they might encounter the Gas Law or Gas Laws selected during summer vacation. The group which was selected as the winning display included all three gas laws, and each criteria correctly.

Discussion

In response to the first research question "*What is the impact of explicit and reflective NOS (Appendix H) embedded within a unit lesson on The Gas Laws and Kinetic Molecular Theory upon secondary school students' understanding of NOS?*", the results of the VNOS-B comparisons between pre-intervention and post-intervention responses suggested that there was an overall improvement in student understanding of NOS for each aspect described. The most substantial improvements appeared to occur within participant understanding of the tentative nature of science, observations versus inference and the social and cultural impacts on science. In addition, substantial growth was observed within student understanding of theory versus law, however, it is possible that the participant responses did not reflect their overall understanding of laws, and that they were impacted by the wording of Appendix H grade level exemplars such as "*Science assumes the universe is a vast single system in which basic laws are consistent*" (Lead States, 2013a). The participants demonstrated less growth in their understanding of scientific process otherwise known as "The Myth of the Scientific Method" (Lederman, 2010). The apparent lack of growth may have been due to many of the pre-interventional responses rated as adequate, as well as the need to specify the term "data" within responses when rating a response as informed.

There does appear to be a benefit to the explicit and reflective inclusion of nature of science aspects derived from the exemplars of Appendix H (Lead States, 2013a). The method included independent and cluster group reflections, followed by who class review. It also included the use of hands on activities and the creation of models or diagrams to reflect understanding. The use of demonstrations and hands on activities prior to instructor discourse on the content was quite successful with this content. Students generally demonstrated the ability to construct their own understandings of each gas law as a community of learners. The inclusion of historical references also appears to be beneficial in student understanding of both content and NOS.

As addressed in the conclusion, the benefits of explicit and reflective embedding of NOS within an NGSS science classroom may also impact student content comprehension. Instructor field notes regarding multiple student discussions indicated that students described reflecting upon science as a positive impact upon their understanding of the Gas Laws. As was discussed in the conclusion, overall students demonstrated growth when discussing the Gas Laws as they related to NOS, specifically when providing evidence in the form of grade level exemplars located on Appendix H (Lead States). It is also notable that the participant who has been absent for multiple days during the academic year, as well as during the action research study showed the least growth in understanding.

The literature does suggest that the explicit and reflective embedding of NOS within the delivered instruction appears preferable to that of implicit delivery. The literature emphasizes common misconceptions in science and in understanding its nature. Frequently, students, and even educators, misunderstand the concept of theory versus law; or expect what a scientist says to be "set in stone" not understanding science as a human endeavor which is tentative. Again, research has shown that students require explicit connections of the content with science (Akerson et al., 2000; Khishfe & Abd-El-Khalick 2002; Lederman, 2007). Therefore, these findings further support the work which has been outlined regarding NOS in a general context. As with the previous work, explicit and reflective embedding of NOS within the unit lesson have increased participant understanding of NOS concepts, as demonstrated by post-interventional responses to the VNOS-B questionaire. In this introductory action research, we have also demonstrated NOS may be explicated by the use of grade level exemplars located on pages 5 and 6 of Appendix H.

When considering the ability to transfer a general list of NOS target aspects to categories and specific grade level exemplars, as outlined in the second research question "*Are students able to identify transition NOS target aspects on categories and specific grade level exemplars of Appendix H*", the data from which to extract evidence resides within instructor field notes. Due to the anonymous nature of student participants, empirical data was not utilized, however the previously described field notes and uncoded analysis indicate that students make significant progress in their ability to transition from a discussion of NOS target aspects or tenets, to more specific categories and exemplars over the course of a unit lesson on the gas laws.

An unintended outcome from this action research is reflected previously in the literature. It has been suggested that students who are engaged in these instructional strategies (explicit and reflective discussion of NOS) demonstrate not only an improved understanding of science but a concurrent increase in growth within the specific content itself (Abdallah, 2018; Peters, 2012). According to multiple discussions and instructor field notes, students indicated that the reflections readily made the content easier to comprehend. As they explained, by thinking about the science they first needed to understand the content.

Conclusion and Implications

This action research study has been completed within an NGSS secondary science classroom. However, it should be noted that the study has been completed during a period of extensive field trips and student quarantining due to the ongoing COVID-19 protocols. In addition, it should be noted that this was academic year marked a “return to normal” (as much as possible) for the students within this particular action research study.

Although delayed field trips are unavoidable, the timing of an action research study should be taken into consideration. Future work within this area may be improved by selecting a part of the academic calendar which is not often impacted by an abundance of absences or state testing. Despite having initiated the implementation of NGSS standards between the years 2014 and 2015, the delivered instruction for science students was impacted in March of 2020, and *The Framework* was abbreviated in its delivery.

It is also worth noting that the student participants were not identified, and the questionnaires were not modified to accommodate students with educational plans (IEP’s or 504’s). Students who needed additional time, regardless of their academic standing would have been allowed at least ten minutes. However, only one student expressed this need and they were referred to the gatekeeper. The instructor was unaware of any additional work completed by this student. Future iterations of this work will include modified questionnaires and possibly proctors who are not concurrently classroom educators and educational researchers.

As outlined in both the background sections and in the conclusion, the study has both reinforced existing literature and provided novel insights regarding NOS instructional strategies within an NGSS classroom. The lessons exemplified the efficacy of connecting activities and demonstrations conducted by students to science, itself (Akerson, Abd-El-Khalick, &Lederman, 2000; Khishfe & Abd-El-Khalick 2002; & Lederman, 2007). The use of specific science tenets such as: observation versus inference, distinction between laws and theories, scientific knowledge is partly empirical, scientific knowledge is subjective (theory laden), science is a human enterprise, scientists are a product of culture, and scientific knowledge is tentative (Lederman, 2007) has been the primary method of embedding NOS within science content in previous research. This study has successfully introduced the method of utilizing the NGSS Appendix H itself, with the accompanying grade level exemplars of each category (refer to Appendix A), rather than the succinct list of tenets. While not suggesting one method of explicating NOS within the classroom is preferable, it is important NGSS classroom educators receive professional development on both NOS tenets and the use of Appendix H as a classroom resource.

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Appendix A. Modified Appendix H (Handout)

Modified From Appendix H:
Understandings About the Nature of Science

Categories	High School	NOS Aspect(s)
Scientific Investigations Use a Variety of Methods	Scientific investigations use diverse methods and do not always use the same set of procedures to obtain data. New technologies advance scientific knowledge. Scientific inquiry is characterized by a common set of values that include logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. The discourse practices of science are organized around disciplinary domains that share exemplars for making decisions regarding the values, instruments, methods, models, and evidence to adopt and use. Scientific investigations use a variety of methods, tools, and techniques to revise and produce new knowledge.	
Scientific Knowledge Is Based on Empirical Evidence	Scientific knowledge is based on empirical evidence. Science disciplines share common rules of evidence used to evaluate explanations about natural systems. Science includes the process of coordinating patterns of evidence with current theory. Scientific arguments are strengthened by multiple lines of evidence supporting a single explanation.	
Scientific Knowledge Is Open to Revision in Light of New Evidence	Scientific explanations can be probabilistic. Most scientific knowledge is quite durable but, in principle, is subject to change based on new evidence and/or reinterpretation of existing evidence. Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.	
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena	Theories and laws provide explanations in science, but theories do not with time become laws or facts. A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment. The science community validates each theory before it is accepted. If new evidence is discovered that a theory does not accommodate, the theory is generally modified in light of new evidence. Models, mechanisms, and explanations collectively serve as tools in the development of a scientific theory. Laws are statements or descriptions of the relationships among observable phenomena. Scientists often use hypotheses to develop and test theories and explanations.	

Science Is a Way of Knowing	Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise, and extend this knowledge. Science is a unique way of knowing, and there are other ways of knowing. Science distinguishes itself from other ways of knowing through the use of empirical standards, logical arguments, and skeptical review. Scientific knowledge has a history that includes refinement of, and changes to, theories, ideas, and beliefs over time.	
Scientific Knowledge Assumes an Order and Consistency in Natural Systems	Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and will continue to do so in the future. Science assumes the universe is a vast single system in which basic laws are consistent.	
Science Is a Human Endeavor	Scientific knowledge is a result of human endeavor, imagination, and creativity. Individuals and teams from many nations and cultures have contributed to science and to advances in engineering. Scientists' backgrounds, theoretical commitments, and fields of endeavor influence the nature of their findings. Technological advances have influenced the progress of science, and science has influenced advances in technology. Science and engineering are influenced by society, and society is influenced by science and engineering.	
Science Addresses Questions About the Natural and Material World	Not all questions can be answered by science. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions. Scientific knowledge indicates what can happen in natural systems—not what should happen. The latter involves ethics, values, and human decisions about the use of knowledge. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.	

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Adapted from https://www.nap.edu/read/18290/chapter/14#434

Appendix B. Boyle's Activity

Name__________________ Date____________

Chemistry: Boyle's Activity

Predict: What will happen to the volume of the closed syringe when pressure is applied?

Materials:

Ring Stand, Weights, Syringe apparatus, Test tube clamp

See example!

Procedure:

1. Clamp the syringe so that the clamp supports the syringe. **Not too tight to limit motion.
2. Place the clamp and syringe so that the syringe points down.
3. Open the syringe clamp and pull the plunger out so the **maximum volume** is shown.
4. Close the clamp!
5. Record the **starting volume (no weight)** on a data table
6. Place 400 grams on bar of the syringe (make sure you "spot" the weights you are adding).
7. Record the volume of the syringe with 400 grams on a data table. Estimated digits please.
8. Carefully repeat steps **6 and 7 until 2000 grams** are on the syringe.
8. Repeat steps 3-8.
9. Clean up.
10. Ambient temperature ____________________

Data table:

Trial #1 Trial #2

Mass (g)	Volume (cc)	Mass (g)	Volume (cc)
400		400	
800		800	
1200		1200	
1600		1600	
2000		2000	

**We will use the mass to reflect pressure here.

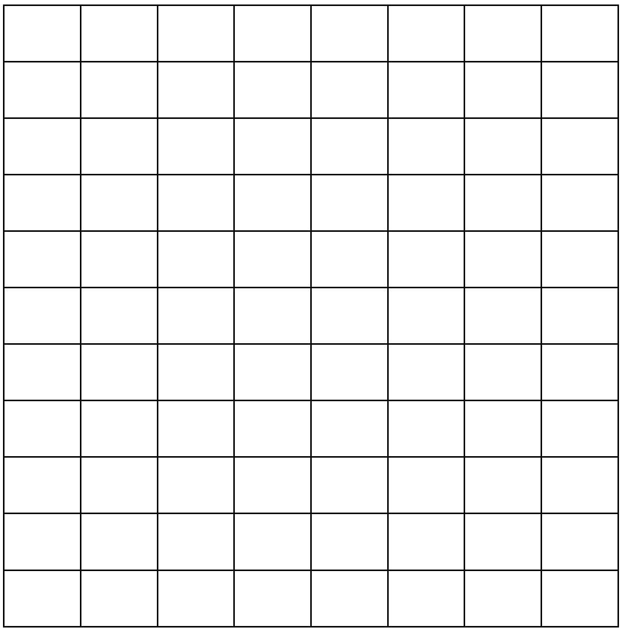
Conclusion: (Answer questions in **complete sentences** on the back of the graph)

1. What remained constant during the experiment? P, V or T?

2. What did you observe that may reflect the properties of a gas?

3. Will the volume of the syringe ever reach zero? Why or Why not?

Graph: Create a **curve of best fit** for **each trial** on the graph. Use dashed line for trial one and a solid line for trial two. Make sure the graph is properly labeled with units and a title. The mass **of weights will be on the x-axis** and **volume on the y-axis**.



Reflections (Complete independently first – **on your notes sheet) (This was a separate page)**

A. What would you need to do to decrease the volume of a closed system such as a syringe?

B. Do you believe this would happen in nature? Would it be the same in most cases?

C. Diagram the system. Include any gas particles, and the direction of the variables (we will review this together, do your best!)

D. Which exemplars would relate to this activity? Why?

Appendix C. Teflon Discovery

Please read the following passages from a post by tefloncoat (2018) and respond to the questions that follow.

The Father of Teflon

Roy Plunkett was a 27-year-old American research chemist working for E.I. du Pont de Nemours and Company in Deepwater, New Jersey in 1938. A veteran of the company for only two years (he graduated with a Ph.D. in chemistry from Manchester University in 1936), he was trying to create a non-toxic refrigerant for the company when he instead stumbled upon a new chemical reaction.

Plunkett was experimenting with a gas chemical called tetrafluoroethylene and noticed that it had stopped flowing inside its pressure bottle. This occurred before the bottle's weight could drop and register as empty. Curious about what was causing the weight, Plunkett sawed the bottle open.

Inside was a white powdery substance that proved to be chemically inert. This means it did not react with any other substances. It was also very slippery.

Teflon's chemical name became polytetrafluoroethylene, or PTFE. Its molecular structure is made up of spirals of carbon atoms each attached to two fluorine atoms.

This carbon-fluorine bond is very tight, which is why a Teflon surface can easily resist food, water, and other substances. It also acts as a superior protectant. In fact, not even a gecko lizard — an animal known for its incredible grip — can climb its way out of a Teflon coated pan.

With Plunkett's exciting discovery, several industries immediately recognized Teflon's potential and started putting it to good use.

Roy Plunkett's Legacy

In 1951, the city of Philadelphia awarded Plunkett the John Scott Medal for his invention that promoted the "comfort, welfare, and happiness of humankind". He was also inducted into the National Inventors Hall of Fame in 1985. In 1990, DuPont was recognized by President George Bush with the National Medal of Technology.

Plunkett passed away in 1994 at the age of 83, but his contribution to chemistry and the world lives on.

Reflection Questions: Feel free to write on the back of this page.

1) Which key words do you see in this passage which relate to science (underline them)? Please **explain** your response
2) How did we (citizens) benefit from this science?
3) How does this relate to the question about Boyle's willingness to publish his experiments?

https://www.industrialcoat.com/the-history-of-teflon-polymer/

Appendix D. Charles's Activity

Charles' Activity **Reflections due today**

Write up due: by end of next class.

Predict: *What might you observe when a balloon is placed over the opening of an Erlenmeyer Flask (which contains heated water) and then submerged in an ice bath?*

Safety: ***If you have a latex allergy please observe only!***

- Appropriate PPE (goggles)
- Hot Plate is … HOT!
- Be certain the hotplate cord does not touch the hotplate and unplug it when you are finished.
- Be careful of ice that may fall on the floor.

Procedure: ***(Lab 2)***

1. Set up the ice bath and hot plate as outlined in pre-lab.
2. Double check that the hotplate is plugged in and on "high". ☺
3. Discuss who is doing what ***before*** you begin. Practice moving the flask with the crucible tongs, without placing it in the ice bath.
4. Add ~ 10 ml of water to the flask.
5. Place an un-inflated balloon over the mouth of the flask.
6. Place the flask onto hot plate and leave there *until contents boil*. What do you observe? **Record:**
7. Carefully, use tongs as demonstrated to move the flask from the hot plate to the ice water. What do you observe? **Record.**

If you have time: (Lab 3)

8. Wipe off the flask
9. *Remove* the balloon.
10. Place the flask onto hot plate and leave there *until contents boil*.
11. **Very carefully place the balloon on the flask.**
12. Use tongs as demonstrated to move the flask and let the flask sit on the lab bench.

Was there a difference in what you observed?

Reflections on *study guide:* (Next page)

A. What happened to the volume of the balloon as the temperature increased? What happened to the volume of the balloon as the temperature decreased? (#'s 6 & 7)
B. What two substances *inside of the balloon* may have been changing its volume? Are you able to see both of them at the molecular level? What makes you believe they are there?
C. Diagram what you believe is happening inside the balloon as it is heated and as it is cooled (#'s 6 & 7 only). Identify the variable observed and then the particles inferred.
D. Locate an exemplar to *describe the activity itself* and then *an exemplar to describe either A or B.*

Whole Class Review

Appendix E. Practice Problems adapted from Chemvista.com Cavalcade Publishing

Please set up these problems showing all work for credit.

Complete the following on lined paper – as explained in class. Units are just as important as numbers, so please show units and numbers in each step.

1) 1.00 L of a gas at standard temperature and pressure is compressed to 473 mL. What is the new pressure of the gas? **2.11 atm**
2) The highest pressure ever produced in a laboratory setting was about 2.0 x 10^6 atm. If we have a 1.0 x 10^{-5} liter sample of a gas at that pressure, then release the pressure until it is equal to 0.275 atm, what would the new volume of that gas be? **72.7 L**
3) Atmospheric pressure on the peak of Mt. Everest can be as low as 150 mm Hg, which is why climbers need to bring oxygen tanks for the last part of the climb. If the climbers carry 10.0 liter tanks with an internal gas pressure of 3.04 x 10^4 mm Hg, what will be the volume of the gas when it is released from the tanks? **2.0 x 10^3 L**
4) Submarines need to be extremely strong to withstand the extremely high pressure of water pushing down on them. An experimental research submarine with a volume of 15,000 liters has an internal pressure of 1.2 atm. If the pressure of the ocean breaks the submarine forming a bubble with a pressure of 250 atm pushing on it, how big will that bubble be? **72 L**

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5) The temperature inside my refrigerator is about 4^0 Celsius. If I place a balloon in my fridge that initially has a temperature of 22^0 C and a volume of 0.5 liters, what will be the volume of the balloon when it is fully cooled by my refrigerator? **0.47 L**
6) A man heats a balloon in the oven. If the balloon initially has a volume of 0.4 liters and a temperature of 20 ^{0}C, what will the volume of the balloon be after he heats it to a temperature of 250 ^{0}C? **0.71 L**
7) On hot days, you may have noticed that potato chip bags seem to "inflate", even though they have not been opened. If I have a 250 mL bag at a temperature of 19 ^{0}C, and I leave it in my car which has a temperature of 60^0 C, what will the new volume of the bag be? **285 mL**
8) Some students believe that teachers are full of hot air. If I inhale 2.2 liters of gas at a temperature of 18^0 C and it heats to a temperature of 38^0 C in my lungs, what is the new volume of the gas? **2.35 L**

---

9) Determine the pressure change when a constant volume of gas at 1.00 atm is heated from 20.0 ºC to 30.0 ºC.

10) A gas has a pressure of 0.370 atm at 50.0 ºC. What is the pressure at standard temperature?

11) A gas has a pressure of 699.0 mm Hg at 40.0 ºC. What is the temperature at standard pressure?

12) If a gas is cooled from 323.0 K to 273.15 K and the volume is kept constant what final pressure would result if the original pressure was 750.0 mm Hg?

Appendix F. VNOS – B Questions and Coding

VNOS B Question	Examples for Codes
Question 1. After scientists have developed a theory (e.g., atomic theory, kinetic molecular theory, cell theory), does the theory ever change? If you believe that scientific theories do not change, explain why and defend your answer with examples. If you believe that theories do change: (a) Explain why. (b) Explain why we bother to teach and learn scientific theories. Defend your answer with examples.	Tentativeness: Inadequate: Science does not change. Adequate: Science changes with new evidence. Informed: Science changes with new evidence or reinterpretation of existing evidence.
Question 2. Science textbooks often represent the atom as a central nucleus composed of positively charged particles (protons) and neutral particles (neutrons) with negatively charged particles (electrons) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine the structure of the atom?	Inadequate: Scientists are certain because they saw atoms with microscopes. Adequate: Scientists are pretty sure, but could change their minds with new evidence. Informed: Scientists are pretty certain, as they have made observations and have inferred the model of the atom. They could change their interpretations with new evidence or reinterpretation of existing evidence.
Question 3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.	Inadequate: A theory becomes a law with more evidence. Adequate: Theories and laws are different kinds of scientific knowledge. Informed: Scientific theories are different from scientific laws and seek to explain laws.

VNOS B Question	Examples for Codes
Question 4. How are science and art similar? How are they different?	Inadequate: They are similar because they seek to describe the world. They are different because science requires rules. Adequate: They are similar because they both create understandings of the world. They are different because science requires evidence. Informed: They are similar in that they both seek to create understandings of the world from the human and cultural viewpoint. They are different because science requires evidence, which is then interpreted by scientists to create an understanding.
Question 5. Scientists perform experiments/investigations when trying to solve problems. Other than in the stage of planning and design, do scientists use their creativity and imagination in the process of performing these experiments/investigations? Please explain your answer and provide appropriate examples.	Inadequate: Scientists never use creativity or imagination or they would not come up with true answers. Adequate: Scientists use their imagination and creativity in all stages of investigations. Informed: Scientists use their imaginations and creativity in all stages of investigations to design an appropriate study for the questions they raise, and to interpret the data they collect. From their interpretations of data they create scientific knowledge.
Question 6. In the recent past, astronomers differed greatly in their predictions of the ultimate fate of the universe. Some astronomers believed that the universe is expanding while others believed that it is shrinking, still others believed that the universe is in a static state without any expansion or shrinkage. How were these	Inadequate: They would all agree if they had enough data. They don't have all the data yet. Adequate: All scientists have different backgrounds and may interpret the data differently. Informed: Scientists come from different nd have different backgrounds, biases, and ved ideas about a scientific problem, all of which

VNOS B Question	Examples for Codes
different conclusions possible if the astronomers were all looking at the same experiments and data?	their interpretations of data and development of knowledge.

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Chapter 3: Looking Through the Lens of Darwin's Theory of Evolution and Seeing the Nature of Science

Shellie Harshberger

Chapter Highlights

- This chapter demonstrates explicit and inquiry methods to teaching NOS in a dual credit high school biology class.
- Embedding the nature of science in a unit on evolution can increase student NOS knowledge.
- Witnessing the events in Darwin's life as he developed the theory of evolution can be an excellent way for students to observe NOS in action.
- Themes of NOS such as tentativeness, subjectivity, inferential, imaginative, creativity, and sociocultural influence are present in Darwin's life as he ponders how life arose and changes over time.
- Through Darwin's life experiences, students can observe that the scientific method is not a linear, rigid, step by step, process.

Introduction

What is the nature of science (NOS)? The answer is an elusive beast challenging anyone brave enough to inquire. It is a method, a way of knowing and a body of knowledge. It is an ever changing target, but yet a vital component of scientific literacy. It's understanding the difference between observation and inference, and scientific laws versus theories. It means recognizing that scientific knowledge is based on observations of natural phenomenon. It is subjective, a product of culture, and is subject to change through further scientific advancements, research and scrutiny (Lederman, 2007). Researchers believe that it is essential for students to understand NOS to recognize why scientists do experiments, why controversies exist, and why learning science can be difficult (Carey & Smith, 1997). Unfortunately, evidence suggests that students lack an authentic understanding of the nature of science (Lederman, 2007). Data is lacking as to the best approach to teach NOS. However, researchers Carey and Smith believe that explicit practices are the most effective strategy, especially ones that involve actively doing science; these strategies help foster interests, attitude and values (1997).

Carey and Smith believe that NOS is essential to helping students make difficult concept changes (1997). Carey notes in *Cognitive Science and Science Education* that, "The paradox of science education is that its goal is to impart new schemata to replace the student's extant ideas, which differ from the scientific theories being taught" (1986, p. 1123). I can attest to the difficulty in concept changes when it comes to evolution. Students' beliefs and scientific theory are generally conflicting. In this case, in my own experience, it is very difficult to shift students' beliefs from a literal Biblical interpretation of the origin of life and process of evolution to a scientific interpretation. This is despite explicit evidence-based activities, labs, instruction and purposeful reflection. Many students will admit to a shift in their belief of evolution in terms of every other organism, but rarely will the explicit instructional practices shift their beliefs about human evolution.

Purpose

The purpose of this action research was to determine if students could apply what they learned about NOS and find evidence of it in life experiences that impacted Darwin's development of his theory of evolution. Additionally, students observed the process in which Darwin's theory evolved to witness that science is not conducted in a linear, rigid, step-by-step manner. This study aimed to use both explicit and inquiry methods to develop and solidify students' nature of science knowledge.

Research Questions

Can the nature of science be integrated in a meaningful way within the context of the theory of evolution? Evidence indicates that NOS must be explicitly taught (Carey & Smith, 1997); however, other evidence indicates that NOS is best taught within the framework of inquiry lessons (Lederman, 2007). Will initial explicit instruction with follow-up inquiry lessons demonstrate a measurable difference between the pre-assessment of students' NOS understandings and a post-assessment of their NOS beliefs? Once given explicit instruction on the characteristics of NOS, will students be able to tease out the tenets of NOS in the life events of Darwin as he develops his theory of evolution? In what way and to what extent will students' NOS views change after experiencing both explicit and inquiry lessons on NOS that are embedded in a unit on evolution?

Background

Darwin's theory of evolution via natural selection spawned an ideological revolution when it was published in 1859 (Mayr, 2009) and continues to ruffle feathers today. The nature of science (NOS) is an evasive creature, an ever-changing target, that eludes many, yet it is a vital component of scientific literacy. Historical evidence shows that Darwin derived his theory of evolution utilizing the tenets of NOS. I believe that we can use Darwin's development of his theory of evolution as a foundation to engage students in the humanness of science. We can examine pivotal junctures in Darwin's life that exemplify components of NOS as a means to expanding students' scientific knowledge. Authors of *Teaching and Learning Nature of Science in Elementary Classrooms* express that scientific literacy is important so that a person can, "…understand articles about science in the popular press so as to engage in social conversation about the validity of the conclusions" (Akerson et al., 2019, p. 392). Unveiling the aspects of NOS through the lens of Darwin developing his theory of evolution may be one way to yield scientifically literate students who have a deeper understanding of the nature of science.

NOS

What is science? Or rather what is the nature of science? It is the body of knowledge derived from the act of doing science. It is a subjective human endeavor that is constantly changing (Lederman & Abell, 2014). Akerson et al. indicate that NOS is the product of human inference, it's imaginative and creative, and culturally and socially infused (2000). Lederman et al. declare that it requires training, life experience, prior knowledge, and commitment. Science is reliable and withstanding, but not absolute. Science changes as new evidence comes to light (2002). Akerson et al. identify seven aspects of NOS that are "virtually noncontroversial". The seven characteristics identify scientific knowledge as: a) subject to change; b) empirically based; c) theory-laden (subjective); d) the result of human inference; e) imaginative; f) creative; g) culturally and socially infused (2000). The nature of science is the body of knowledge that is derived from scientific inquiry and scientific processes (Lederman & Abell, 2014).

NOS in Education

Lederman et al. declare that within the context of K-12 education, students' NOS knowledge should include being able to distinguish between observation versus inference and scientific theories versus laws (2002). Students should understand that scientific knowledge is a human endeavor that is influenced by the individual(s) and the culture in which the practice is taking place. It is important to debunk the myth of the scientific method in education. Lederman et al. declare, "There is no single scientific method that would guarantee the development of infallible knowledge." They elaborate that scientists perform all of the associated scientific tasks but not in a specific sequence (2002, pp. 499-502). Akerson et al. mirror this conviction: "no single scientific method exists, but there are shared characteristics of scientific approaches to science" (2013, p. 246). Studying the route Darwin took to develop his theory of evolution may facilitate students' understanding of NOS and increase their scientific literacy.

Why NOS via Darwin's Theory of Evolution?

Darwin gave us the foundation for nearly everything we know about life today. He changed our view of the world in aspects such as diversity, evolutionary adaptations, intraspecific competition and gradual phenomena (Sousa, 2016). He advanced several disciplines including geology, plant morphology, physiology, and psychology. He developed the theory of evolution, defined a new area of biology and new philosophy of biology (Ayala, 2009). Despite Darwin being arguably one of the most important scientific figures of all time, the route to his theory was paved with potholes and dead ends. In studying the path that Darwin took to publish his theory, we witness the struggles and the courageousness; the risks and the persistence; the flawed humanness of the nature of science.

A Human Endeavor Influenced by Culture and Society

In Darwin's life experiences we witness how social and cultural norms influence the practice and direction of scientific knowledge and discovery. In Darwin's time, the diversity of organisms was not attributed to science, but credited to a divine creator. Darwin was aware that his theory of evolution was akin to cultural and social suicide and he delayed his publication of *The Origin of Species by Means of Natural Selection* because of how it would be received. He developed the theory in 1838 but did not publish until 1859 for fear of ramifications. In Darwin's autobiography, he notes on October of 1838 that he was so impacted by what others would say about his theory that he was unwilling, "…to write even the briefest sketch of it" (Darwin, as cited in Ayala, 2009, p. 10038). Darwin was so influenced by his fear of how his theory would be received that he may have never published if it wasn't for another scientist, Alfred Russel Wallace. In June of 1858, Wallace sent Darwin a paper he wrote for Darwin to review. The paper postulated that two factors controlled evolution: 1) "Every species comes into existence coincident in time and space with a preexisting closely allied species"; 2) the winner of the struggle for existence would ultimately lead to a new species (Wallace, as cited in Clough, n.d.). It took Wallace developing a parallel theory to spur Darwin to publish his life's work (Ayala, 2009). Darwin's delay in publishing what he knew was a controversial theory shows the inherent humanness of science and the extreme impact of culture and society on scientific endeavors and possibly on scientific progress.

Historical Influence, Imagination, and Creativity

Charles Darwin was the grandson of Erasmus Darwin. While Erasmus died before Charles was born, there's little doubt that Erasmus's view on evolution contributed to Darwin's theory. Erasmus writes, "Would it be too bold to imagine, that all warm-blooded animals have arisen from one living filament…with the power of acquiring new parts…continuing to improve by its own inherent activity, and of delivering down those improvements by generation to its posterity world without end" (Erasmus, 1794, quoted in King-Hele, 1999, pp. 299-300). Would it be too bold to imagine that Charles was influenced by the writings of his deceased grandfather?

Author Ayala states that a hypothesis is an imaginative creation of the mind (2009). An example of this can be seen as Darwin shares how the hypothesis on the diversity of species came to him, "I can remember the very spot in the road…when to my joy the solution came to me…The solution, as I believe, is that the modified offspring…tend to become adapted to many and highly diversified places in the economy of nature" (Darwin & Barlow, 1958, pp. 120-121). Ayala proposes that imagination and creativity are the initial stages of scientific inquiry; they breathe life into the idea and provide the incentive to seek the truth (2009).

Human Inference and Empirically Based Research

Darwin's hunger to seek the truth led him to artificial selection. It was through artificial selection that he inferred a similar form of selection could be taking place in nature (Kampourakis & Gripiotis, 2015). During Darwin's time, when the diversity of life was attributed to a divine creator, organisms were thought to have been placed on Earth fully formed and unchanging. Darwin's life experiences, years of experimentation with artificial selection via pigeon breeding, barnacles and orchids (Ayala, 2009), as well as a critical and keen eye for observation, challenged that perception. Darwin believed that species changed and that the similarities among species was not due to the creator using the same blueprint, but were a result of descent from a common ancestor. Darwin's theory of evolution via natural selection grew from inferences made from experiments in artificial selection, keen observations of the natural world, as well as readings from the economist, Malthus, about increasing population growth and demand for limited resources (Malthus, 1798). Darwin proposed that: 1) organisms reproduce at unsustainable rates; 2) members of a species have heritable variations; 3) competition occurs due to limited resources; 4) the most well-adapted will survive to reproduce (Cohen, 2016).

Subject to Change

As Darwin developed his theory of evolution, his ideas were amended as a result of assistance from other sources and contemplation. One example was in Darwin's study of the Galapagos finches. When Darwin first gathered and attempted to classify his collection of birds from the Galapagos islands, he believed they were all unrelated. Fortunately, Zoologist, John Gould assisted Darwin and was able to determine that the birds were 13 species of closely related finches. When Darwin analyzed the finches through the lens of Gould's classification, he was better able to see how an original species of bird could diversify over time through small adaptations to different environments (Cohen, 2016). This experience contributed to Darwin's theory of how and why species adapt as well as demonstrates an important aspect of NOS; that all data, publications, and research are subject to review and revision.

Method

The nature of science was explicitly taught and then students examined events in Darwin's life to determine if there was evidence of Darwin utilizing aspects of NOS in the development of the theory of evolution. To foster a personal connection with Darwin, as well as learn about the events that shaped his theory, students watched segments of the PBS video *Darwin's Dangerous Idea* (DDI) for each of the 6 evidence-gathering days. I am familiar with this video and have often used it in previous classes as an introduction and support of evolutionary learning targets. With the exception of Day 1 and Day 7, where the focus was exclusively on NOS, each video segment aligned with the evolutionary learning goals for the day and with the standards for the unit. Thus, despite our focus being on NOS while watching the segment, students were also gaining evolutionary knowledge that supported each daily lesson. For example, on Day 4, students watched a segment of DDI that discussed how the eye is an example of evolution fashioning imperfect structures. After that section, students dissected a sheep eye to witness the imperfect structure first-hand.

Participants

The research was conducted within a Northern Indiana high school dual credit biology class. While the ethnicity of the research group is unknown, the school diversity score is 0.44, which means that there's a 44% chance of two students selected at random will be members of a different ethnic group. This diversity score is less than the state's score of 0.51 (Public School Review, 2021). The school is primarily Caucasian at 74%, African American is 9%, Asian is 6%, Hispanic is also 6%, 4% of the population is multiracial, and finally 1% of the student population is Native American. 21% of students are considered economically disadvantaged, 8.3% are English Language Learners and 10.6% of the students require exceptional education services. In this school there are 3,877 total students; 871 Freshman, 881 sophomores, 848 juniors and 830 seniors (Indiana Department of Education, n.d.).

The biology class in which the research was conducted is not a required class, however, the class contributes to the total number of requisite science credits for high school graduation. In addition, students were concurrently enrolled in Indiana University where they received five college credits for a freshman level basic biology class. The class was composed of 21 total students either in eleventh or twelfth grade; 18 of the students in the class chose to participate in the research. Of the 18 research participants, 11 of the students were female and 7 were male. Of the 11 females, 6 were juniors and 5 were seniors. The male participants were composed 4 juniors and 3 seniors. To provide anonymity, codes were used to represent each student. ST1 represented student number 1, ST2 stood for student number 2 and so on.

Day 1 Intervention

Students completed the VNOS(C) survey prior to class. In class, students brainstormed on a scrap piece of paper: What is science? How do we DO science? Is there a particular order, or way, that we, or scientists, do science? What do you know/remember about the scientific method? I displayed a scientific method image (see Figure 1) and asked students to give me a thumbs up if their brainstorming of the scientific method resembled the image. Then, a bright red X appeared over the linear model with the word *False* flashing on the screen. Students were directed to ball up their scrap piece of paper and throw it into the trash bin that I carried as I walked around the room. My goal was to make a big, lasting impression by this action.

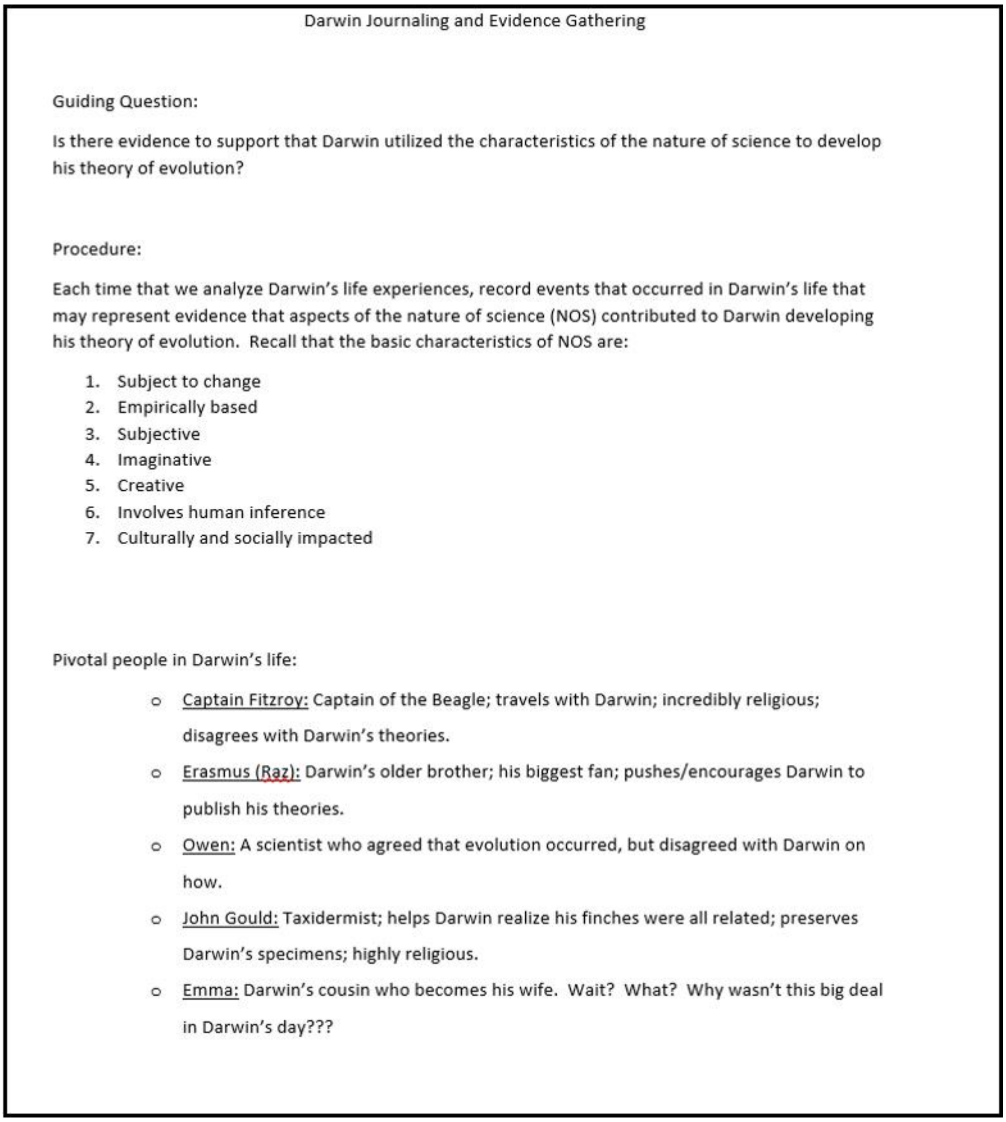
Next, I revealed a chart with 25 terms and phrases on it (see Figure 2). Some of them were characteristics of NOS and others were the antithesis of it. I asked students to brainstorm on their small whiteboards for several minutes what terms best described how scientific knowledge is acquired, since it's not acquired via a step-by-step process. After the brainstorming session, I had students tell me how many of the terms they wrote down. My claim was that 21 of the 25 terms and phrases represented NOS characteristics. One very enlightened student had listed 18-20 of them, most students had somewhere between 7 and 13. We went over the 7 virtually noncontroversial tenets: subject to change, empirically based, subjective, imaginative, creative, the result of human inference, and culturally and socially infused (Akerson et al., 2000). With the newly acquired knowledge about the 7 characteristics of NOS, I asked the students to take a look at the phrases and terms again and add to their original whiteboard list. Highly engaged students added many more, whereas other students were still only at about 9-10. I admitted that I thought 21 of the terms were NOS components and we discussed those.

Figure 1. Linear Scientific Method Model

Tentative	Subjective	Unchanging	Based on observation	Involves make inferences
Open to interpretation	Linear process	Impacted by society and culture	Imaginative	Creative
Flawed	Ever-changing	Influenced by peers	Requires life experience	Impacted by personal beliefs
Way of knowing	Changes based on new evidence	Rigid, step-by-step experiment	Requires commitment & tenacity	Involves forming scientific theories
Requires prior knowledge	Involves forming scientific laws	100% fact	Requires reflection	Involves curiosity

Figure 2. Phrases that may or may not Represent NOS

Students were then asked to brainstorm and develop a list of famous scientists that probably utilized NOS. I was hoping for Darwin to be on that list. The students did not disappoint and all of them had Darwin as one of the scientists. I asked, “Do you think there is evidence to support that the aspects of the nature of science contributed to Darwin's theory of evolution? Let's find out!" Students were given the Darwin Journaling and Evidence Gathering assignment (see Figure 3). We went over the pivotal people in Darwin's life and discussed the expectations of the assignment. Students were directed to journal evidence of NOS as we watched 20 minutes the *Darwin's Dangerous Idea* PBS video.



Darwin Journaling and Evidence Gathering

Guiding Question:

Is there evidence to support that Darwin utilized the characteristics of the nature of science to develop his theory of evolution?

Procedure:

Each time that we analyze Darwin's life experiences, record events that occurred in Darwin's life that may represent evidence that aspects of the nature of science (NOS) contributed to Darwin developing his theory of evolution. Recall that the basic characteristics of NOS are:

1. Subject to change
2. Empirically based
3. Subjective
4. Imaginative
5. Creative
6. Involves human inference
7. Culturally and socially impacted

Pivotal people in Darwin's life:

- Captain Fitzroy: Captain of the Beagle; travels with Darwin; incredibly religious; disagrees with Darwin's theories.
- Erasmus (Raz): Darwin's older brother; his biggest fan; pushes/encourages Darwin to publish his theories.
- Owen: A scientist who agreed that evolution occurred, but disagreed with Darwin on how.
- John Gould: Taxidermist; helps Darwin realize his finches were all related; preserves Darwin's specimens; highly religious.
- Emma: Darwin's cousin who becomes his wife. Wait? What? Why wasn't this big deal in Darwin's day???

Figure 3. Darwin Journaling and Evidence Gathering Assignment

In this portion of the DDI video, we learned about Darwin's voyage on the Beagle and witnessed discussions on natural selection, which was being coined a "revolutionary and dangerous idea" (Dennett, 1996). We also saw Darwin ponder about the relationships between the Galapagos finches, as well as contemplate ideas about adaptations and how new species developed. We witnessed the role his brother, Erasmus, played in Darwin's life, as well as other naturalists (Dennett, 1996). After viewing the segment of *Darwin's Dangerous Idea*, I gave students time to collaborate and share with each other the evidence they saw in the video. Then, we viewed the NOS terms and phrases chart and placed a checkmark by the ones that the students believed were witnessed in the video. We wrapped up class discussing the associated Darwin life events that aligned with the chosen terms and phrases.

Day 2 Intervention

Students had eLearning due to weather conditions. Students were directed to complete their journaling as they viewed another portion of *Darwin's Dangerous Idea*. In this chapter of the video, Darwin explored the relationship between all organisms and he had the epiphany that all organisms were related to a common ancestor. He explained that he thought the relationship among organisms was akin to a tree, where the trunk represented a common ancestor and the branches represented species (Dennett, 1996). After students viewed the video segment, they were instructed to complete a quiz via the online management system Canvas. Students were directed to record what evidence they gathered and identify which characteristic(s) of NOS they believed it aligned with based on the characteristics of NOS chart (see Figure 4).

Characteristics of NOS

Tentative	Subjective	Unchanging	Based on observation	Involves make inferences
Open to interpretation	Linear process	Impacted by society and culture	Imaginative	Creative
Flawed	Ever-changing	Influenced by peers	Requires life experience	Impacted by personal beliefs
Way of knowing	Changes based on new evidence	Rigid, step-by-step experiment	Requires commitment & tenacity	Involves forming scientific theories
Requires prior knowledge	Involves forming scientific laws	100% fact	Requires reflection	Involves curiosity

Figure 4. Characteristics of NOS

Day 3 Intervention

Students had eLearning again due to inclement weather. Students followed the same procedure as Day 2. In this segment of *Darwin's Dangerous Idea*, several life events unfolded that could easily be viewed as evidence of NOS. We witnessed the role Erasmus and scientific peers play in Darwin's development of his theory. Darwin considered Malthus's theories on human growth and struggle and postulated that something similar happens in nature (Dennett, 1996).

Day 4 Intervention

For this lesson, we were back to in-person learning. Students journaled NOS evidence as we watched DDI. In this portion of the video, we witnessed the emotional turmoil Darwin experienced having developed a theory that ran counter to the church. We also learned that in Darwin's time, people would use complex structures as the eye as evidence of life having been created by a designer. We heard testimonies from scientists and a patient with a retinal tear rebutting the eye as a perfect structure (Dennett, 1996). Students collaborated after journaling to discuss what evidence they saw and which of the 7 NOS categories they placed the evidence in and why. Students dissected sheep eyes to directly observe the imperfectness of the eye.

Day 5 Intervention

Students had eLearning again due to inclement weather. Students followed the same procedure as Day 2 and 3. In this segment of *Darwin's Dangerous Idea*, we witnessed Darwin working tenaciously to produce evidence of his theory. We saw the continued struggle Darwin underwent at the thought of publishing his ideas. The emotional turmoil was palpable watching Darwin struggle with the fear of being ostracized for his dangerous theory. Darwin experienced the tragedy of his daughter's death in this portion of the video. We learned that Darwin lost faith in God after this life event. He could not believe a good and fair God would take away his daughter (Dennett, 1996). We might infer that he may be less fearful of going against the teachings of Christianity when he's beginning to question the existence of God.

Day 6 Intervention

Students finished the rest of the DDI video in this lesson. As the video wrapped up, many life events could be seen as evidence of NOS. Darwin read a paper written by Alfred Wallace that proposed a very similar idea about how evolution occurred. Darwin finally agreed to publish his findings after having read Wallace's work. We also learned of modern-day evidence of evolution in fossils, DNA, and comparison of human and chimpanzee childhood development (Dennett, 1996). Students completed an online quiz like Day 2, 3, and 5, and were given the Looking Through the Lens of Darwin's Theory of Evolution and Seeing the Nature of Science? PreActivity (see Figure 5). In this assignment, students were asked to identify 10 events from their journal that they felt most confident they could defend as examples of NOS. Students were directed to highlight those events and bring the highlighted work to the next class.

Looking Through the Lens of Darwin's Theory of Evolution and Seeing the Nature of Science?

PreActivity

Background

Recall that science is not a linear, step-by-step process, but a mixture of many different characteristics. While not all experts agree on what the nature of science is, there are seven basic principles that are virtually noncontroversial. Those are:

1. Subject to change
2. Empirically based
3. Subjective
4. Imaginative
5. Creative
6. Involves human inference
7. Culturally and socially impacted

Within those 7 tenets, we see the following characteristics:

Characteristics of NOS

Tentative	Subjective	Unchanging	Based on observation	Involves make inferences
Open to interpretation	Linear process	Impacted by society and culture	Imaginative	Creative
Flawed	Ever-changing	Influenced by peers	Requires life experience	Impacted by personal beliefs
Way of knowing	Changes based on new evidence	Rigid, step-by-step experiment	Requires commitment & tenacity	Involves forming scientific theories
Requires prior knowledge	Involves forming scientific laws	100% fact	Requires reflection	Involves curiosity

Recall our research question: *Is there evidence to support that aspects of nature of science contributed to Darwin's theory of evolution?*

Recall our goal: *Study events in Darwin's life that may have contributed to the development of his theory of evolution via natural selection to determine if NOS played a role in the theory development.*

Procedure

1. Now that you have completed your journaling of the events in Darwin's life from the movie *Darwin's Dangerous Idea*, it is time to analyze the data. Read through your journal with the 7 principles and the NOS chart above nearby. **Underline** the following:

   a. Only events that were specifically related to Darwin (and not other scientists/characters from the movie).
   b. Events that you can easily associate with the 7 principles and/or the NOS chart.

2. Once you've underlined the events, go back through and **highlight** 10 events that you feel most confident that you can defend your reasoning that they are examples of NOS characteristics.

3. Bring your journal with you to class next class to complete the activity.

Figure 5. Darwin and NOS PreSynthesis Activity

Day 7 Intervention

Students were instructed to share and discuss with a partner what events they highlighted as a warm-up activity. Students were given the Looking Through the Lens of Darwin's Theory of Evolution and Seeing the Nature of Science? Synthesis Lesson (see Figure 6).

Looking Through the Lens of Darwin's Theory of Evolution and Seeing the Nature of Science? Synthesis Lesson

Objective

Use data collected by studying events in Darwin's life to determine if there is evidence that the development of the theory of evolution occurred utilizing aspects of the nature of science in a non-linear process.

Materials

- PreActivity with 7 tenets and NOS chart
- Journal with 10 highlighted events (completed in PreActivity)
- Chalk markers
- Yellow cards of associated terms/phrases
- Green cards of additional events/experiences in Darwin's life
- Cellphone to take a picture

Procedure

1. Working with your tablemate, use the chalk markers to create a desk-sized chart that looks like this:

NOS Characteristics	Subject to Change	Empirically Based	Subjective	Imaginative	Creative	Involves Inference	Socially/Culturally Influence
Associated Terms/Phrases							
Darwin Life Events							

2. Analyze the yellow cards of terms and phrases associated with NOS. Discuss and agree as a group which of the 7 tenets the characteristic best fits into. Place each card in the agreed upon category.
3. Analyze the green cards of additional events/experiences in Darwin's life. Use the characteristics placed in each category to help you determine which tenet the event best fits into and place the event in the agreed upon category.
4. Share the 10 highlighted events from the preactivity with your partner. Discuss and defend the relationship between the life event and one, or more, of the 7 principles. Make note of the event and the principle(s) it best aligned with.
5. Take a picture of desk chart. Submit it on Canvas.
6. Complete the synthesis and reflection.

Synthesis and Reflection

1. Share one life event from each of the 7 tenets and defend how it represents that particular characteristic of NOS.
2. Do you believe there is evidence that the development of the theory of evolution occurred utilizing aspects of the nature of science? Explain using data from Darwin's Dangerous Idea and the events of Darwin's life shared in this lesson.
3. Do you believe that science is conducted in a linear, step-by-step, process? Elaborate and defend your answer.
4. Have your thoughts on science, or the nature of science, changed since you took the NOS Survey? Explain.

Figure 6. Darwin and NOS Synthesis Activity

In this culminating activity, students worked in pairs to create a chart on their desktops with chalk markers based on the sample table in the assignment. Students love working with the chalk markers and I use them as a way to make the lesson fun, engaging, and memorable. Students were given two sets of cards. One set of cards included 20 different cards based on the terms and phrases in the NOS chart that we have referenced throughout the lesson (see Figure 7). Students were asked to place the terms into one of the 7 tenets of NOS column that they believed it most aligned with. The thought process behind this idea is that some students may have difficulty comprehending some of the tenets such as *empirically based*. Once students placed the associated terms/phrases in the 7 categories, students were directed to analyze the other set of cards. The second set of cards included pivotal Darwin life events that were either not included in *Darwin's Dangerous Idea* or were so important that I didn't want the students to have missed them in the video, especially considering that many of the lessons were done independently at home during eLearning (see Figure 8).

Tentative	Subjective	Creative	Based on observation
Open to interpretation	Involves make inferences	Impacted by society and culture	Involves curiosity
Flawed	Ever-changing	Influenced by peers	Requires life experience
Way of knowing	Changes based on new evidence	Impacted by personal beliefs	Requires commitment & tenacity
Requires prior knowledge	Involves forming scientific theories and laws	Imaginative	Requires reflection

Figure 7. Terms and Phrase that Represent NOS

After developing a basic evolutionary theory, Darwin tested it by breeding pigeons and orchids.	Darwin made public the details of his trip on the Beagle, but kept secret journals of his thoughts on evolution.	While finalizing his theory, Darwin walked around in nature 3 times a day to clear his mind and reflect.	Geologist, Charles Lyell, proved the Earth had went through slow, gradual changes, which helped shape Darwin's theory.	The original evolutionary theory did not accurately explain how traits were inherited. That part of the theory was adapted after Gregory Mendel's experiments in heredity.
Darwin communicated constantly with other scientists, breeders, naturalists, botanists, and anyone with knowledge of heredity.	Darwin's theory was developed by 1842, but he did not publish until 1859 out of fear of how it would be received.	Darwin tenaciously maintained a schedule everyday while researching and testing his theory.	While in school, Darwin performed lab experiments at home by choice.	Economist and friend of Darwin, Thomas Malthus, wrote about the struggle for human existence, which helped shape Darwin's theory.
As a child, Darwin collected beetles, shells and plants.	The death of Annie, Darwin's daughter, crushed his belief in Christianity.	Darwin was actually not a good student.	Darwin used fossils and specimens to support his theory.	Darwin used what he observed about artificial selection to infer natural selection as the way evolution occurs.

Figure 8. Important Darwin Life Events

All of the events on the cards could reasonably be considered evidence of NOS. Students collaborated and categorized the events into one of the 7 categories (see Figure 9 as an example of one groups' classification). Lastly, students shared their highlighted events from their journal with their partner and discussed where the events would fit within the tenets of NOS. Throughout the process, I emphasized that this was an open-ended, subjective process and that as long as they could defend their placement of the events, there was not a right or wrong answer. Listening to the students' challenge each other and make their determinations was insightful. I really felt like they had a strong comprehension of NOS and the experience left me hopeful that I would see evidence of that in the post VNOS(C) Survey.

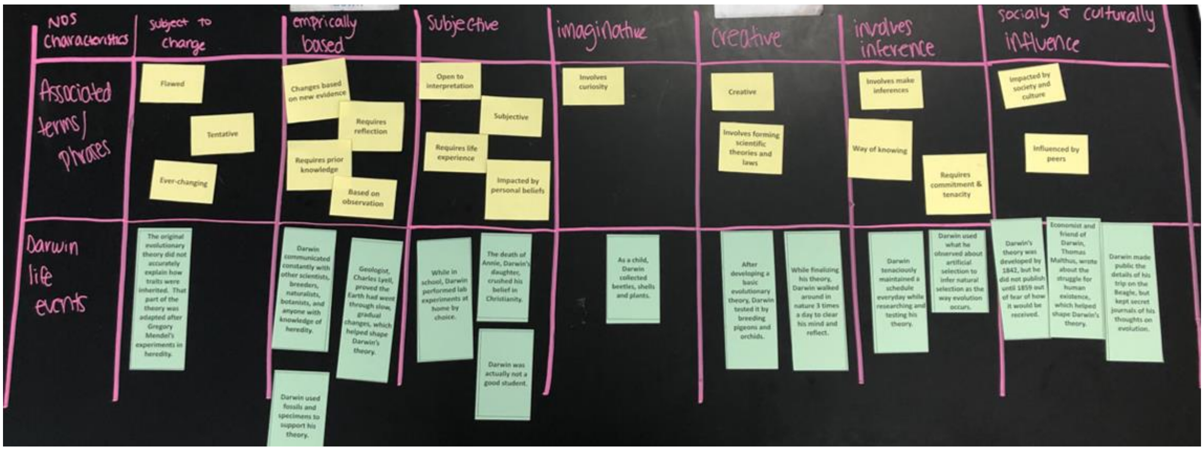


Figure 9. Student Example of Synthesis Chart Activity

Individually, as a wrap-up, students defended one life event for each of the 7 tenets, discussed if they believed those experiences were evidence of NOS, shared their thoughts on how science is conducted, and contemplated if their beliefs regarding NOS had changed since the start of the unit. Students were given the VNOS(C) Survey to complete again as homework with the expectation that it would be brought back the next class.

Data Collection

Despite NOS importance, student NOS comprehension continues to fall short, or so it seems. Lederman et al. propose that one of the reasons that student understanding of NOS continues to fall short is based on the method of assessment. Lederman et al. question the validity of the standardized paper and pencil assessments used to measure learners' comprehension of NOS. They assert that the views ascribed to the learners' in these traditional assessments are an artifact of the instrument of measure, not an authentic representation of their NOS knowledge. Lederman et al. propose the View of Nature of Science Questionnaire (VNOS) which uses open-ended questions to assess learners' NOS comprehension. They caution that establishing validity is an on-going process but they feel that the VNOS questionnaire is a better instrument to measure learners' NOS knowledge than traditional methods (2002). Based on this information, I chose to use the VNOS form C as my pre and post assessment of students' NOS knowledge.

The VNOS(C) questionnaire is the third iteration of the survey. The original VNOS survey was developed by Lederman and O'Malley to assess students' views on the tentative nature of science. It was then modified two separate times to develop the final form, VNOS (C), by Abd-El-Khalick (1990, as cited in Irez, 2006). The VNOS-C survey is composed of 10 open-ended questions about the characteristics of NOS such as: 1) the tentative and empirical nature of scientific knowledge; 2) the subjectivity of science; 3) the creative and imaginative aspect of NOS; 4) the aspects of the scientific method; 5) the nature of scientific theories and laws; 6) as well as the cultural and social impact on scientific knowledge. These characteristics, when analyzed together, reveal a comprehensive synopsis of the participants' belief about NOS (Irez, 2006).

Data Analysis

Data were analyzed using content analysis. NOS themes in the students' responses to the VNOS(C) questionnaire were grouped and classified. Beliefs about NOS were classified as naïve (N), emerging (E), or informed (I) (Irez, 2004, as cited in Erdas Kartal et al., 2018, p. 4). Table 1 provides definitions for each classification.

Table 1. Definition for Each Classification (Erdas Kartal et al., 2018)

Classification	Definition
Naïve (N)	Inadequate belief about NOS theme
Emerging (E)	Contradictory or partially adequate belief about NOS theme
Informed (I)	View aligns with contemporary beliefs about NOS theme

A rubric similar to one developed by Irez (2004, as cited in Erdas Kartal et al., 2018, p. 5) was used to assist in the grouping and classification procedure (see Table 2).

Table 2. Rubric for Grouping Students' NOS Beliefs (Irez, 2004, as cited in Erdas Kartal et al., 2018, p. 5)

Themes	Naïve (N)	Emerging (E)	Informed (I)
Empirical NOS	Science is entirely dependent on direct evidence.	Science is entirely dependent on direct evidence, however, that evidence supports, rather than proves, a scientific claim. Science does not entirely depend on direct evidence, but evidence proves scientific claims.	Science uses both indirect and direct evidence to support scientific claims.
Scientific Method	Scientific method is a linear, step-by-step process.	Scientific method is universal, but not necessarily step-by-step.	There are many ways to investigate science.
Tentative NOS	Scientific knowledge is fact.	Scientific laws are facts, however, theories are tentative.	Scientific knowledge is subject to change.
Scientific Laws and Theories	Theories are not well supported and are subject to change, whereas, laws are irrefutable.	There is not much differentiation between a law and theory, although, laws have a higher status and don't change.	Theories and laws are different kinds of scientific knowledge and both are subject to change.
Role of Inference in Scientific	Because science is based on direct evidence, inference	A few theories may be based on inference, however, most require	Some theories rely on inference.

Theory	does not play a role.	direct evidence.	
Subjective NOS	Science is an objective process due to the scientific method.	There might be subjectivity in scientific knowledge based on the researcher's experience, values, or beliefs.	Subjectivity is an inherent part of scientific knowledge due to researchers' personal and professional experiences.
Social and Cultural Impact on Science	Science is not impacted by society or culture.	Some disciplines are impacted by society and culture, but most are not.	Scientific knowledge affects and is affected by culture and society.
Imagination and Creativity of Science	Science is not influenced by imagination or creativity.	A few steps of the scientific process may rely on creativity or imagination.	Imagination and creativity infiltrates the scientific process.

Results

All participant NOS beliefs showed improvement at the end of the unit. Collectively, student naïve views about NOS themes decreased, whereas their informed views increased (see Table 3). Initially, 40% of the research group held naïve views about NOS in general, however, by the end of the unit, only 8% of the participants still held naïve views about NOS. The theme in which naivety still significantly loomed was scientific laws and theories, whereas, themes where no naivety remained were tentativeness, subjectivity, imagination and creativity.

Prior to the unit, 24% of the students held informed views about NOS; post-unit, 58% of the participants held informed views. The themes in which views were the most informed included: 1) tentativeness; 2) subjectivity; and 3) sociocultural influence. These findings may be as expected because the Darwin life events studied demonstrated several aspects of sociocultural influence, imagination, subjectivity, creativity and tentativeness, however, none of the life experiences witnessed addressed scientific laws or their relationship to scientific theories.

Table 3. Side by Side Comparison of the Entire Research Group in Each of the Three Classifications Pre and Post-Unit

	Pre-Unit Naïve	Post-Unit Naïve	Pre-Unit Emerging	Post-Unit Emerging	Pre-Unit Informed	Post-Unit Informed
Empirical NOS	67%	11%	22%	39%	11%	50%
Scientific Method	67%	11%	22%	44%	11%	44%
Tentative NOS	6%	0%	44%	22%	50%	78%
Scientific Laws and Theories	61%	22%	33%	56%	6%	22%
Inferential NOS	28%	11%	50%	28%	22%	61%
Subjectivity of NOS	28%	0%	56%	28%	17%	72%
Sociocultural Influence	39%	11%	22%	17%	39%	72%
Imaginative and Creative NOS	22%	0%	44%	33%	33%	67%
Average	40%	8%	37%	33%	24%	58%

Individual Analysis and Results

Initial student beliefs about NOS are indicated in Table 4. This table shows individual student viewpoints in each of the eight categories identified in the rubric in Table 2. For anonymity purposes, students were coded with symbols. ST1 represents the first student participant, ST2 the second student and so on. Capital letters are used in the table to represent one of the three classifications: Naïve (N), Emerging (E), or Informed (I). These classifications are defined in Table 1. In the preassessment VNOS(C) survey, 7 of the 18 total participants showed 50% or greater naïve views of NOS and 6 of the participants showed 0% informed beliefs of NOS.

Table 4. Pre-Unit Individual Student Beliefs about NOS. Identified as Naïve (N), Emerging (E), or Informed (I)

	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10	ST 11	ST 12	ST 13	ST 14	ST 15	ST 16	ST 17	ST 18
Empirical NOS	N	N	I	N	I	N	N	N	N	N	N	E	N	E	E	N	E	N
Scientific Method	N	E	I	N	I	N	N	N	E	N	N	N	N	E	N	N	E	N
Tentative NOS	N	E	I	E	I	I	I	E	E	I	E	E	I	I	I	I	E	E
Scientific Laws and Theories	N	N	E	N	E	N	E	N	E	E	N	I	E	N	N	N	N	N
Inferential NOS	N	N	I	E	E	E	I	N	E	E	E	N	I	I	N	E	E	E
Subjectivity of NOS	E	N	I	N	E	E	E	N	E	E	E	N	I	I	N	E	E	E
Sociocultural Influence	E	N	I	N	I	E	I	I	N	E	I	N	N	N	I	I	N	E
Imaginative and Creative NOS	E	N	I	E	I	I	I	E	N	E	N	E	I	E	E	I	N	E
% Naïve	63 %	75 %	0 %	63 %	0 %	38 %	25 %	63 %	38 %	25 %	50 %	50 %	38 %	25 %	50 %	38 %	38 %	38 %
% Emerging	38 %	25 %	13 %	38 %	38 %	38 %	25 %	25 %	63 %	63 %	38 %	38 %	13 %	38 %	25 %	25 %	63 %	63 %
% Informed	0 %	0 %	88 %	0 %	63 %	25 %	50 %	13 %	0 %	13 %	13 %	13 %	50 %	38 %	25 %	38 %	0 %	0 %

Post-unit individual student viewpoints based on the VNOS(C) questionnaire can be seen in Table 5. After the unit on NOS and evolution, only one student still held 25% naïve views, whereas the rest of the students' naïve views ranged from 0% to 13%. Informed views increased to as much as 88% and 15 of the 18 students showed 50% or greater informed views. In the empirical NOS category, 5 students, ST1, ST4, ST11, ST16, and ST18, improved from naïve to informed.

For the scientific method theme, 3 students, ST4, ST7, ST13, moved from naïve to informed. Most students either initially held an emerging understanding of the tentativeness of science or an informed viewpoint, thus, only one student, ST1, shifted from naïve to informed when considering the tentativeness of NOS. As previously mentioned, the unit did not address scientific laws, nor did it cover their relationship to theories, so as expected, few students held informed beliefs about this theme of NOS and only 2 students, ST1 and ST14, showed a shift from naïve to informed. Similarly, only 2 students, ST12 and ST15, demonstrated a leap from naïve to informed in the inferential theme of NOS, however, this may have been due to many of the participants (50%) already having an informed view of the concept prior to the lesson (see Table 3).

Several students, ST2, ST4, ST12, and ST15, made the leap from naïve to informed when considering the subjective nature of NOS and no one still held a naïve belief about this tenet of NOS (see Table 3). Sociocultural influence was a primary theme in the Darwin life events witnessed, so it is no surprise that it is one of the categories that shows the most informed students, 72%, (see Table 3). However, given it was such a relevant theme during the unit, it is surprising that it was not a big transition from naïve to informed for most of the participants and only ST2 and ST4 demonstrated that change in belief.

For the last theme considered, imaginative and creative NOS, only ST9 and ST11 transitioned from a naïve to an informed understanding of the topic, however, this may have been due to the fact that many students held either emerging or informed beliefs to begin with, 44% and 33% respectfully (see Table 3), and thus, those beliefs transitioned into a better understanding of the tenet with 33% emerging and 67% informed (see Table 3) after the unit of study.

Table 5. Post-Unit Individual Student Beliefs about NOS. Identified as Naïve (N), Emerging (E), or Informed (I)

	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10	ST 11	ST 12	ST 13	ST 14	ST 15	ST 16	ST 17	ST 18
Empirical NOS	I	E	I	I	I	E	E	E	N	E	I	I	N	E	E	I	I	I
Scientific Method	E	I	I	I	I	E	I	E	I	E	N	E	I	I	N	E	E	E
Tentative NOS	I	I	I	E	I	I	I	E	E	I	I	I	I	I	I	I	E	I
Scientific Laws and Theories	E	I	E	E	E	N	I	N	E	E	E	I	E	I	N	E	E	N
Inferential NOS	E	N	I	N	E	I	I	E	E	I	I	I	I	I	I	I	E	I

	ST 1	ST 2	ST 3	ST 4	ST 5	ST 6	ST 7	ST 8	ST 9	ST 10	ST 11	ST 12	ST 13	ST 14	ST 15	ST 16	ST 17	ST 18
Subjectivity of NOS	E	I	I	I	E	I	I	E	E	I	I	I	I	I	I	I	E	I
Sociocultural Influence	I	I	I	I	I	I	I	I	E	I	I	N	E	N	I	I	E	I
Imaginative and Creative NOS	I	E	I	E	I	I	I	E	I	I	I	E	I	E	I	I	E	I
% Naïve	0 %	13 %	0 %	13 %	0 %	13 %	0 %	13 %	13 %	0 %	13 %	13 %	13 %	13 %	25 %	0 %	0%	13%
% Emerging	50 %	25 %	13 %	38 %	38 %	25 %	13 %	75 %	63 %	38 %	13 %	25 %	25 %	25 %	13 %	25 %	88%	13%
% Informed	50 %	63 %	88 %	50 %	63 %	63 %	88 %	13 %	25 %	63 %	75 %	63 %	63 %	63 %	63 %	75 %	13%	75%

While the initial observation of the emerging (E) viewpoint showed a decrease from 37% to 33% (Table 3), individual analysis reveals that students emerging beliefs either stayed the same or increased significantly in comparison to their naivety. For example, ST2 initially had 0% informed beliefs with 25% emerging beliefs, after the unit, ST2 still held 25% emerging beliefs, however, their informed views increased to 63%. This same phenomenon was witnessed in ST3, ST4, ST6, ST7, ST9, ST11, ST12, ST14, ST15, AND ST16 (See bold columns in Table 6). One can infer that while these participants are not fully informed about NOS, their beliefs are an improvement over their initial stance.

Table 6. Individual Student Comparison of Pre-Unit and Post-Unit Emerging (E) and Informed (I) Beliefs

		ST 1	**ST 2**	**ST 3**	**ST 4**	ST 5	**ST 6**	**ST 7**	ST 8	**ST 9**	ST 10	**ST 11**	**ST 12**	ST 13	**ST 14**	**ST 15**	**ST 16**	ST 17	ST 18
Pre-Unit	E	38%	**25%**	**13%**	**38%**	38%	**38%**	**25%**	25%	**63%**	63%	**38%**	**38%**	13%	**38%**	**5%**	**5%**	63%	63%
	I	0%	**0%**	**38%**	**0%**	63%	**25%**	**50%**	13%	**0%**	13%	**13%**	**13%**	50%	**38%**	**25%**	**38%**	0%	0%
Post-Unit	E	50%	**25%**	**13%**	**38%**	38%	**25%**	**13%**	75%	**63%**	38%	**13%**	**25%**	25%	**25%**	**13%**	**25%**	88%	13%
	I	50%	**63%**	**38%**	**50%**	63%	**63%**	**88%**	13%	**25%**	63%	**75%**	**63%**	63%	**63%**	**63%**	**75%**	13%	75%

Table 7 shows a side by side comparison of each students' classification pre and post-unit. Focusing on the informed (I) classification, all students made improvements and many made huge leaps in their NOS knowledge. ST1, ST2, ST4, ST9, ST17 and ST18 went from 0% informed to at least 13% informed, whereas ST1, ST2, ST4, ST10, ST11, ST12, and ST18 increased their informed classification by 50% or greater.

Table 7. Side by Side Comparison of Individual Student's Total Percentage in Each of the Three Classifications Pre and Post Unit

Student	Pre-Unit	Post-Unit	Pre-Unit	Post-Unit	Pre-Unit	Post-Unit
	Naïve	Naïve	Eclectic	Eclectic	Informed	Informed
ST1	63%	0%	38%	50%	0%	50%
ST2	75%	13%	25%	25%	0%	63%
ST3	0%	0%	13%	13%	88%	88%
ST4	63%	13%	38%	38%	0%	50%
ST5	0%	0%	38%	38%	63%	63%
ST6	38%	13%	38%	25%	25%	63%
ST7	25%	0%	25%	13%	50%	88%
ST8	63%	13%	25%	75%	13%	13%
ST9	38%	13%	63%	63%	0%	25%
ST10	25%	0%	63%	38%	13%	63%
ST11	50%	13%	38%	13%	13%	75%
ST12	50%	13%	38%	25%	13%	63%
ST13	38%	13%	13%	25%	50%	63%
ST14	25%	13%	38%	25%	38%	63%
ST15	50%	25%	25%	13%	25%	63%
ST16	38%	0%	25%	25%	38%	75%
ST17	38%	0%	63%	88%	0%	13%
ST18	38%	13%	63%	13%	0%	75%

Discussion

The purpose of this action research was to teach students about the tenets of NOS and determine whether students could apply what they learned by recognizing NOS themes in Darwin life experiences as he developed the theory of evolution. Additionally, I aimed to ensure that by witnessing the events that led to Darwin's theory, students would recognize that science is not conducted in a specific step-by-step manner. This study used both explicit and inquiry methods to advance students' nature of science knowledge.

My primary research question was to determine in what way and to what extent students' NOS views would change after experiencing lessons on NOS that were infused in a unit on evolutionary biology. I pondered, if given explicit instruction on the characteristics of NOS, would students then be able to tease out the tenets of NOS in the life events of Darwin as he develops his theory of evolution?

In response, the research findings showed that these methods of instruction improved students' NOS knowledge in the 8 identified areas:

1) empirical NOS;
2) scientific method;
3) tentativeness of NOS;
4) laws versus theories;
5) inferential NOS;
6) subjective nature of NOS;
7) social and cultural influence on scientific knowledge;
8) and the creative and imaginative aspect of NOS.

Areas that were frequently witnessed in Darwin life events made the most significant gains, whereas, areas that were not observed, such as laws versus theories, showed less gains in student comprehension. The subjectivity of science showed the most substantial improvement, followed by the imaginative and creative aspect of NOS. Both the empirical nature of science and inferential component shows similar gains, as did the sociocultural aspect and the scientific method. Given that one of my goals was to ensure students understood that the scientific method is not a rigid, linear process, seeing significant gains in this area supports that these teaching methods were effective at increasing students' knowledge of this tenet of NOS. Additionally, since the biggest improvements were in the areas witnessed in Darwin life events, one can infer that inquiry lessons, after an initial explicit introduction, were effective in aiding student's NOS comprehension.

This study enriches current research about effective methods of NOS education. The data demonstrated that using both explicit and inquiry methods, as well as making a personal connection with the material, was a successful strategy at improving students' NOS knowledge. This research revealed that embedding NOS into a unit on evolution allowed for the observation of NOS in action. The real-life examples of Darwin's struggles as he developed his theory of evolution may have made the content more relevant and meaningful to the students. The data from this study showed that students were able to transfer the knowledge they developed while studying Darwin's life events to the post VNOS(C) survey; a skill that requires authentic understanding of the material. The data from this study adds to the breadth of NOS education research that the applied methods were a meaningful way of clarifying NOS misconceptions, extending students' understanding of the tenets of NOS, and enhancing students' scientific literacy.

Conclusion

Charles Darwin was a complex and flawed human being who spent the majority of his life passionately seeking answers about the natural world. His theory of evolution is an amalgamation of his morality, spirituality, and his understanding of order, economics, geology and zoology (Clough, n.d.). Analyzing the key components of Darwin's life and how he developed his theory of evolution demonstrates that NOS requires life experience, prior knowledge, and commitment (Lederman et al., 2002). It is an approach that sheds light on the personal nature and humanness of science. Looking through the lens of how Darwin developed his theory allowed students to see behind the curtain to recognize that advances in scientific knowledge are often messy, non-linear and infused with unsuspecting influences such as personal experience, cultural and social perceptions of the time. Socioscientific context affects the questions that scientists, such as Darwin, ask and influences how and when they present their work.

Recommendations

To expand on studying Darwin as a means to illustrate the nature of science in the classroom, future research could involve delving more deeply into other historical influences of Darwin's, his personal life experiences, scientific and religious community reactions to his theory, as well as the reaction of his family and friends. Darwin was influenced by more than Wallace and Malthus and that would be a potential area to investigate further. His wife, Emma, was a very religious individual. What role did Emma play in Darwin's theory? Was Emma partially responsible for Darwin waiting over twenty years to publish his theory? Darwin was a religious man until the death of his daughter, Annie. What role did the death of Annie play in his willingness to go against the belief of a divine creator? The scientific community did not readily accept his theory until geneticists incorporated evolution into their work on heredity (Clough, n.d.). How did the lack of support impact Darwin's scientific endeavors after he published his theory? Future research could also look at DNA, the heritable factor that Darwin alluded to but was unaware of in his time, does DNA support or refute Darwin's theory? How has what we know about DNA shaped our understanding of evolutionary theory today? Studying DNA would be another way to support that NOS involves empirical data and is subject to change based on current scientific evidence. One could postulate that investigating any of these areas of Darwin's life and current scientific data would reveal the tenets of NOS.

The priority for science education is to generate students who have the ability to interpret and apply scientific information to make informed decisions (Sousa, 2016). For students to become scientifically literate they need to be able to recognize that NOS is a body of knowledge that is derived by asking questions and seeking answers under conditions that are:

a) subject to change;
b) empirically based;
c) theory-laden (subjective);
d) the result of human inference;
e) imaginative;
f) creative;
g) culturally and socially infused (Akerson et al., 2000).

Students should identify that NOS is not a rigid, step-by-step process that occurs in a vacuum without influence. Much like Darwin's theory of evolution caused a paradigm shift in our understanding of the natural world, NOS in the classroom needs to reveal that science is a socially and culturally infused human endeavor. It is a process of seeking answers for natural phenomena through inference and experimentation, using imagination and creativity, which is typically influenced by the scientist's own life experiences and previous research on the topic. The nature of science is messy, but it is in the mess that we derive our bed of scientific knowledge.

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Chapter 4: An Action Research Study: How do Values and Faith Affect Students' Views on the Nature of Science?

Tina N. Stamper, Nicole Conrad Nelson

Chapter Highlights

- This study addresses how values and faith affect a student's views on the nature of science.
- This study addresses scientific misconceptions that may prevent students from viewing science and religion as compatible.
- This study suggests ways that teachers can more effectively and accurately teach nature of science concepts in a way that coexists with religious principles.

Introduction

As a college-level science instructor at a private, Christian, university, I encounter many students who exhibit a great deal of theological knowledge and religious faith. A number of these students have shared with me, over the years, how they appreciate having been raised in a home with Christian values, and then being given the opportunity to express those values freely within a higher education setting (i.e., my classroom). While the university requires me to teach scientific concepts in a way that adheres to Christian principles, it never ceases to amaze me how many students initially question my faith, values, and motives as an instructor when explaining various science topics, such as evolution, climate change, and advancements in medical technology. During these instances, it appears that these students have been so strongly indoctrinated with the Christian faith and an unfavorable view on science, that they cannot possibly comprehend the idea of the two existing together. As a result, I find myself trying to deconstruct false notions and pretenses learned previously through hearsay by my students and attempting to show them that religion and science can coexist and even complement one another. To quote the great Albert Einstein, "*Science without religion is lame, religion without science is blind*" (1941).

Purpose

The purpose of this study is to determine how values and faith affect students' views on the nature of science (NOS) prior to entering the college classroom, and how I, as a college instructor, can more effectively teach students that science and religion are compatible with one another.

Research Questions

This study aims to answer the following research questions:

Research Question 1: How do values and faith affect students' views on NOS?

Research Question 2: What misconceptions of scientific topics prevent students from viewing science and religion as compatible?

Research Question 3: How can teachers more effectively and accurately teach NOS in a way that coexists with religious principles?

Background

It is no wonder that Christian students struggle with combining religion and science, as the two have struggled to coexist peacefully throughout history. This can be seen throughout the works of ancient philosophers, as many of them fought to bring their findings to light under the pressure of religious and political leaders. The rise in philosophy was strongly intertwined with the Greeks' views on theology, their desire to understand the beginning of the world, and their tendencies towards monotheism in relation to the divine. The ideology of one God creating the universe can be seen in the philosophical work of Pythagoras, Xenophanes, Parmenides, Anaxagoras, Empedocles, Diogenes, Socrates, Plato, and Aristotle in their individual pursuits to explain the beginning of the world, or the cosmic *arché* (Drozdek, 2016).

While historians of modern day may view the work of ancient philosophers with reverence and adoration, some of them faced criminal charges and convictions of impiety, or *asebeia*, due to religious and societal norms of their times (Drozdek, 2016). For example, Aristotle was forced to flee from Athens and enter isolation in Euboea after the death of Alexander the Great left Greece in political disarray (Cohen, 2000). Socrates faced a much harsher fate when he was forced to go on trial for the offense of impiety against Athens. His prosecution brought much attention at the time and ended with a guilty verdict and the death penalty carried out by hemlock poisoning (Waterfield, 2009). Charges of impiety and Persian leanings were also brought against Anaxagoras, thought to be political in nature, due to his association with Pericles (Mansfield, 1980). This condemnation led Anaxagoras to be put on trial and sentenced to death, at which time Pericles aided in his escape from Athens to Lampsakos in Asia Minor (Cleve, 1973).

While the philosophical reasonings of these pre-Socratic philosophers was novel and scandalous at the time, they led to the observation and explanation of natural phenomena without resorting to the Greek mythology of the past. Later philosophers, studying at the Ionian School, focused more on abstract reasoning to explain the nature of matter. These scholars were mainly physicalists, or *physiologoi*, and included Anaximander, Anaximenes, Heraclitus, Anaxagoras, Hippon, and Thales. Like the pre-Socratics, they moved away from Greek mythology, and sought to explain nature through philosophy and reasoning. While students at the Ionian school are considered to be the first philosophers in Western culture, later students at the Eleatic school broadened their scope and added epistemology to their educational studies in order to examine how humans know what exists in the world around them. The Eleatics hoped to provide rationality to how the universe came to be (New World Encyclopedia, 2021; Pinto, 2017; Theodossiou & Manimanis, 2010).

The experimental methods, developed by past philosophers, continue to provide today's scientists with information and explanations regarding the natural world. Our understanding of science continues to grow as new investigations lead to more in-depth understandings (Tillery et al., 2017). However, it seems that present-day teachers lack a thorough comprehension of NOS and are ineffective in teaching science to their students (Kampourakis, 2016; Lederman, 2007). As Lederman (2007) writes, based upon Miller's (1963) conclusion, "many teachers do not understand science as well as their students, much less understand science well enough to teach it effectively." Therefore, we must ask ourselves, how do we prepare our students to effectively ask questions and make scientific observations of the world around them? Moreso, how do we teach students that science and religion are compatible and can complement one another?

Past research is limited in regard to how one's values and faith might affect their views on NOS. However, a study by Bell and Lederman (2003), determined that factors associated with NOS played an insignificant role when it came to decision-making on "complex, controversial science and technology based issues." Their study also found that a person was more likely to consider social and political issues, personal values, and ethical considerations when deciding on complex issues such as fetal tissue implantation, global warming, greenhouse gas emissions, and links between diet, exercise, smoking, and cancer (Bell & Lederman, 2003).

A study by Zeidler and Schafer (1984), focused more on how science teachers can help students to utilize moral reasoning in solving social and scientific dilemmas. Their findings implied that students should be involved in open discussions which may lead to the use of moral reasoning in solving science-related problems. While the researchers recognized that developing a scientifically literate society, capable of dealing with various issues from a moral standpoint, is a huge undertaking, they also recognized the importance of teachers in doing so. As their research states, "Science teaching is considered more than helping students acquire scientific knowledge; it is educating them for the difficult task of resolving moral dilemmas regarding science and social policy" (Sabar, 1979, as cited in Zeidler & Schafer, 1984, p. 13).

Methods

Author Positionality

Having served as a science instructor at a private, Christian, university for the past ten years, my research is structured to cater to the educational needs and desires of students attending similar institutions and the instructors who teach them. I realize that instructional and educational needs will differ based upon religious affiliation, or lack thereof. While I have a great deal of religious freedom within my college classroom, it can be assumed that teachers working within public educational institutions may not have the same liberties. Therefore, I present my findings based upon my own religious affiliation and the students whom I teach. However, I do hope that my research will assist *any* teacher or instructor in expanding dialogue with their students to prevent misconceptions of controversial scientific issues and promote a cultural and societal understanding of NOS related topics.

Participants

Upon receiving approval from the principal at a private, Christian, high school in Southern Indiana, the senior class was approached for participation in the research study. Eight senior students agreed to participate, seven students being 18-years-old, and one student being 17-years-old with parental consent. Of the eight students, two were female and six were males. Only one student stated that they had attended the school grades K-12, while three students mentioned they were previously homeschooled, and four said they had attended a different public or private school at some point in time. At the time of the research study, none of the students had committed to a post-secondary degree or training program of any type. In addition, all students stated that they were undecided in their future education and career endeavors. Students were in their final nine-weeks of the school year and had not been given science instruction since the conclusion of their junior year. As I was a guest speaker/researcher within the school, the guidance counselor was present throughout the research study and during all related student interactions.

Data Collection

The following dates within the timeline table were proposed by the school and utilized for completion of the research study (see Table 1).

Table 1. Timeline for Research Project

Timeline	
Date	Task(s) Completed
April 04, 2022	• Explained project to students. • Passed out consent/assent forms.
April 11, 2022	• Collected signed consent/assent forms and confirmed ages with school. • Students completed expanded *VNOS-Form B.* • Lesson 1. • Students completed Exit Slips.
April 21, 2022	• Lesson 2. • Students completed Exit Slips.
April 25, 2022	• Lesson 3. • Students completed Exit Slips.
May 02, 2022	• Lesson 4. • Students completed Exit Slips. • Students completed expanded *VNOS-Form B.*

The following table lists the research questions of this study, and the data collection instruments that were utilized in an attempt to answer each question (see Table 2).

Table 2. Data Collection Instruments

Research Questions	Data Collection
1. How do values and faith affect students' views on NOS?	• *VNOS-Form B,* expanded with two additional questions. • Exit Slips. • Students' Commentary.

2. What misconceptions of scientific topics prevent students from viewing science and religion as compatible?	• *VNOS-Form B*, expanded with two additional questions. • Exit Slips. • Students' Commentary.
3. How can teachers more effectively and accurately teach NOS in a way that coexists with religious principles?	• Teaching Journal. • Critical Friends' Group. • Exit Slips. • Students' Commentary.

On April 11th, students were presented with an expanded version of the *Views of Nature of Science (VNOS)-Form B Questionnaire* (See Appendix A). In addition to the seven questions that are asked on the original *VNOS-Form B* utilized by Lederman, et al. (2002), an additional two questions asked,

1.) "*How do your values and faith as a Christian affect your views on the nature of science?*"

2.) "*Do you believe religion and science are compatible- why or why not?*"

After finishing the expanded *VNOS-Form B*, a brief NOS activity was completed by the students and afterwards, they provided their thoughts regarding the activity on an exit slip. Additional NOS-related activities were completed on April 21st, April 25th, and May 2nd. After each science activity, students completed an exit slip (See Appendix B), where they were asked to share their thoughts on the activity and how their biblical faith could have been more clearly integrated into the lesson plans. Upon completion of the final session, students were again asked to complete the expanded *VNOS-Form B*. Students chose a pseudonym to use when completing all forms and exit slips to protect their anonymity throughout the research study. Data obtained from the forms and exit slips, as well as student commentary, were then utilized to determine how values and faith affect a student's views on NOS, and what misconceptions of scientific topics prevent them from viewing science and religion as compatible.

It should be noted that two students joined the study after its inception (*Students 7 & 8*). The 17-year-old student (*Student 7*) was not included in the study until April 25th, as this is when parental consent was obtained. Therefore, the only data collected from this student was an exit slip on April 25th during Lesson 3, as a previously planned college visit prevented their attendance on the final day of the study. Therefore, data from *Student 7* regarding the expanded

VNOS-Form B is not available for either occasion, nor the exit slips from Lessons 1, 2, or 4. In addition, one 18-year-old student (*Student 8*) did not provide consent until April 29th and as a result, was not included in the study until the final day for which they completed an exit slip and the expanded *VNOS-Form B*. Two of the 18-year-old students (*Students 1 & 5*) were absent on April 21st due to illness, while an additional 18-year-old student (*Student 3*) was absent on April 25th due to a planned college visit. Therefore, they did not complete exit slips on days missed. Due to availability and time allowed by the school, students were not provided an opportunity to makeup missed research sessions.

In order to determine how teachers can more effectively and accurately teach NOS in a way that coexists with religious principles, a teaching journal was kept that detailed the instructor's teaching strategies, student reactions, and the researcher's own perceptions of how she might be more effective in teaching NOS in a way that is compatible with Christian beliefs and principles. In addition, four critical friends' meetings were scheduled between the author and co-author of this paper to provide additional perspective and guidance. Information and feedback provided on student exit slips was also utilized, as well as student commentary.

Intervention

Throughout the four-weeks of this research study the instructor/researcher engaged students in four NOS-related activities. The first activity was a tangram puzzle which was specifically designed to introduce students to NOS, engage them in an active learning process, and illustrate that science is an ever-changing and dynamic process (Choi, 2004; NASA Solar Dynamics Laboratory, 2008). The second activity was designed to engage students in the social and cultural aspects of NOS. During this activity students were asked to briefly research a place they have been or would like to go someday. Students were instructed to explore geography of the area, demographics, native plant and animal communities, any products or scientific advancements that have come from the area, as well as political affiliations or religious beliefs amongst the people living there. Students were asked to share their findings with their classmates and an opportunity was taken to discuss how the needs of a certain society dictate the direction science will take (McComas, 2015). During the third activity, students were asked to work collaboratively, using different building materials (e.g., Legos®, K'NEX, wood, metal, string, etc.) to build a bridge at least 12-inches in length and having the ability to hold a three-pound weight. This activity was designed by the instructor/researcher to engage students in an active, collaborative, learning process while allowing them to use their own creativity and imagination, along with observation and inference, in relation to scientific theories and laws that may be utilized by architects, physicists, and engineers (Heyman, 1999; Salingaros, 1995). This activity was also used to explain that while science is used in engineering and technology, it is distinct from the two (McComas, 2015).

As with the study by Akerson, et al. (2000), these activities were chosen and/or designed to be introductory, generic, and non-threatening in nature. Throughout each activity, the instructor/researcher provided explicit NOS instruction, and upon completion of each activity, students were asked to reflect upon the various NOS concepts and how they could otherwise be used in different science activities or science-related career fields. The instructor/researcher used each opportunity as a trust building exercise to engage students in active learning, while listening to their concerns, and answering questions in a scientifically, fact-based, manner.

The fourth activity, conducted during the final week of the research study, again delved into the human elements of NOS as it relates to society and culture (McComas, 2015). However, instead of researching a particular topic, students were asked to think of a controversial science topic and verbally describe how their values and religious beliefs affected their personal thoughts and/or emotions on that topic. In addition, students were asked to consider how their own past, personal, experiences might influence their thoughts on that topic, but also consider an alternative by imagining themselves in “someone else’s shoes.” To complete the exercise students were asked if they believed media or politics played a role in the controversy of their topic, and if that in turn influenced the direction that science would take in regard to novel ideas.

After each session the instructor/researcher recorded a written journal entry detailing her thoughts on the lesson, positive responses from the students, any negative reactions, and ways that she could have more effectively utilized religious concepts in teaching NOS principles while also deconstructing scientific misconceptions.

Data Analysis

Triangulation of data was achieved by comparing students’ answers on the expanded *VNOS-Form B Questionnaire* (pre- and post- instruction), exit slips, and verbal communication, while also reflecting upon personal entries within a teaching journal, and receiving feedback from a critical friend. Data analyses of these items is described below.

Questionnaires

Data provided by the students on the expanded version of the *VNOS-Form B*, pre- and post-instruction, were analyzed and coded individually by both the author and co-author of this study. Due to the subjective nature of analysis and coding, an independent, third-party, individual also analyzed and coded the data in order to provide consensus amongst the three. Student answers for Questions 1-7 were coded as, "Inadequate," "Adequate," or "Informed," based upon the research of Akerson, et al. (2019). As the *VNOS-Form B* was expanded for this particular study, the table utilized by Akerson, et al. (2019) was adapted and expanded to meet the needs of this particular research project. Therefore, Questions 8-9 were coded as, "Minor," "Moderate," or "Substantial." Codes were evaluated pre- and post-NOS instruction to determine the changes that occurred in the students' views of NOS, their views on scientific and religious compatibility, and any scientific misconceptions that they may hold. Answers and comments provided on exit slips were also analyzed by the primary author to determine trends of how religion could better be incorporated into each NOS lesson.

Teaching Journal

A self-reflective methodology was utilized to determine how the instructor/researcher could better incorporate religious principles into NOS lesson plans. Journal entries focused on the instructor's impressions of student reactions, student comments, and student participation. Entries were also evaluated in regard to the instructor's thoughts on self-performance within the classroom. Notes were made in regard to successful teaching methods, needed improvement, and teacher/student interactions. A critical friends' group formed between the author and co-author of this study also served as feedback in regard to instructor performance.

Students' Commentary

Verbal comments made by students were recorded, transcribed, and evaluated to determine how they believed scientific misconceptions occur, as well as their thoughts on how controversial science topics affect their own scientific research and decision making in relation to their values and religious faith. Student comments were also evaluated for their thoughts on how science instruction can be improved to incorporate religious and scientific principles.

Results

Questionnaires

Expanded VNOS-Form B

The following table illustrates the coding of the six students' answers in relation to each question as they pertain to Questions 1-7 of the *VNOS-Form B,* utilized by Lederman, et al. (2002) (see Table 4).

Table 4. Total Student Responses to the Expanded VNOS-Form B, Questions 1-7

Question	Response Coding (n = 6)					
	Inadequate		Adequate		Informed	
	Pre	Post	Pre	Post	Pre	Post
1	0	0	5	6	1	0
2	5	3	1	3	0	0
3	3	5	2	1	1	0
4	3	5	3	1	0	0
5	0	0	4	6	2	0
6	0	0	6	5	0	1
7	1	0	5	6	0	0

In this section, results will be shared as they relate to each research question. The following results apply to answers provided by *Students 1-6*, as they completed the expanded *VNOS-Form B* after both pre- and post-NOS instruction (See Table 4). Thoughts and comments provided by the author and co-author of this paper have been included where applicable.

In regard to Question 1, pre-NOS instruction, five of the six students had an adequate understanding when it came to the tentative aspects of NOS, while one of the six students was informed. However, all students failed to address the difference between theories and laws. The following is an example of a student's answer that was coded as adequate in regard to tentative NOS.

Student 2: "Yes, if there has been new research found to prove otherwise. With new information being found everything is changing."

The following is an example of a student's answer that was coded as informed in regard to tentative NOS.

Student 4: "Theories do change after time as knowledge is gained. An example is the theory that the Earth used to be viewed as being in the middle [of our solar system]. We teach theories to get us thinking until it's proven or corrected. Going back to when the Earth used to be thought as being in the center of our solar system and how it later was debunked and that the sun is in the middle."

In regard to post-NOS instruction, Question 1, the answers of all six students were coded as being adequate in regard to the tentativeness of NOS. However, they continued to omit the difference between theories and laws. The post-NOS instruction response provided by *Student 1* is shown below, as well as a response from *Student 4.*

Student 1: "The theory can change. Theories are proposed ideas, so the scientist might find information that opposes that idea (theory)."

Student 4: "Yes, it changes over time as you experience and gain more knowledge. We teach theories to get us thinking. An example is the Earth used to be thought to be in the center of everything."

Comments from the author and co-author in relation to the students' answers to Question 1, pre-NOS instruction are shown below.

Author: "Students' views ranged from adequate to informed. However, none of them referenced the difference between theories and laws. They seemed to focus on either science or theory; they didn't combine the two."

Co-Author: "All had at least an adequate understanding of the tentative NOS. None of the students were able to adequately explain or tie theory into their answer."

In regard to Question 2, pre-NOS instruction, five of the six students had an inadequate understanding when asked what an atom looks like and how certain scientists are about the structure. Only one of the six students provided an adequate answer. Most students mentioned the use of a microscope to determine what an atom looks like. Below are examples of students' responses in relation to Question 2, pre-NOS instruction, coded inadequate and adequate, respectively.

> *Student 6: "An atom consists of a nucleus in the center, made up of protons and neutrons. Then surrounding that is the electron cloud with electrons in it. I don't know how certain scientists are about the structure of atoms. I also am not sure of what evidence scientists used to determine this."*

> *Student 5: "From studies that scientists have had on atoms, they are pretty certain about the structure."*

In regard to post-NOS instruction, three out of six students were coded as being inadequate, while the remaining three students were coded as being adequate in regard to their answers for Question 2. Thoughts from the author and co-author are below.

> *Author: "One student asked, 'What is an atom?' Several of the students mentioned that scientists are very certain based upon the use of a microscope."*

> *Co-author: "Several students have misconceptions that an atom can be viewed with the use of a microscope."*

In regard to Question 3, pre-NOS instruction, three of the six students had an inadequate understanding regarding the difference between a theory and a law. Two students had an adequate understanding, and one student had an informed understanding. Below are examples of students' responses in relation to Question 3, pre-NOS instruction, in order of inadequate, adequate, and informed.

> *Student 1: "Yes, there is. A person can have a theory and be wrong, while a law is never wrong. I can theorize that a ball will stop rolling, but the 1st law of physics says that it won't."*

Student 3: "Theory describes phenomena that the scientific community has found to be true. Law describes what will happen in a given situation."

Student 6: "Yes. A theory is something that is not always fully understood. A law states fact, which is true. Theories try to give an explanation of the fact, why something happens the way that it does. Scientific law says that gravity is real. The theory of gravity tries to explain it."

In regard to Question 3, post-NOS instruction, five of the six students had an inadequate understanding regarding the difference between a theory and a law. The remaining one student had an adequate understanding. While all of the students seemed to understand that there is a difference between a theory and a law, they failed to mention what that difference is. An example of one student's answer, coded as inadequate, is shown below.

Student 2: "Yes, theory is an educated guess. Scientific law is known."

In relation to Question 4, pre-NOS instruction, three of the six students had an inadequate understanding regarding the difference between art and science. The other three students appeared to have an adequate understanding. Below are examples of students' responses in relation to Question 4, pre-NOS instruction, coded inadequate and adequate, respectively.

Student 3: "They are both attempts to understand the world around us. Science deals with chemicals and life, art doesn't."

Student 5: "They are similar because when you look at things related to science and art, you have to comprehend and study these things to be able to know what they are. They differ because science is based on theories and hypotheses to learn about things and explain them. Art is different, it needs no proof. It cannot be proven."

In relation to Question 4, post-NOS instruction, five of the six students had an inadequate understanding regarding the difference between art and science. The remaining one student appeared to have an adequate understanding. Below are examples of students' responses in relation to Question 4, post-NOS instruction, coded inadequate and adequate, respectively.

Student 4: "They are similar because you can use both to build off each other. Art is theory in a sense just like science. They are different based off of their general concepts."

Student 6: "Science and art are similar because creativity is a part of both. Art is more about creativity, while science is about fact. They are different but have some things in common."

Thoughts from the author are below.

Author: "Students gave a variety of responses. Most knew there was a difference between art and science; however, they failed to mention that science requires evidence."

In relation to Question 5, pre-NOS instruction, four of the six students provided answers which were coded as adequate. Two of the six students provided answers which were coded as informed. Below are examples of students' responses in relation to Question 5, pre-NOS instruction, coded as adequate and informed, respectively.

Student 3: "Yes, they do because without their creativity they wouldn't have as wide of an imagination for the experiment."

Student 5: "Yes, they use these things to try and experiment with different things to try and get different results. After doing so, they then take what they have collected and put pieces together to try and learn new things."

In regard to Question 5, post-NOS instruction, all six students provided answers which were coded as adequate. Below is an example of one student's response in regard to Question 5, post-NOS instruction.

Student 4: "You almost have to use creativity and imagination to gain more knowledge or understanding. It's how you go outside the box by taking your own thoughts and ideas. An example is that without Albert Einstein's equation for the atomic bomb they probably wouldn't have created them."

Comment from the author is shown below.

> *Author: "Most students understood creativity but failed to realize it occurred throughout the scientific process."*

In relation to Question 6, pre-NOS instruction, all six students provided answers which were coded as adequate. Below are examples of students' responses in relation to Question 6, pre-NOS instruction.

> *Student 2: "Yes, a scientist can say something they think and it [might] be wrong. Knowledge will be able to be backed up with evidence."*

> *Student 5: "Yes, knowledge is what you know and what has been proven as a fact from research and study. Opinion is what someone believes based on what they believe. An example would be gender. It has been proven that there is male and female. Others will argue that there is no gender and that it is opinion based."*

In relation to Question 6, post-NOS instruction, the answer of one student was coded as informed, while five out of the six students provided answers that were coded as adequate. Examples of students' responses to Question 6 are listed below in the order of adequate and informed, respectively.

> *Student 3: "Yes, opinion is something that someone has and no one can change that. Knowledge is something that someone gains from eagerness to learn."*

> *Student 6: "Yes, scientific knowledge and opinion are different. Knowledge has to do with fact, what has been proven to be true. Scientific opinion is more of what someone thinks about something, there are more options for this because imagination and creativity are involved."*

In regard to Question 7, pre-NOS instruction, one of the six students had an inadequate understanding when asked about the expansion of the universe. Five of the six students provided an adequate answer. Below are examples of students' responses in relation to Question 7, pre-NOS instruction, coded inadequate and adequate, respectively.

Student 1: "Some don't want to admit they are wrong, or others may convince them their data is wrong."

Student 5: "They are different because different scientists look at things and think they see something, so then they take that knowledge. It's really opinion based from what they studied."

In relation to Question 7, post-NOS instruction, all six students exhibited adequate knowledge when asked about the expansion of the universe. Most students seemed to reference how individual scientists can see things differently and also have different thoughts and perceptions of various subjects.

The following table illustrates the coding of the six students' responses in relation to each question as they pertain to Questions 8-9 of the expanded *VNOS-Form B,* as designed for this study. (See Table 5).

Table 5. Total Student Responses to the Expanded VNOS-Form B, Questions 8-9

Question	Response Coding (n = 6)					
	Minor		Moderate		Substantial	
	Pre	Post	Pre	Post	Pre	Post
8	0	0	0	0	6	6
9	0	0	1	1	5	5

In regard to Question 8, pre-NOS instruction, all six students stated that their values and faith as a Christian substantially affected their views on NOS. Below are examples of students' responses in relation to Question 8, pre-NOS instruction, coded as substantial.

Student 2: "God made this world in His image and everything in it."

Student 6: "I see everything through a Biblical lens. So, when I look at science, I see it with a creator in mind. The nature of science is set up by God, I believe. So, my faith makes a difference in how I see science and the world."

In regard to Question 8, post-NOS instruction, all six students continued to state that their values and faith as a Christian substantially affected their views on NOS. All student responses were coded as substantial.

In regard to Question 9, pre-NOS instruction, one student's response was coded as moderate in regard to their thoughts on scientific and religious compatibility. The remaining five students' responses were coded as being substantial in regard to the compatibility of science and religion. Below are examples of students' responses in relation to Question 9, pre-NOS instruction, coded as moderate and substantial, respectively.

> *Student 2: "I think they're [compatible] in certain aspects, but also contrast in others. I think when certain topics are left out, the better the compatibility."*

> *Student 1: "Yes, specifically Christianity according to the Bible, because God created it, and He is right and perfect."*

In regard to Question 9, post-NOS instruction, again, one student's response was coded as moderate in regard to their thoughts on scientific and religious compatibility while the remaining five students' responses were coded as being substantial in regard to the compatibility of science and religion. While *Student 8* was not included in the data results of the expanded *VNOS-Form B*, post-NOS instruction, as explained earlier, her response to Question 9 is shown below.

> *Student 8: "I believe that they go hand-in-hand together. God created this world and the things around us. Things that scientists figure out would not be here without God. Everything in the world has to do with God and most of the Earth has something to do with science."*

While the above results focused on student answers as a whole, the following table shows individual student responses and changes in ideology from pre- to post-NOS instruction (see Table 6). In regard to Question 1, *Students 1, 2, 3, 5, and 6,* were considered to have adequate knowledge on the tentativeness of NOS, pre- and post-instruction. *Student 4* seemed to decrease in understanding, going from an informed to adequate understanding. In regard to Question 2, *Students 1, 2, 3, and 5* remained consistent in having inadequate knowledge regarding the structure of an atom. However, *Students 4 and 6* increased their knowledge from an inadequate to adequate understanding. When looking at Question 3, *Students 1, 2, and 5* continued to have an inadequate understanding regarding the differences between scientific theory and law. *Students 3 and 4* decreased in knowledge with answers coded as adequate prior to pre-NOS instruction and inadequate post-NOS instruction. The same was seen in *Student 6,* as their answer was coded as informed prior to pre-NOS instruction and adequate post-NOS instruction.

Table 6. Individual Response Codes for Answers to Expanded *VNOS-Form B,* Pre- and Post-Instruction

Student Number	Expanded *VNOS-Form B* Questions, Pre- and Post-NOS Instruction																	
	Q1		Q2		Q3		Q4		Q5		Q6		Q7		Q8		Q9	
	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2	R1	R2
Student 1	A	A	I	I	I	I	I	I	A	A	A	A	I	A	S	S	S	S
Student 2	A	A	I	I	I	I	A	I	A	A	A	A	A	A	S	S	M	S
Student 3	A	A	I	I	A	I	I	I	A	A	A	A	A	A	S	S	S	S
Student 4	IF	A	I	A	A	I	I	I	A	A	A	A	A	A	S	S	S	S
Student 5	A	A	A	A	I	I	A	I	IF	A	A	A	A	A	S	S	S	M
Student 6	A	A	I	A	IF	A	A	A	IF	A	A	IF	A	A	S	S	S	S

Key:
Q = Question
R1 = Round One, Answer Pre-Instruction
R2 = Round Two, Answer Post-Instruction
A = Adequate
I = Inadequate
IF = Informed
M = Moderate
S = Substantial

In regard to Question 4, *Students 1, 3, and 4,* continued to have an inadequate understanding of the similarities between art and science, while *Student 6* continued to have an adequate understanding. *Students 2 and 5* appeared to decrease in knowledge with answers going from adequate to inadequate pre- and post-NOS instruction, respectively. In relation to Question 5, all students remained the same in regard to their knowledge base pre- and post-NOS instruction. Question 6 showed similar results with *Students 1-5* remaining consistent in their knowledge, while *Student 6* increased their knowledge post-NOS, moving from adequate to informed. In regard to expansion of the universe, Question 7 showed *Students 2-6* remaining consistent with adequate knowledge between pre- and post-NOS instruction, while *Student 1* increased their knowledge from inadequate to adequate. Question 8 demonstrated that all students remained consistent through pre- and post-NOS instruction by stating that values and faith substantially affect their views on NOS. And lastly, Question 9 demonstrated a shift in the thoughts of *Student 2*, as their answer went from moderate to substantial regarding their beliefs on scientific and religious compatibility, pre- and post-NOS instruction, while the thoughts of *Student 5* shifted from substantial to moderate. *Students 1, 3, 4, and 6* continued to believe that religion and science were substantially compatible from pre- to post-NOS instruction.

Exit Slips

Information provided by the students on exit slips seemed to be considerably lacking. When asked what the clearest concept was during each lesson, all students were specific in describing at least one new fact that they had learned. When asked which scientific concepts were least clear, students provided very little, if any, information regardless of the lesson that was taught. In addition, none of the students made suggestions for improving any of the lessons in relation to the integration of NOS and faith. However, all students were very opinionated in describing how their biblical faith could have been more clearly integrated into each lesson. Based upon responses, it would appear that the students felt Lesson 3, Bridge Building, was the least capable of being integrated into biblical faith. Many students stated that they were unsure of how the lesson could be integrated with faith, or that the two simply weren't related.

Teaching Journal

Notes from the instructor/researcher's teaching journal showed a shift in the students' demeanor and willingness to participate in the research project. During the initial visit with the students, they were very quiet and showed little interest in participating in any activities. Two of the students seemed agitated and voiced their frustration with having to be there. Another student asked, "Why are you doing this project?" However, upon the second visit, six students provided their consent to participate in the study and were much more receptive to the instructor/researcher meeting with them. The journal entry for the second visit notes that students spent an adequate amount of time completing the expanded *VNOS-Form B* and appeared to genuinely be interested in providing thoughtful, intelligent answers. Students seemed to really enjoy the NOS tangram puzzle, and several stated that they didn't think it would be as challenging as it was.

Students seemed very eager to participate during the second and third activities. They were very excited during Lesson 2, for which they were asked to research and explore a place that they would like to visit. As students conducted their research, you could hear gasps around the room as they would find something new. One student exclaimed, "I never knew this!" Another stated, "I just saw this on National Geographic last week!" Students found information on location, habitat, climate, plant and animal communities, geography, and demographics. They seemed excited to present their findings to their classmates and were actively engaged in asking questions and providing information to each other through personal knowledge or lived experience.

Students were equally engaged during Lesson 3, the bridge building activity. The instructor had barely finished explaining the activity before students jumped out of their seats to grab various construction materials to begin building their bridges. Most of the students chose to work in groups, while one student chose to work individually. Through groupwork and collaborative ideas, all students working in a group were able to build a bridge at least 12-inches in length that withstood a 3-pound weight. Only the student who chose to work individually was unable to complete the task. Students seemed to recognize that various scientific concepts, theories, laws, observation, and inference are utilized in the building process.

During Lesson 4, students were engaged in conversation regarding controversial science topics. To begin the lesson, an explanation of evolution was provided by the instructor/researcher, describing the differences between micro- and macroevolution. Many students had never heard of either microevolution or macroevolution; therefore, were unaware that there was a difference between the two. While initially reserved regarding this topic, most students were open to learning about it and sharing their thoughts. In addition, students seemed genuinely excited to hear that microevolution is generally accepted by Christian circles and can be compatible with one's Christian faith. Upon completion of this conversation, students were asked if scientific evidence could sway their thoughts on science in regard to their religious beliefs. Several students said that it could, provided they were shown adequate scientific evidence.

Students' Commentary

Student commentary from Lesson 4, regarding controversial science topics, showed that students were most concerned with evolution, gender identity, and Covid-19 vaccines. However, one student's comments were found to be particularly interesting in how he described his experience with being taught evolution as a student in the public school system. A conversation between *Student 2* and the instructor/researcher is shown below as he explains being taught the subject of evolution without being able to question the topic or the teacher…

> *T.S.: "Could you give your thoughts on how that type of teaching relates to your faith on science topics?"*
>
> *Student 2: "It [evolution] was completely against it [my faith] and it was very disheartening to hear that we didn't have any say, and we didn't have any feedback or response that we appreciated or respected. And the way that he [the teacher] did go about it."*
>
> *T.S.: "O.K., so how did he [the teacher] go about it that put you off on the topic [evolution] so much?"*
>
> *Student 2: "We didn't really have a say and all of our questions were kind of pushed to the side and I wasn't really listened to, and it felt like we were getting disrespected the whole time in our conversations."*
>
> *T.S.: "So, he wasn't really open to you asking questions about the topic?"*
>
> *Student 2: "No."*
>
> *T.S.: "Was he open to explaining the topic, other than what he had planned out to say, do you think?"*
>
> *Student 2: "No. I think what he had in mind was his final, cut, decision on what he was going to say."*

Critical Friends' Meetings

Conversations between the author and co-author during critical friends' meetings showed that NOS is a novel concept to most students. While many students are open to learning new concepts and new ideas regarding NOS, it cannot be assumed that they will acquire this knowledge without proper, explicit instruction. Statements regarding the thoughts and realizations of the author and co-author are shown below.

> *Author: "I had the realization that a lot of these students, whether they're in college or high school, they are open to learning about different things and they are open and excited, actually, to learn about controversial topics and different things that they previously didn't know about or weren't aware of. But, it has to be* done in a non-*threatening manner."*

> *Co-Author: "Nature of science is new to the students. They don't really have a very sophisticated understanding of the nature of science, even less so than I expected at this age, but just doing the activities, or not even activities, but just discussing some of the questions with them, I feel like planted a seed to help them at least kind of look for those concepts. For me, personally, it was this big realization that nature of science actually has to be explicitly taught and not just assumed that they're just going to pick it up through regular science content."*

Discussion

Limitations

As mentioned within the author's positionality statement, this particular study was meant only to provide results from a Christian perspective, and fails to address how the values and faith of students belonging to other religious affiliations might affect their views on NOS. In addition, the findings of this study may not be applicable to those teachers or students within the public school system, as government sponsored religious speech is prohibited by the Establishment Clause of the First Amendment of the U.S. Constitution (McCarthy, et al., 2019; U.S. Const., Amend. I).

In addition, the sample size for this study was quite small as we relied on voluntary participation from the senior students at one, private, Christian, high school in a particular geographic area. Therefore, the ideas portrayed may not be representative of the Christian faith as a whole. Data collection was also limited to a certain time period in order to fit the students' daily schedule and the school's yearly academic calendar. Therefore, results are only representative of the four instructional periods that the instructor/researcher was able to meet with the students. Moreso, all students were not present for every research session due to illness and/or college visits which prevented a complete data set from being obtained. It should also be recognized that the data collected is only as reliable as that which was provided by each student. As students were in the final nine-weeks of their senior year and also in the process of planning for their senior class trip, it could be assumed that their focus and priorities may have been elsewhere during the times of data collection.

Lastly, the coding of students' answers was a very subjective process. While the author may have coded an answer one way, the co-author may have coded it completely differently. Thus, the reason for the third-party coding in an attempt to reach consensus. While the results of coding may have been limited due to the subjectivity involved, all attempts were made to achieve adequate data and reliable results.

Conclusion

This study aimed to determine 1.) how values and faith affect students' views on NOS; 2.) what misconceptions of scientific topics prevent students from viewing science and religion as compatible; and 3.) how teachers can more effectively and accurately teach NOS in a way that coexists with religious principles. By expanding the *VNOS-Form B* originally utilized by Lederman, et al. (2002), we were able to show that individual values and faith held by the students in this particular study substantially affected their views on NOS. In addition, notes made within the teaching journal regarding the students' lack of knowledge in relation to micro- and macroevolution, indicate that incomplete or inaccurate information leads to misconceptions of scientific topics. This, in turn, prevents students from viewing science and religion as compatible. Students' commentary would also indicate that *how* a teacher teaches something is just as important as *what* is being taught. Therefore, not only should a teacher be armed with accurate and complete information, but also encourage the students to actively participate in the learning process by asking questions and challenging or disputing information that they may not agree with. Based upon our findings, teachers should equip themselves with accurate, complete, and factual information in an attempt to decrease misconceptions that students may hold regarding religious and scientific compatibility. As discussed in the study by Akerson and Abd-El-Khalick (2003), teachers need to internalize the importance of teaching NOS to their students, but also receive support in translating their own NOS knowledge into meaningful and explicit NOS instruction. Hopefully, this will help to ensure more informed decision making when students are confronted with cultural, societal, and political issues.

Recommendations

Based upon this active research study, it is our recommendation that teachers make every effort to fully understand the NOS concepts they intend to teach, prior to introducing such information to their students, in an attempt to prevent scientific misconceptions. In addition, teachers should be aware that some students will hold preconceived notions regarding certain scientific topics as a result of having received incomplete or inaccurate information in the past. In an effort to counteract these falsehoods, teachers should present information in a way that engages students in the material and encourages them to ask questions and investigate the information further. While students' values and faith were shown to significantly affect their views on NOS, teachers should be aware that these same students wish to have intelligent conversations and make informed decisions regarding scientific topics and the political and societal issues that surround them. And lastly, it should be noted that this particular study focused soley on the NOS views of one group of students from a single demographic, who were being educated within a private, Christian, K-12 school just north of the "Bible Belt." Future research is needed to account for the NOS views of students belonging to different religious affiliations, diverse demographic backgrounds, as well as varying geographic areas and schools within public and private sectors.

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Appendix A. Expanded Views of Nature of Science Questionnaire

1. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the structure of atoms? What specific kinds of evidence do you think scientists used to determine what an atom looks like?

3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.

4. How are science and art similar? How are they different?

5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.

6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.

7. Some astronomers believe that the universe is expanding while others believe it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

8. How do your values and faith as a Christian affect your views on the nature of science?"

9. Do you believe religion and science are compatible- why or why not?

Appendix B. Exit Slip

Lesson: ____1 ____2 ____3 ____4 ____5

1. What was the clearest scientific concept that you learned during this lesson?

2. What scientific concept do you feel was least clear, or needed further discussion during this lesson?

3. How do you feel your biblical faith could have been more clearly integrated during this lesson?

4. Please make any other suggestion(s) that you feel would improve this lesson in regard to the nature of science and faith integration.

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Commentary: Action Research Studies on In-Person Nature of Science Teaching and Learning

Mills (2018) defines action research as:

> any systematic inquiry conducted by teacher researchers, principals, school counselors, or other stakeholders in the teaching/learning environment to gather information about how their particular schools operate, how they teach, and how well their students learn. This information is gathered with the goals of gaining insight, developing reflective practice, effecting positive changes in the school environment (and educational practices in general), and improving student outcomes and the lives of those involved (p.10).

The authors in this section, all teachers, engaged in action research studies to explore how they embedded nature of science (NOS) within their in-person teaching contexts. While those contexts differed, the authors found that their inquiry-based, explicit, and/or reflective instruction (Akerson, Abd-El-Khalick, & Lederman, 2000) supported an increased understanding of various tenets of NOS.

Poindexter explored how an engaging context (fairy tales and mock crime scenes) can impact kindergarten students' understanding of NOS, in particular in making observations and inferences. She found that whole-class discussions were valuable in supporting her kindergartener's conceptualizations of observation and inference. Johnston and Akerson explored Johnston's high school chemistry students' understandings of NOS after participating in a unit on The Gas Laws and Kinetic Molecular Theory. They found that Johnston's explicit and reflective NOS instruction in her chemistry course that focused on the Next Generation Science Standards (Lead States, 2013) supported increased understanding of all of the six NOS tenets measured. Furthermore, in her exploration of how NOS can be emphasized in a unit about evolution, Harshberger facilitated learning experiences for her high school students to emphasize how science is not conducted using a linear, rigid "method." By focusing on

Darwin's work, students explored how scientists can be influenced by his life circumstances, thus it is logical that Harshberger's students' conceptions of the subjectivity of science improved more than any other conception of NOS. Indeed, her instruction supported growth in students' understandings about NOS and the dynamic contexts in which science is conducted. Stamper and Nelson explored a unique topic of exploring how 8 senior high school students' values and faith may have affected their views of NOS. Students shared some of their experiences pondering if and how science and religion are compatible, and the authors indicate, "Students commentary would also indicate that how a teacher teaches something is just as important as what is being taught."

These action research studies conducted in an in-person learning context further support prior research that indicates that students can learn NOS through inquiry-based, explicit, and/or reflective instruction (Akerson, Abd-El-Khalick, & Lederman, 2000) across grade levels. Furthermore, the teachers in this section were able to successfully embed tenets of NOS into their instruction as they selected key components of NOS based on their teaching context (e.g., observation and inference for kindergarteners; Scientific Investigations Use a Variety of Methods, Science Is a Human Endeavor for high school students).

Critical to action research, each author gleaned important insights about teaching NOS within their context, in particular how to scaffold and support students' thinking as they develop their understanding of NOS. Indeed, Harshberger found that by framing her NOS instruction with the life story of Darwin, students became familiar with the "humanness" of science (i.e., Science in a Human Endeavor). Poindexter found that whole-class discussions were valuable in supporting her kindergarteners' conceptualizations of observation and inference as they viewed a mock crime scene based on a familiar story. Similarly, Stamper and Nelson suggest that "accurate and complete information" is critical to facilitating learning about NOS that may be unfamiliar or that challenges students' beliefs, and that discussion, or as Stamper and Nelson state, "encourage[ing] the students to actively participate in the learning process by asking questions and challenging or disputing information that they may not agree with," is important. Thus, narrative and discursive aspects of science teaching were shown to be effective components of the authors' NOS instruction. Moreover, while Harshberger focused on Darwin's life and work to elucidate NOS, Johnston and Akerson suggested use of more examples, either within lessons or science concepts, of NOS as they relate to NGSS.

Action research can be a powerful tool for examining one's own teaching and exploring not only the effect of one's teaching, but also ways in which facilitation of students' learning can be more impactful. The authors in this section systematically explored their NOS instruction and offered insights about the impact of their instruction as well as further ways to support students' development of NOS conceptions. The following section includes action research studies conducted in an online context.

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SECTION II - ACTION RESEARCH STUDIES ON ONLINE NATURE OF SCIENCE TEACHING AND LEARNING

Chapter 5: Effectiveness of Teaching Key Concepts of the Nature of Science in an Online Introductory Forensic Science Course: An Action Research Study

Gina Londino-Smolar

Chapter Highlights

- Teaching the nature of science key concepts in a science course in higher education
- Using basic forensic science topics, such as fingerprints, to impress nature of science concepts
- Evaluating undergraduate students' level of understanding of the nature of science course both before and after instruction
- Demonstrating the use of an online environment to teaching the nature of science concepts

Introduction

There has been a variety of studies done on how the nature of science (NOS) is taught in both elementary and secondary schools. This has included both from the student perspective and how the educator teaches the areas of the NOS in the classroom. However, teaching NOS in undergraduate-level science courses is not very common or if NOS is being taught, it is not defined. This could be for various reasons, such as the professor's background, course content, or required student learning outcomes of the course.

Many college educators are not formally trained to teach, mainly focusing on research and finding financial support for their interests, which is a major requirement (Brownell & Tanner, 2012). This is often seen as more work that takes time away from research and at large research institutions, graduate teaching assistants (TAs) many times are in the classroom teaching undergraduate courses, both for science majors and non-majors. For this reason, introductory science courses focus on content rather than how key science concepts can align with NOS (Akgun & Kaya, 2020). There are opportunities within the curriculum in various introductory undergraduate level science courses to incorporate a linkage to NOS, however, due to lack of knowledge, time, or interest, it is not done (Abd-El-Khalick, 2013; Koksal & Cakroglu, 2010).

Many introductory level science courses have a heavy content load that must be covered to prepare students for sequential courses in the curriculum. This may hinder the ability to cover common NOS topics in the course. Course content is usually directly related to the student learning outcomes of the course and aligned with the assessment used to evaluate student learning. Specific concepts of NOS may not be required in the course, therefore, these are overlooked and not included in the instruction of the course content (Wahbeh & Abd-El-Khalick, 2013). However, there is a great opportunity to teach the main concepts of NOS related to the course material. This can be done in introductory undergraduate-level courses.

It is important to be familiar with each of the NOS concepts and how these can be applied into the classroom through specific course materials. The main concepts included in the nature of science are (Wheeler, 2019):

- scientific knowledge is empirically based
- science is both reliable and tentative (revisionary)
- scientific knowledge is based upon both observations and inferences

- creativity is important to the development of scientific knowledge
- science is subjective and theory-laden
- scientific theories and laws are different types of scientific knowledge, but both are supported by evidence and can be modified in light of new evidence or interpretation of data
- science is socially and culturally embedded
- scientists use a variety of approaches (methods) to answer questions about the natural world

Some areas may benefit from doing hands-on activities, where other concepts may be best taught in a group setting, encouraging student collaboration. There are also different methods an educator can use to incorporate concepts into the teaching style, both implicit and explicit methods are highlighted throughout the NOS research (Khishfe & Abd-El-Khalick, 2002). Explicit methods seem to be more effective in teaching the NOS to K-12 students (Akerson et al., 2019; Akerson et al., 2000), which can be applied to the undergraduate learning experience as well. There might also be a need for specific concepts to be taught within specific disciplines, for example, the ways in which culture has affected an individual's view and acceptance of science concepts. There are many considerations when thinking about how NOS is taught in higher education. Many college-level institutions require all students to complete a general education core curriculum, which includes physical and natural sciences, and may also include laboratory experience. This applies to students that are not science majors and who many times struggle with science concepts, especially at the college level. Undergraduate students usually struggle with what scientific knowledge is and the importance of science in modern life (Gallucci, 2009.) Also, many college-level instructors' primary education is within the discipline taught and not in how to teach.

Background

Throughout the discovery of the influence of NOS in higher education, there were specific areas that are key to this research study. Research in these areas will be discussed below.

- The level of science courses being taught in higher education - ranging from non-science major courses, lower (introductory) and upper (advanced) level science courses for majors, and science for K-12 teachers (pre-service teachers)
- The science discipline taught in the course - specifically looking at biology coursework,

engineering, and the use of technology in the classroom

- The application of NOS in forensic science education

Level of Science Coursework

Course level courses within science to be dramatically different, depending on the students' major as well as the intended degree. Many universities have a general education core curriculum, which requires all learners to complete a variety of courses in order to have a well-rounded education. Therefore, if a student is majoring in liberal arts, there is still a requirement to complete a physical science course. This is the same for a science major required to fulfill a course requirement in world history, for example.

The main purpose of requiring coursework in disciplines outside one's major is to familiarize learners with all areas of knowledge and to provide literacy among all disciplines. Studying science is needed in a good liberal education due to the ability to practice critical and analytical thinking skills in today's culture, effective use of teamwork and communication, and the ability to problem-solve (Ramaley, 2005). Embedding NOS concepts in coursework is a valuable aspect of scientific literacy that affects learners' ability to make informed decisions and act responsibly when faced with complicated scientific issues (Kahana, 2019). Due to these types of requirements, there is a need to have non-science major coursework throughout scientific departments, such as chemistry, biology, and physics. This can be a prime example of NOS that should be taught in a university course to instill scientific literacy in students without a strong scientific background. Many times, young students view science as facts that cannot be changed. Students thus think that scientists have already discovered all the facts and science concepts are already known, which can discourage student learning and attitude toward science (Cavallo, 2008).

Throughout the literature, biology and evolution introductory courses were commonly used to study undergraduate students' understanding of NOS because of the connection between social culture and science. Students' views of evolution were often connected to the empirical NOS views (Borderding, 2019). These types of courses were geared towards non-science majors. Science learners, unfamiliar with science, commonly misunderstand that scientific knowledge is based on multiple types of evidence that may change and can be reinterpreted from a different perspective. Non-science learners expect knowledge to be certain, unchanging, and consistent with authorities such as religious dogma (Borderding, 2019). This can be done using case studies and common real-world examples which are familiar to learners. One example of a NOS case study is the use of family photographs which allowed students to test hypotheses through observations, develop reasoning, and summarize conclusions (Gallucci, 2009). This can be especially effective in non-science major coursework, by connecting a real-life example to a scientific background, as well as exposing college students to the nature of science (Gallucci, 2009).

For courses geared toward science majors, both lower and upper-level coursework were used to examine the learners' perspectives of the NOS. Borgerding et al. (2019) found that there was a significant relationship between NOS understanding and the specific course. Upper-level biology students had more exposure to NOS concepts during their undergraduate experiences compared to non-biology majors. Also affecting the understanding of NOS views may be the biology majors' ability to be more aligned with these concepts. Students in non-majors' classes less often identify themselves as 'science people.' It was commonly found that students majoring in science had a better understanding of NOS concepts than non-science majors. "Epistemological development was also found to be connected to the ability to learn and retain more sophisticated NOS views" (Borgerding, 2019, p. 292).

For pre-service teachers, the focus has been on the use of NOS concepts in the required curriculum. Often science teachers have naive beliefs about NOS as well as a lack of understanding, knowledge, and skills needed to teach science (Wahbeh & Abd-El-Khalickb, 2013). This may be due to the teacher's non-interest in science, limited understanding of scientific concepts, or judgments in science based on bias or by prior beliefs (Kahana, 2014). Whatever the reason for the lack of teaching NOS in the K-12 classroom, many major reforms of science education have advocated for more education in science for pre-service teachers. Kahana et al. (2014) suggests that "science teachers should adopt NOS as 'must-teach' content, not merely as a by-product of the inquiry process or historical illustrations" (p. 11).

Nature of Science in Various Disciplines

Exploration of NOS was most commonly explored in biology college-level courses throughout the literature reviewed. This is due to topics in biology that are common to most individuals and have a variety of viewpoints, such as evolution. It is common for individuals to already form opinions on evolutionary concepts based on their culture, therefore, using the main areas of NOS to teach biology curriculum can be a powerful way to incorporate an understanding of NOS (Borgerding, 2019). Evolution is also the basis for acceptance and rejection of many important issues such as genetic modifications, global climate changes, and health issues, which are common topics found within the current culture and media (Sorgo, 2014).

However, multiple disciplines have been used within the literature to look at both undergraduate and graduate students' understanding of NOS. Using various disciplines to teach NOS might be a good approach for science students to develop a high level of knowledge on the basic concepts of NOS. Cronje (2008) stated that "...that science was 'more objective than artistic subjects', and … that 'science is just straight facts whereas engineering is more like problem-solving based'" (p. 304). For each key area of NOS, one discipline may be better suited for explaining the concepts. This may also be the case for different types of science courses, such as lecture versus laboratory courses.

Cavallo (2008) found that students that collaborated on course concepts geared towards NOS gained a better overall understanding of many of the key concepts. Students working together and communicating on activities with scientific concepts were able to gain experience from each other, and started to use scientific language, form ideas together, and consider others' viewpoints and ideas (Cavallo, 2008). This was true for students in mathematics courses as well. Students shared points of view with each other, which encouraged them to evaluate their own thinking (Wainwright, 2014).

In addition to collaborative teaching methods, other teaching models have also been found to improve students' learning of NOS. This has included problem-based learning, application of science experiments, and research experience, which are based on explicit learning styles (Wheeler, 2019). It has been found that the explicit, reflective NOS teaching methods is effective in improving students' understanding of NOS (Wheeler, 2019). Problem-based learning (PBL) teaching methods use real-world applications to guide learners through experiences. Learners use prior knowledge and new concepts to make decisions on how to best approach the problem. This causes the learners to use forward-thinking and embed adaptable skills that can be applied to everyday situations, even after the student graduates. Therefore, teaching students how to research information will develop the student's critical thinking skills and apply the research process and searching for information in the "real world" (Cowden, 2016). Students in summer research programs were found using inquiry throughout their research and avoiding the typical scientific method (Harwood, 2004). This was also the case in Cavallo's (2008) study of students within an undergraduate science course. Through the semester-long study, students essentially used all the processes of science, including observation, data collection, inferences, analysis, communication, questioning, and testing, found connections throughout the literature, and made conclusions (Cavallo, 2008). Allowing undergraduate students to develop an understanding of NOS can be accomplished through multiple teaching methods.

The use of technology in teaching NOS can also impact learners' ability to better understand NOS. This can be particularly important in teaching digital literacy. Technology is used by individuals to investigate and understand what is currently going on within our community and throughout the world (Turkmen, 2006). Teaching undergraduate students how to use technology both through discovery and to interpret science is a powerful tool that can be used both throughout an educational career as well as outside of the classroom. New technologies can be used to support learning of all disciplines and can be applied to the students' skills in exploration, development, and application phases of science understanding (Turkmen, 2006). This may also depend on the ability of the educator to use technology in the classroom. Many educators lack the effectiveness in how to apply new and current technologies in the science classroom (Turkmen, 2006).

Using Forensic Science Content to Teach the Nature of Science

Forensic science content has been used in various settings to teach basic science concepts in multiple disciplines, such as biology, chemistry, and physics (Ahrenkiel, 2014). This has been positive for a number of reasons, including the presence of forensic science on television and the effects of social media in real criminal investigations and trials. Both of these concepts allow individuals to be able to relate to forensic science and feel accomplished trying to solve a mystery (Duncan, 2006). This is not a new way to use forensic science, which was first introduced in entertainment with Arthur Conan Doyle's Sherlock Holmes. However, today this concept has become very popular and interesting to young adult learners.

Summer camps revolving around mock casework tied to specific disciplines in science have been successful in allowing upper-level secondary students to determine if science is a career choice (Akrenkiel, 2014). A primary goal of the camp is to teach students observation skills, how to perform experiments to test hypotheses, and collecting and interpreting data to form conclusions. Basic concepts of NOS are taught, even though there is not a direct statement about this relationship. Television shows, such as Crime Scene Investigators (CSI) have been used to help students understand biology and genealogy concepts (Duncan, 2006). Students review the episode which uses biology concepts to solve the case and then students participate in experiments to answer questions about the samples. The real-life problems and scenarios seen on television create an authentic and engaging environment for students and foster engagement in science concepts.

Forensic science as a whole has taken concepts from other disciplines and repurposed methods, instruments, and interpretations specific to answer the questions about the evidence involved (Quarino, 2009). Therefore, the key concepts within NOS can also be incorporated into teaching forensic science. There are certain concepts in NOS that fit well into forensic science content. This includes the socioscientific concepts, science is tentative, and scientific knowledge is based on observations and inference. There have been studies on student perceptions of science, based on socioscientific concepts of NOS. College-level students are found to have a different understanding of socioscientific issues and answer differently based on certain viewpoints on NOS (Zeidler, 2001). Because of this, college-level students' understanding of NOS should also be examined. As Bell and Lederman (2003) stated, "By knowing the characteristics of scientific knowledge and the way it is constructed, the argument proceeds, citizens will be better able to recognize pseudoscientific claims, distinguish good science from bad, and apply scientific knowledge to their everyday lives" (p.353).

Purpose

The purpose of this study was to determine if an asynchronous online introductory level science, taken by both science and nonscience majors, could be used to teach undergraduate students' areas of NOS. There have not been many science educational studies done in an asynchronous online environment. This will determine if an effective study can be done in an online classroom. Specific learning technologies used in the course will be used to introduce students to the NOS concepts. During this action research study, undergraduate students were exposed to NOS using forensic science content. Throughout the fingerprint unit of the patterned evidence module, specific assignments incorporated nature of science concepts.

Research Questions

- Can undergraduate students learn key concepts of the nature of science in an introductory level undergraduate forensic science course? Does this improve students' overall grade in the course?
- What key concepts of the nature of science are most improved with forensic science content?
- Can undergraduate students apply key concepts of the nature of science to real-world situations and opinions in forensic science?
- Can the nature of science be effectively taught in an asynchronous online environment? Do specific demographics affect students' ability to learn key concepts in the nature of science?

Method

Study participants were students enrolled in an online section of Concepts in Forensic Science 1 (FIS 20500) during the summer of 2022. FIS 20500 is an introductory course to forensic and investigative science, has no prerequisites, and is the first course taken in the major, as well as open to all students. The course is offered face to face in the fall during the regular 16-week semester and has a maximum enrollment of 400 students. During the summer, the course is taught asynchronously online only during a 6-week summer session and has a 40-student enrollment cap. A variety of undergraduate students enroll in the course, from majors to nonmajors and freshmen to seniors. Both courses have been designed and taught by the same instructor for the past 15 years, with the exception of the fall of 2019. The online section of FIS 20500 was certified externally by Quality Matters™ in the fall of 2020 and was taught for the first time with the certification in the summer of 2021.

Course Description from the IUPUI Bulletin

> Forensic science is the application of scientific methods to matters involving the public. One of the primary applications is the scientific analysis of physical evidence generated by criminal activity. During this course, you will learn basic concepts in forensic science and the criminal justice system. Apply the basic concepts toward evidence collection and analysis. Topics will include fingerprints, impression evidence, firearms,

questioned documents, pathology, entomology, anthropology, computer and mobile devices, and the law and ethics of forensic science.

The course is set up in the learning management system (LMS) utilizing modules. There are a total of five modules:

- Module 1: Introduction and History of Forensic Science
- Module 2: Forensic Science Basics - lab, evidence, and law
- Module 3: Patterned Evidence in Forensic Science
- Module 4: Death Investigation - ologies
- Module 5: Preparing for the Final Exam

One of the main concepts taught in forensic science is fingerprinting and the importance of fingerprints in the identification of individuals. The Fingerprint Unit, within the Patterned Evidence Module, highlights various aspects of the key areas in NOS. The learning objectives within the unit have been linked to a concept in NOS:

- Describe the history of the use of fingerprints in the US
    - The Social and Cultural Embeddedness of Scientific Knowledge
    - Society have viewed fingerprints as the primary way of identification since the 1900s which has evolved over time with technology of both enhancement of fingerprints and the electronic means to compare prints (Cole, 1999). There is a depiction of this process highly used in media and entertainment that does not adhere to the forensic procedures. Due to this, being able to connect the true science of fingerprints ties to the tenant on social and cultural embeddedness of scientific knowledge.
- Determine and recognize types of fingerprint patterns, minutia, and ridge details
    - The Theory-Laden and Empirical Nature of Scientific Knowledge
    - Much of the analysis and interpretation of fingerprint individuality comes from observation. During the examination and comparison of fingerprint, details of the ridge pattern, ridge formation, and features on the ridge are observed and noted. It is important that this examination is done every time a different fingerprint is examined and that preconceived notions are not formed by the observer.
- Explain, evaluate, and identify characteristics of fingerprints
    - The Creative and Imaginative Nature of Scientific Knowledge

    - In order to develop fingerprints to evaluate, one must use the correct means of visualization the fingerprint. Using creativity methods to examine a fingerprint is the first step in fingerprint analysis. It is also imperative that the forensic scientists are able to disseminate their findings and conclusion. Using creative means to explain fingerprint characteristics is part of fingerprint analysis.
- Calculate the Henry Classification Value of a fingerprint set
    - The Tentative Nature of Scientific Knowledge
    - New technology has advanced how fingerprints are examined for similarities. It is important to look at older techniques to learn that scientific knowledge is subject to change with new evidence or interpretation of existing evidence. This can also relate to the new technologies. Henry Classification is a system that organizes fingerprint sets in groups, now computer software can do this more efficiently.

During the course, students were required to complete specific activities and assignments within the Fingerprint Unit. Each assignment has been created using the TILT method (Transparency in Learning and Teaching) which highlights the purpose, task, and criteria for the assignment. Students were given explicit instructions on how to do the assignment, why it is important to the context of the course, and a rubric for how the assignment is graded. All learning material, activities, and assignments can be found in Appendix C. Each activity or assignment relates to one or more of the major concepts in NOS, exposing students to the concepts through forensic science content. After students completed the Fingerprint Unit, they were asked to complete another VNOS-B.

Data Collection

All assignments and surveys were completed in Canvas™ (Learning Management System) using the Discussion Board, Assignments, and Quizzes tool. This includes the demographic survey, pre-VNOS-B, post-VNOS-B, and all the learning material, activities, and assignments within the fingerprint unit. Both Canvas™ Assignments and Canvas™ Discussion Forum were used to collect key assignments and activities and the Quizzes tool were used to collect survey data. Within the Fingerprint Unit, there were course learning materials, including readings from the text and lecture slides, activities geared towards fingerprint matching and classification, and discussion with peers on fingerprint analysis.

First, a survey of the demographics of the students in the class was conducted, see appendix A. This will allow for a better understanding of the typical student in the online section, the number of science majors, science background, and the reason for completing the course online. Students will then complete the survey on the nature of science (VNOS-B), found in appendix B, before any course content is completed. These will both be completed within the first module of the course before students are exposed to any forensic science content.

Throughout the study, a researcher log was kept. This included weekly reflections on student work as it was reviewed. This allowed recognition of common themes throughout the study in survey data as well as students' overall grades in key assignments and activities.

Data Analysis

Final grades were compared to previous course offerings. The demographic survey was used to look at the over student population in the course, including science vs. nonscience major, traditional vs. nontraditional student, student status, i.e. freshman vs. senior, and reasoning for completing an online course. This was used in relation to other data points, such as pre-understanding of NOS. Student responses before and after assignments were compared, looking at either both improved and stagnant responses.

Activity Timeline

In an online asynchronous course, course content is taught within the students' time. Each module within the course opens and closes on specific dates when students are expected to complete all the learning materials, including lecture content, activities, assignments, and assessments. Typically, each module is open for two weeks during the 6-week summer session of the online course and roughly takes approximately 24 hours to complete. Each module includes four units; therefore, an estimated total of six hours is expected for students to spend on each unit. The Fingerprint unit was covered during the fourth week of the summer session and opened at the start of the third week, giving students two full weeks to complete the unit. Table 1 highlights the instructional topics within the Fingerprint unit, learning objectives, and learning materials and assignments linked to each nature of science concept.

Table 1. Alignment of Course Learning Materials

Instructional Topic	Learning Objective(s)	Learning Material(s)	NOS Concept
Overview of Fingerprints • History in the US • Defining what a friction ridge is and how developed • How are fingerprints made - patent, latent, and plastic • Collecting fingerprints - physical, chemical, and alternate light source • Preserving fingerprints for analysis	Describe the history of the use of fingerprints in the US Explain, evaluate, and identify characteristics of fingerprints	Google Slides - Lecture Textbook Reading (Chapter 6 pages 129-139 in Criminalistics: An Introduction to Forensic Science, 12th edition. Richard Saferstein, Pearson, 2016.)	Scientific Theories and Laws The Creative and Imaginative Nature of Scientific Knowledge The Myth of The Scientific Method

Analysis of Fingerprints
• Characteristics and classification of fingerprint patterns
• Identification of fingerprints via minutiae and ridge details
• Comparison of fingerprints
  ○ Activity: fingerprint matching)
  ○ Integrated Automated Fingerprint
	Determine and recognize types of fingerprint patterns, minutia, and ridge details	Google Slides - Lecture
		
		Friction Ridge Patterns - Activity
		
		YouTube Video - Mythbusters
		
		Superglue Fuming - Discussion
		Case Study: 30-Year-Old Cold Case Fingerprints Come to Light
			The Empirical Nature of Scientific Knowledge
			
			The Theory-Laden Nature of Scientific Knowledge
			
			The Social and Cultural Embeddedness of Scientific Knowledge

Identification System (IAFIS) • Fingerprint Myths		ScienceDirect Website of the article) National Library of Medicine Website of the article)	
Calculation of Classification Value Activity - Calculating Henry Classification Value	Calculate the Henry Classification Value of a fingerprint set	Article - The Henry Classification System	The Tentative Nature of Scientific Knowledge

Results

Each research question was tied to a specific measurement tool which was used to analyze the data collected throughout the action research study. Throughout this section, each research question is listed with the data collected to evaluate and respond to each question.

Research Question 1

Can undergraduate students learn key concepts of the nature of science in an introductory level undergraduate forensic science course? Does this improve students' overall grade in the course?

Comparison of Pre-VNOS and Post-VNOS Responses

First, the total number of responses for each NOS question was noted, as this was different for the pre- and post- survey, as well as for each individual question. Each answer in both the pre- and post- VNOS surveys was examined for understanding at three levels - inadequate, adequate, and informed. Responses that did not fully answer the question were coded inadequate.

Table 2. Pre- and Post- VNOS Survey Responses

NOS Concept	VNOS Survey Question	Pre- vs. Post- Survey Responses	Inadequate Responses - Pre vs. Post	Adequate Responses - Pre vs. Post	Informed Responses - Pre vs. Post
The Empirical Nature of Scientific Knowledge	1. After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we other to teach scientific theories. Defend your answer with examples.	32 19	9 (28.1%) 2 (10.5%)	19 (59.4%) 12 (63.2%)	4 (12.5%) 5 (26.3%)
The Empirical Nature of Scientific Knowledge Scientific Theories and Laws	2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?	30 19	19 (63.3%) 13 (68.4%)	11 (36.7%) 4 (21.1%)	0 (0%) 2 (10.5%)
The Tentative Nature of Scientific Knowledge	3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.	29 19	8 (27.6%) 6 (31.6%)	20 (69.0%) 11 (57.9%)	1 (3.4%) 1 (5.3%)
The Empirical Nature of	4. How are science and art similar? How are they different?	28 18	20 (71.4%) 12 (66.7%)	7 (25.0%) 6 (33.3%)	1 (3.6%) 0 (0%)

Scientific Knowledge The Social and Cultural Embeddedness of Scientific Knowledge					
The Social and Cultural Embeddedness of Scientific Knowledge	5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.	28 18	5 (17.9%) 2 (11.1%)	14 (50.0%) 9 (50.0%)	9 (32.1%) 7 (38.9%)
The Creative and Imaginative Nature of Scientific Knowledge	6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.	27 18	11 (40.8%) 7 (38.9%)	13 (48.1%) 9 (50.0%)	3 (11.1%) 2 (11.1%)
The Theory-Laden Nature of Scientific Knowledge	7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still	27 18	11 (40.7%) 6 (33.3%)	15 (55.6%) 9 (50.0%)	1 (3.7%) 3 (16.7%)

	others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?	

Look at Overall Grade Distribution

The average percentage of exam grades, key assignments in the fingerprint unit, final exams, and overall course grade were calculated and can be seen in Table 3.

Table 3. Average Percentage of Graded Assessments

Assessment	Average Grade
Exam 1	71.4%
Response - Superglue Fuming	75.7%
Activity - Fingerprint Matching	89.7%
Activity - Henry Classification	73.6%
Quick Check - Fingerprints	91.3%
Exam 2	80.4%
Exam 3	81.9%
Final Exam	81.0%
Overall Course Grade	88.0%

The overall course grade averages were similar to previous semesters as seen in Table 4. Table 4 highlights the overall letter grade distribution with comparison to the averages for both the online and face to face sections for the past five years. For the current summer (2022) there were a greater number of A grades awarded (<90%) as well as an increase in DWF grades, compared to the average of summer online grades over the past five years.

Table 4. Overall Grade Distribution of Online Sections

Academic Term	A	B	C	D	F	W	Total Students
Summer 2022	24	10	0	3	2	3	42
Summer Percentage	57.1%	23.8%	0%	7.1%	4.8%	NA	
Overall Average	14.4	21	9	1.8	0.8	2.2	47.4
Percentage	30.4%	44.3%	19.0%	3.8%	1.7%	NA	

Research Question 2

What key concepts of the nature of science are most improved with forensic science content?

Key NOS concepts that improved between the pre- and post- survey include the Empirical Nature of Scientific Knowledge, the Social and Cultural Embeddedness of Scientific Knowledge, the Creative and Imaginative Nature of Scientific Knowledge, and the Theory-Laden Nature of Scientific Knowledge. As seen in Table 2, most of the concepts in NOS was improved - by means that the percentage of inadequate responses decreased, which the exception to questions 2 and 3, which both slightly increased, between the pre- and post- VNOS surveys. The percentage of informed responses increased, with an expectation to question 4, which decreased, and question 6 which had no change, between the pre- and post- surveys. Each NOS concept was mapped to a question(s) in the survey to analyze which concepts improved with learning content. Responses that decreased in inadequate but stayed the same or increased for adequate and informed were determined to show improvement in the key NOS concepts. Key NOS concepts that improved between the pre- and post- survey include the Empirical Nature of Scientific Knowledge, the Social and Cultural Embeddedness of Scientific Knowledge, the Creative and Imaginative Nature of Scientific Knowledge, and the Theory-Laden Nature of Scientific Knowledge. Therefore, it can be stated that specific post-NOS responses improved after completion of core unit.

Research Question 3

Can undergraduate students apply key concepts of the nature of science to real-world situations and opinions in forensic science?

Key assignments used in the fingerprint unit were labeled to help teach basic NOS concepts which are geared toward students achieving the specific learning outcomes of the unit, directly related to the course learning objectives. By examining the overall grades on key assignments, it was evident that students did well on assignments. There were both forensic science examples used with both the pre- and post-survey. There were a total of 201 responses on the pre-survey and only four used forensic related examples (2.0%) The examples from either forensic science or criminal justice can be seen below.

> I do not think that theories change. I am looking at this from a criminal justice perspective. The criminal justice theories offer an explanation as to why people behave the way they do and why crime may be high in certain areas, etc. I don't think they change because it explains a wide range of behaviors that are constant (Coded Inadequate).
>
> I believe scientists use their own creative thinking while collecting data and after because when they find evidence and witnesses, they predict where the suspect may have gone or done with the evidence which helps them provide more to the case. An example of this can be the Boston Marathon Bombers and which during the investigation they predicted where the suspect was based on his moves and cameras and found him in someone's boat a little bit outside of Boston (Coded Informed).
>
> I think that knowledge is something absolute; whereas, opinion is only based on someone's thoughts. For example, a person can have the opinion that OJ Simpson did kill his wife, but it's considered knowledge that OJ Simpson was never convicted for killing his wife (Coded Adequate).
>
> With something as difficult to determine as the size of the universe, interpreting data requires creativity. All three astronomers could have different knowledge prior to conducting the experiment, which would lead their mind in different directions while interpreting the data. They could also have biases they are looking to confirm when interpreting the data. Similar to when arson investigators look for [signs] of arson. They might unintentionally ignore other important signs when looking for what they are trained to look for (Coded Adequate).

There was a total of 129 total responses on the post-survey, of those five used forensic related examples (3.9%). This was an increase from the pre-survey responses, whereas only 2.0% of the responses included forensic related content. The examples specifically related to forensic science or criminal justice are seen below.

> I believe that theories can change because you can learn new things about what you theorized about. You can find evidence to support a change in theory. For example, My theory for why someone's reports of being a victim of domestic violence could change if a witness was introduced after the theory (Coded Adequate).

> I believe theories are built on very concrete examples, but have the flexibility to change. The theory of identification we have discussed recently I think follows this idea. The idea that body parts don't change was something that was based on research at first. Then with more developed researched, it changed to fingerprints. While at a time the theory was concrete, the theory changed as technology and times changed (Coded Informed).

> A scientific law predicts the results of instance and a scientific theory tries to prove why something happens in the most logical way. Scientific law, proves how genetics can transfer DNA while a theory would state how certain genes explain a tall vs short person (Coded Adequate).

> I think scientists do use their imagination to collect data because they have to plan out a theory and find clues to evidence. An example of this can be a murder scene where a criminal took his footsteps somewhere and left something behind him and scientists used their imagination to find that evidence and footsteps to trace it back to that specific person (Coded Adequate).

> Scientists use creativity and imagination both during and after data collection. Thinking outside of the box or thinking of possible outcomes can help eliminate or determine answers. Jumping to logical conclusions can help see what is not always right in front of them. For example, I arrive at a crime scene that has no evidence close by, I have to think where and how and answer a lot of questions that may not be so obvious. Thinking outside the box can help get me in the correct path to figuring out what happened (Coded Adequate).

The specific NOS concepts that were aligned with key learning outcomes within the fingerprint unit are listed in Table 1. Three of these concepts showed improvement with forensic science content through student responses to the pre-survey compared to the post-survey questions. There were the Empirical Nature of Scientific Knowledge, the Social and Cultural Embeddedness of Scientific Knowledge, and the Theory-Laden Nature of Scientific Knowledge. The Tentative Nature of Scientific Knowledge being the only NOS concept that did not show improvement. The assignment linked to this concept, calculator of the Henry Classification Value of a fingerprint set, had the lowest average grade (73.6%) as seen in Table 3. It was seen that students responded with forensic science or criminal justice related examples in both the pre- and post- survey - with more students using forensic related examples in the post-survey. Students were not influenced to use forensic science examples; however, some students did use topics from the fingerprint unit to explain their reasoning for a given question. For example, a student stated, “I believe theories are built on very concrete examples but have the flexibility to change. The theory of identification we have discussed recently I think follows this idea. The idea that body parts don’t change was something that was based on research at first. Then with more developed researched, it changed to fingerprints. While at a time the theory was concrete, the theory changed as technology and times changed.” This was a response to the question, *After scientists have developed a theory (e.g. atomic theory), does the theory ever change? If you believe that theories do change, explain why we other to teach scientific theories. Defend your answer with examples*. This first question in the survey is aligned with The Empirical Nature of Scientific Knowledge NOS concept which did show improvement.

Research Question 4

Can the nature of science be effectively taught in an asynchronous online environment? Do specific demographics affect students’ ability to learn key concepts in NOS?

Grades have been consistent over time. Table 5 shows the grade distribution of both the face-to-face and online sections over the past five years. DWF rates are higher in the face-to-face section of the course, 20% versus 10% (on average), while online sections have more students earning As and Bs, roughly 70%, whereas in the face-to-face section about 60% of students are earning As and Bs.

Table 5. Grade Distributions for Online and Face-to-Face Sections

Online Sections							
Academic Term	A	B	C	D	F	W	Total Students
Summer 2021	17	18	3	2	2	1	43
Summer 2020	8	19	9	0	0	2	38
Summer 2019	15	16	11	2	0	2	46
Summer 2018	12	21	14	3	2	3	55
Summer 2017	20	31	8	2	0	3	55
Average	14.4	21	9	1.8	0.8	2.2	47.4
Face to Face Sections							
Academic Term	A	B	C	D	F	W	Total Students
Fall 2021	70	78	50	17	28	11	254
Fall 2020	66	83	65	13	30	13	271
Fall 2019	88	79	44	15	18	9	253
Fall 2018	69	60	56	18	27	2	232
Fall 2016	68	138	54	15	16	8	301
Average	72.2	87.6	53.8	15.6	23.8	8.6	262.2

The overall course grades and grades on key assignments were above average as seen in Table 3. This shows that nature of science topics can be taught in an online environment.

Student Demographics

Do specific demographics affect students' ability to learn key concepts in NOS?

The results of the student demographic survey are seen in Table 6 and Figure 1. There were 36 students out of 39 enrolled students that completed the demographics survey, seen in Appendix A. Students were asked various questions relating to their student status as a non-traditional student, academic year, science affiliation, and reasons for taking the course. The course consisted of over 40% non-science majors and students completing the course due to interest.

Table 6. Student Demographics

Student Response	Percentage
Self-identified as a non-traditional student	58.3%
More than one non-traditional student factor	22.2%
Not a science major	41.7%
Taking the course online to get ahead on course work	58.3%
Taking the course because they are interested in the topic	41.7%

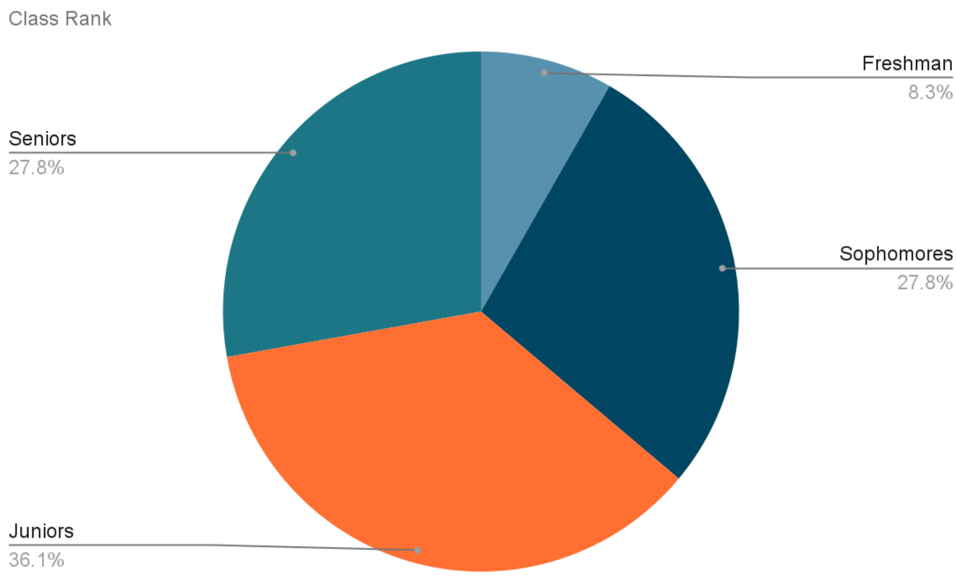

Figure 1. Class Rank

It was also found that more than half the class of students self-identified as a non-traditional learner, seen in Table 6, with over 20% identifying with more than one factor. These include working full-time, being a part-time student, having a dependent, being a single parent, over the age of 23, or earning a GED. Due to the high number of non-traditional students in the course and the fact that there was an increased knowledge in responses to the NOS concepts targeted by the course learning materials, demographics do not affect students' ability to learning key concepts of NOS.

Discussion

The data collected was used to best answer the research questions and evaluate the results. For each research question there is an overall statement answering each question from the results.

Research Question 1

An introductory level undergraduate forensic science course can be used to teach certain concepts of NOS. The concepts that seemed to improve throughout instruction of the course were linked to specific learning outcomes.

Research Question 2

The key NOS concepts that showed improvement with forensic science content through student responses to the pre-survey compared to the post-survey questions were:

- The Empirical Nature of Scientific Knowledge
- The Social and Cultural Embeddedness of Scientific Knowledge
- The Theory-Laden Nature of Scientific Knowledge

The Tentative Nature of Scientific Knowledge being the only NOS concept targeted with course content, which did not show improvement.

Research Question 3

There was not a specific direction or requirement for students to use forensic science examples, however, it is interesting to see that some students did in fact relate the question at hand to the topic of the course. Rewording of the survey to specific include a requirement to explain reasoning through forensic examples would aid in determining if students could relate forensic science to NOS concepts.

Research Question 4

The online environment can be used to teach many subjects, as well as concepts within NOS. Learning materials used in both face to face and online environments are similar and courses can have the same learning objectives which can be effectively meet in both learning environments. One major issue with teaching online is the integrity of students' submitted assessments. This would also apply to surveys given to students in an online course. There were clear instructions, asking students not to use any resources when answering the questions, however, there is no way to monitor if students are following directions. Because the VNOS-

B is designed as open-ended questions, students may be more likely to look up answers if they are unsure of the correct response. A multiple-choice survey maybe a better measuring tool for a survey given in an online course. Students may be less likely to look up answers and just choose the statement they believe is true. Overall, an online asynchronous course can be used to teach basic science topics, however, assessments might need to be redesigned to best measure student learning.

Conclusion

The nature of science has been looked at in a variety of undergraduate disciplines, courses, and universities. The most common subject area used in studying students' understanding of NOS was found to be biology and evolution-based courses. This is a familiar topic throughout our culture and often has multiple viewpoints. There is importance in teaching NOS at multiple levels, as this may be the only exposure an undergraduate may have to science concepts. Therefore, a forensic science course that includes a diverse set of learners is a good avenue to teach basic nature of science concepts.

Multiple teaching methods have been used to teach NOS in undergraduate education, including collaborative learning, problem-based learning, and research-based methods (Abd-El-Khalick, 2004; Lederman, 2007; Kubicek, 2005). Some of these approaches may be best depending on which concepts of NOS that are being emphasized. For example, research experiences can teach students the importance of scientific inquiry and myths about the scientific method. Students working together can allow for students to be exposed to different perspectives on scientific concepts and can encourage students to investigate their reasoning. This can also be true for an online environment, as students engage in discussion boards to communicate their opinions on a topic as well as get insight from their peers' views.

For research in undergraduate student understanding of NOS, it can be useful to examine introductory and advanced level courses and when basic concepts of NOS are taught in the curriculum. Many times, in introductory science courses, the focus is on terminology and basic concepts that can be carried forward in advanced coursework. Often students don't realize the expectations of knowledge from previous courses in sequential courses. However, if these key concepts are taught using NOS, students may be able to make better connections between concepts in both introductory and advanced level courses or sequential courses in a major. This could also be applied to a lecture and laboratory course that are taken simultaneously. The focus on a first-year course without a required science background is used to incorporate NOS into the curriculum.

The purpose of this study was to use an introductory level science, taken by both science and nonscience majors, to teach undergraduate students' areas of NOS. During this action research study, undergraduate students were exposed to NOS using forensic science content. The outcomes of action research outcomes can lead to direct change in the classroom. This could be an effective way to make change to improve student learning by redesigning specific learning materials, rewriting assessments, or creating activities seen to be lacking in the course. From this study, there was a focus on the ability to use specifically the fingerprint unit which included specific assignments to incorporate nature of science concepts. The study also evaluated the ability of the online environment to teach undergraduate students about NOS. There have not been many science educational studies done in an asynchronous online environment. This action research study looked at the effectiveness of extending research into the online classroom. This allows for evaluation of studying student learning in the online science course which can benefit the science community.

With an increase in online learning, both in higher education and K-12 education, providing means to continue research and scholarly activity is needed. This study can be used as an example of both effective and noneffective participation, data collection, and analysis. Having students complete the pre-survey was effective, however, the participation in the post-survey decreased, only 63% of the students that completed pre-survey completed the post-survey. For data collection, using the learning management system (LMS) or another tool students are familiar with, such as Google Forms, can easy collect and collate data. This can also be used to analyze the data and interpret the results. Overall, the study had good participation and demonstrated the effectiveness of forensic science topics to teaching basic understanding of NOS.

Forensic science content can be used to teach various aspects of NOS in higher education. The use of science topics that are popular in the culture, such as forensic science, gives educators options to relate interesting topics and course materials to concepts embedded in NOS, such as the Creative and Imaginative Nature of Scientific Knowledge and the Social and Cultural Embeddedness of Scientific Knowledge. These concepts have various ways to relate to forensic science, with this study fingerprint content was used to showcase NOS concepts with change in identification methods used in the criminal justice system and ability and tools used to compare fingerprint patterns over time. As students interact with the learning materials, there are "quick check" questions embedded within the content, allowing for self-assessment. This can be used to encourage students to think about basic scientific knowledge on the topic, creative and imaginative ways to analyze the evidence, and share social and cultural context of forensic science. Students also read case studies and reflect on questions directly related to the analysis of evidence within discussion groups. This allows for active participation where novice students can learn from more experienced students. Learners can experience different perspectives that one student has that another student doesn't, as this is especially important in science-related topics (Akerson, et al., 2019). This reaches the tentative nature of scientific knowledge through more information an increased or altered level of understanding of the topic can be reached.

There is a need to introduce NOS concepts in higher education. Most programs require undergraduate students to complete a general science course in order to have a well-rounded education (Ramaley, 2005). This can be done in introductory level courses in the science curriculum. Typically introducing NOS concepts in biology coursework has been successful in college courses (Borgerding, 2019), however, this can also be done in other science courses, such as forensic science. With the increase of forensic science courses to meet the demand of interest in forensic science careers (Gilman, 2005), the basic NOS concepts can be incorporated into the introductory level forensic science coursework. This study is a good example of how basic forensic science content, such as fingerprints, can be used to teach common NOS concepts.

Recommendations

One big takeaway for evaluating the effectiveness of NOS in an online classroom, a different method of issuing the surveys should be reviewed. Students are not proctored during the survey process; therefore, it is unknown if students used resources when answering the open-ended questions on the pre- and post- VNOS-B survey. Using online testing techniques that discourage using resources would ensure the student answers are their own thoughts. This may include timing questions, offering one question at a time, and not allowing students to re-answer questions. Students were told explicitly not to use resources to answer the questions, however, this cannot be known for sure. Other tools that would be useful would have been to individually or in small focus groups, directly ask students to comment on survey questions. This could also be used to serve as a follow up for students to reiterate and explain their answers. It would allow for the researcher to have a better insight on the meaning of the student responses. Specifically linking the NOS concepts to the learning materials and activities for students would have given learners a better understanding of how each concept was linking throughout the fingerprint unit. All learning materials used in the course, readings, lecturers, formative and summative assessment, use Transparency in Learning and Teaching (TILT). This could have been used more effectively by stating the NOS concept that was directly linked to the learning content. Students may have then become more familiar with the NOS concept and how it applied to forensic science content.

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Appendix A. Demographic Survey

What is your current student status?

- Freshman (0-29 credit hours completed)
- Sophomore (30 - 59 credit hours completed)
- Junior (60 - 89 credit hours completed)
- Senior (90+ credit hours completed)
- Graduate (have you completed a bachelor’s degree)

Which of the following are true for you? (check all that apply)

- Older than 23 years of age
- Work a full-time job
- Are a single parent
- Have at least one dependent
- Attend college part-time (enrolled in less than 12 credit hours fall/spring semesters)
- Earned a GED rather than a high school diploma

What is your reason for completing an online course?

- Get ahead of my course work
- Make up course work to stay on track
- Enrolled in an online program at IU
- Retaking the course
- Other

Do you consider yourself a science major?

- Yes
- No

Why are you taking this course?

- This course is part of my major
- This course is an option for my major
- Interested in the course topic
- Other

Appendix B. View of the Nature of Science (VNOS) B Form*

Instructions: Answer the following questions, using the back of the page if you need more space. Please note that there are no "right" or "wrong" answers to these questions. I am simply interested in your views of a number of issues about science.

1. After scientists have developed a theory (e.g., atomic theory), does the theory ever change? If you believe that theories do change, explain why we bother to teach scientific theories. Defend your answer with examples.
2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine what an atom looks like?
3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.
4. How are science and art similar? How are they different?
5. Scientists perform experiments/investigations when trying to solve problems. Other than the planning and design of these experiments/investigations, do scientists use their creativity and imagination during and after data collection? Please explain your answer and provide examples if appropriate.
6. Is there a difference between scientific knowledge and opinion? Give an example to illustrate your answer.
7. Some astronomers believe that the universe is expanding while others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if all of these scientists are looking at the same experiments and data?

Appendix C. Course Material, Activities, and Assignment Details in Fingerprint Unit

Overview and Content - Fingerprints

Fingerprints in the Media

In most cases, the act of alteration will make the fingerprints easier to ID by adding cuts/scars to the ridge structure. We have seen numerous examples of individuals trying to alter their fingerprints. In the 1930s, John Dillinger put acid on his fingers but was unsuccessful in destroying his ridges completely. Others try to make copies of other people's fingerprints, Mythbusters did a segment on making casts of fingerprints and overlaying them.

Learning Materials

Textbook Reading (Chapter 6 pages 129-139 in Criminalistics: An Introduction to Forensic Science, 12th edition. Richard Saferstein, Pearson, 2016.)

Lecture Slides

Key Assignment - Superglue Fuming Doorknobs

There are different ways to capture and visual latent fingerprints. These include both physical means, dusting powders, and chemical methods. A popular chemical method for visualizing latent prints is superglue fuming. This method heats superglue into a vapor which then sticks to skin oils left on a surface in the shape of a fingerprint. This method is popular because it is a permanent way to capture the fingerprint left on hard surfaces.

Purpose

The purpose of this assignment is to learn about different methods that are commonly used in visualizing latent prints found at crime scenes. This article will discuss common methods that are used at crime scenes to locate fingerprints and what the challenges are to collecting fingerprints for analysis. This will give you a better understanding of how fingerprints are collected at crime scenes.

Task

Read the article, Case Study: 30 Year-Old Cold Case Fingerprints Come to Light. Then, use the discussion to discuss your opinion of superglue fuming fingerprint analysis, including some of the challenges and how they are addressed in the article. Reply to three other students' responses and why you agree or disagree with their comments.

Your original response must include:

- Your opinion of superglue fuming fingerprint analysis.
- Some of the challenges of superglue fuming.
- How the challenges are addressed in the article.

Reply to three different student statements. For each reply in this discussion with your peers you must include:

- Why you agree or disagree with their comments.

Criteria

You must first post an initial response which includes your opinion on superglue fuming. Make sure to have reasoning behind your answer and describe what you think the challenges are in the method. Reply to at least three of your peers with whether you agree or disagree and what you do or don't like about their response.

Post an initial response to the statements. (Due 11:59pm EST on Thursday)

Reply to 3 peers' comments throughout the week. (Due 11:59pm EST on Sunday)

Key Activity - Fingerprint Matching

When comparing fingerprints, it is necessary to look closely into the ridges to find the small differences between each print. There are many different characteristics that can be found when looking at fingerprints. Figure 1 shows some of the ridge characteristics you are looking to find.

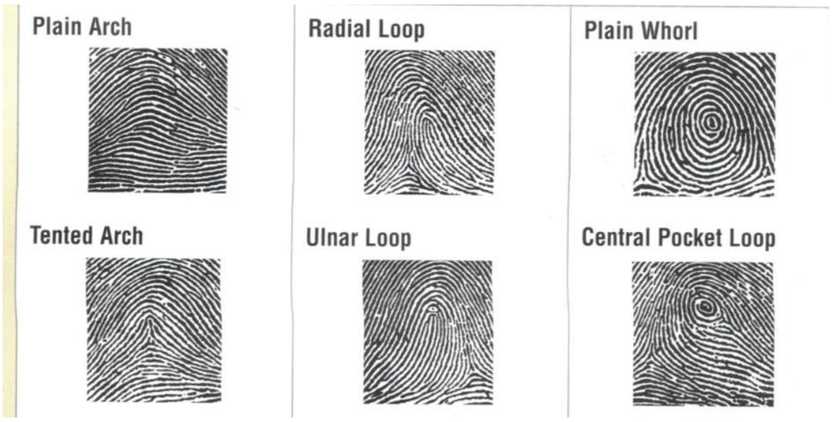

Figure 1. Fingerprint Ridge Patterns

Purpose

The purpose of this activity is to learn how fingerprints are matched to a known source. This will give you a better understanding of the different levels that are used to identify prints. You will also learn that matching an unknown print to a known source can be difficult and sometimes not possible.

Task

View the fingerprint images on the slides. which have ten different known fingerprints and five unknown fingerprints. Match each of the five unknown partial prints to one of the known ten prints. Hint: some of the knowns may be used more than once. Post your answers in the Discussion Board.

Criteria

Post your answers in the Discussion Board. Think about what identification features you used to determine what known print matched to each of the unknown prints.

Key Activity - Calculating Henry Classification of a Fingerprint Set

The Henry Classification System is a long-standing method by which fingerprints are sorted by physiological characteristics for one-to-many searching. Developed by Sir Edward Henry in the late 1800s for criminal investigations in British India, it was the basis of modern-day AFIS classification methods up until the1990s. In recent years, the Henry Classification System has generally been replaced by ridge flow classification approaches.

Purpose

The purpose of this activity is for you to learn how to use Henry Classification on a set of fingerprints. You will learn the basic calculation to determine the value of your set of fingerprints.

Task

Read the following article, The Henry Classification System. Using the information from the article to calculate the Henry Classification System value of your fingerprints. Remember only whorls receive values and each finger receives a specific number if a whorl is present.

Criteria

Complete all the information:

- Show all your work - including the pattern and Henry Classification value for each of your fingers
- The completed table with your fingerprint set information

- Calculation used to determine your Henry Classification value
- The Henry Classification value of your fingerprint set

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Chapter 6: College Students' Views of the Nature of Science

Stephanie Marin Rothman

Chapter Highlights

- Many of my students gained a better understanding of the Nature of Science after participating in my class.
- Most students were not able to accurately differentiate knowledge from opinion.
- Grades in my class do not currently serve as way to delineate those students who understand NOS versus those who do not.
- Most students watch most of my lectures, where they learn about NOS.
- The major of the student did not appear to have an influence on student understanding of NOS.

Introduction

Student Views of the Nature of Science

For over 100 years, most scientists, science educators, and science education organizations have agreed upon the goal of aiding students in developing adequate conceptions of Nature of Science (NOS) (Abd-El-Khalick, Bell, & Lederman, 1998). Indeed, student understanding of NOS is still considered an important educational goal by contemporary science education researchers (Allchin, Anderson, & Nielsen, 2014; Olson, 2018). Nevertheless, numerous studies have shown that many students hold naïve views of NOS (Abd-El-Khalick, 2012; Abd-El-Khalick & Boujaoude, 2003; Dogan & Abd-El-Khalick, 2008; Kang et al., 2005; Lederman, 1992). This study adds to the existing literature about students' perceptions of NOS, examining students in the first author's introductory biology online asynchronous class at a diverse Southern California 4-year public university. There is a dearth of research examining the NOS views of a population similar to my own students. Many of the studies I have found focus on the NOS views of K-12 students. When researchers study adult views of NOS, papers that I have found study pre-service or in-service K12 teachers, which is not representative of my wider student population, many of whom are STEM majors without plans for becoming teachers. The campus in which I teach is incredibly diverse, and this qualitative study will include new voices in the literature that may not have been heard before. It is my goal as an educator to develop teaching methods that most effectively help all my students meet their learning goals, regardless of learning style or background. Since many of my students are STEM majors, they may already possess a more advanced understanding of NOS than children or non-science major adults.

Problem Statement

In order for students to gain a more sophisticated understanding of NOS, instructors need to know ways to effectively teach it in order to facilitate that learning. Research that examines how students understand and perceive NOS can provide educators with tools to facilitate learning in their own classroom through improved curriculum and instruction.

Purpose

The purpose of this action research is to explore my students' views of NOS, examining specifically how their understanding of NOS may or may not have changed after completing my class compared to before starting my class, and to consider what specific sources of instruction and curriculum contributed to any increase in understanding of NOS by examining the ways in which they engage with my class, specifically through watching my class lectures. Upon examining the data, this study serves to inform us what effect my instruction has on my students' understanding of NOS. This is the very first formalized action research study conducted on my class. While I believed that I was teaching students NOS, this formalized study will give me more confidence in this assumption. By comparing how students engaged with my class, I can gain a more precise understanding of the aspects of my class that influence their views of NOS. It is my hope that this study will provide other instructors advice on how to include effective NOS instruction and curriculum in their own classes.

Furthermore, my classes are very diverse. While other studies have certainly examined different strategies for teaching the NOS, what works for some students may not work for others, because everyone learns differently. By examining my class, I will help us gain a richer understanding of how to teach a diversity of students NOS. While many other studies have certainly put forth various strategies for effectively teaching NOS, what works for some students does not necessarily work for all due to different learning styles. By examining my own class, this study will add to the literature and help us gain a richer understanding of various ways to teach a greater diversity of students NOS.

Background/Theory: Explicit-Reflective NOS Instruction

There are two different approaches used to improve NOS views: implicit and explicit (Abd-El-Khalick & Lederman, 2000). Implicit assumes that NOS views develop incidentally through conducting science, whereas explicit assumes that NOS views can be improved through instruction that explicitly includes NOS aspects in the student learning outcomes (Wahbeh & Abd-El-Khalick, 2014). Explicit instructional framework was advanced through the addition of reflection, which includes opportunities for students to reflect on their learning experiences (Abd-El-Khalick, 1998). Learners are better able to achieve a more advanced understanding of NOS through reflective explicit activity-based teaching (Abd-El-Khalick & Lederman, 2000). This has been found to be the case for both students (Akerson et al., 2014a) and teachers (Akerson et al., 2000).

Numerous practical and research-based strategies for teaching NOS based on explicit-reflective instruction have been described (Akerson et al., 2019). While the aforementioned paper catalogues strategies tested on elementary classrooms, I believe they can be slightly altered for a college setting. In conjunction with my action research in Spring 2022, I added more explicit-reflective curriculum to my Life Science class. I recorded a new lecture video that explicitly teaches NOS for my students to view at the beginning of my course. I also provided an accompanying document listing the aspects in each module so students can consistently reflect on NOS throughout the class, rather than just hearing about it once.

The year before, I added "Notes" as an assignment, as a means to encourage my students to study while giving them some easy points. I learned about "skeletal notes" in my Association of College and University Educators (ACUE) class, and I decided to utilize this assignment type to serve as a way for students to reflect on NOS. For this new reflective note taking assignment, I made a skeletal notes template that includes reflections on NOS with every module, following the explicit-reflective teaching practice that has shown to be effective (Abd-El-Khalick & Lederman, 2000). The skeletal notes template I provided my students included an outline of my lectures that students can add their notes to, a section for them to write down questions that have arose as they watched lecture, a section for them to write the answers after they've done their own investigating, and a place for them to reflect on NOS aspects. I anticipated that this explicit-reflective curriculum would help students connect lecture content to NOS and help them synthesize the aspects of NOS (Abd-El-Khalick & Lederman, 2000).

Research Questions

How do my students' views of NOS change after completing my class?
Do my students actually watch my pre-recorded asynchronous lectures?
Do students of different majors hold different views of NOS?

Methods

This study uses utilize grounded theory qualitative design, specifically with the systematic subtype, to determine the effect that my class has on students' views of NOS. No action research study nor a self-study have been conducted on me or my classes before, and this study will tell me whether or not I am effectively teaching my students NOS. A follow-up study on this topic may include emergent and constructivist design. In this action research study, I utilize a qualitative approach to explore my students' views of the Nature of Science, and to examine how their understanding of NOS may change after completing my class, specifically through watching my lectures and completing class assignments.

Data Collection

Data sources included information and responses from students in my online asynchronous introductory biology classes I taught Spring semester 2022 at a diverse public university in Southern California. Data sources included their responses to the VNOS-Form B pre- and post-tests, their grades, amount of lecture viewing, and their major. This study used qualitative methods to gain a better understanding of individual students' perspectives. During the course of this study, I had approximately 350 students taking my three sections of online Life Science, but I only analyzed the data of a random sample of thirty students from the population who consented at the end of the term when they took their post-test.

Views of Nature of Science Questionnaire (VNOS)

In this research study, I determined through a pre-test my incoming students' views on NOS using the validated open-ended instrument survey Views of Nature of Science Questionnaire (VNOS) Form B (Lederman et al., 2002a). At the conclusion of my class, I administered a post-test and compared the results with the pre-test to determine if students' understanding of NOS changed. Both tests were administered to all my students as part of their class assignments, and were administered through our Learning Management System, Canvas. I included a consent question in the post-test, so I only used data from students who consented to have their responses used in my research. I did not view the pre-test until I had also administered the post-test, so that I could score them congruently and randomly, without me knowing whether I was coding a pre-test or post-test. In this way, I could not have subconsciously rated pre-tests worse and post-test better, because I did not know which I was scoring. In assigning my students the VNOS questionnaire, I did not "teach to the test." In fact, I did not alter my lectures at all, but only added the short introductory lecture on the aspects of NOS. The VNOS questionnaire posed questions that I never explicitly covered, but nevertheless challenged students with expressing their thoughts on NOS.

Lecture Viewing

One more question I included in the VNOS post-test: "How much of Professor Rothman's recorded lectures did you watch?" I included the possible responses "I watched none of the lectures, I watched less than half of the lectures, I watched about half of the lectures, I watched most of the lectures, and I watched all of the lectures." I looked for any correlations between how much of my lectures they watched with their VNOS responses.

Major

In their VNOS post-test, I also ask them in what college their major is in. Our university has 8 distinct colleges, with the College of Science standing alone, encompassing the departments Biology, Chemistry and Biochemistry, Physics and Astronomy, Mathematics and Statistics, Kinesiology and Health Promotion, Geology, and Computer Science. The other seven colleges are Agriculture; Business Administration; Education and Integrative Studies; Engineering; Environmental Design; Hospitality Management; and Letters, Arts, and Social Sciences. My class is for non-biology majors, but other science majors may take it. My students come from colleges and departments all around campus, but the College of Engineering is particularly well-represented.

Data Analysis

Views of Nature of Science Questionnaire (VNOS)

Of the 304 students who completed my VNOS questionnaires, 279 consented to have their responses used in this research. I separated those who consented from those who did not. In Excel, I assigned each consenting student a random number using the website www.random.org. I then took the first thirty students' pre- and post-test responses and consolidated them into one Excel document. While their responses were indicated in a column as either pre- or post-test, I then hid the designating column and randomized the lines in Excel so that I would not know whether I was scoring a pre- or post-test. I tried to eliminate bias in my analysis so that I could not rate pre-tests worse nor post-tests better than they should be, since it would be a reflection on my teaching.

I analyzed my students' VNOS responses in the way detailed in its debut paper (Lederman et al., 2002b). I categorizing their responses as "Naïve," "Adequate," or "Informed," a similar coding strategy used in other research (Akerson et al., 2014b). I coded responses as Naïve if students could not demonstrate adequate understanding of the NOS concept such as believing that data speaks for itself. I coded responses as adequate if students could accurately explain most of the components of the NOS aspect, such as demonstrating their understanding that science is subjective depending on the perspective of the scientist conducting the research. I coded responses as Informed if students demonstrated accurate and thorough understanding of the NOS aspect and were able to provide examples in their responses (Akerson et al., 2014b).

Lecture Viewing

While I was a little afraid of knowing the answer, I collected data on how much of my lectures students watched. I compiled the data first on my sample of students from whom I analyzed their VNOS. I inputted their responses to the question into the Excel document with their VNOS analysis.

Major

Within the VNOS, I included a question asking my students "In which College is your major a part of?" I also looked up their majors in our campus portal and included this information in the Excel document with their VNOS responses. I compared their responses to their majors, looking for Naïve versus Adequate/Informed responses in the post-test.

Results

How do my students' view of NOS change after completing my class?

Of the thirty students sampled, most had at least an adequate response to the first question, even in the pre-test, when it came to expressing their understanding of scientific theories, whether theories change, and why we both to teach theories. Of the five who had an answer I coded as naïve in the pre-test, four provided at least adequate responses in the post-test. One student scored adequately in the pre-test, then provided a naïve answer in the post-test.

Student 27 began class with the popular misconception that scientific theories imply a lack of evidence, as the word is used in other contexts: "Yes, theories can change because they are not facts or scientifically proven. They are not considered to be hypotheses; however, they are relatively close in the definition….” However, they appeared to have gained a deeper understanding of not just theories, but also of the tentativeness of NOS and the continuous progress of science: “I believe that theories can always change if more data is concluded from the experiment and more knowledge is obtained. Perhaps at the moment, our current understanding of science and technology is correct for our current technology and education. However, perhaps in a few decades or years, there can always be changes due to humans being filled with human error that is always inevitable.” They demonstrated their understanding of the tentativeness of theories, but also the tentativeness of science in general due to the fact that it is a human artifact and humans are not infallible.

In contrast to the first question, many students came to class lacking an understanding of what atoms were or looked like: I coded 20 of the 30 students' responses as naïve in the pre-test. Only some of the students came to class able to name the subatomic particles protons, neutrons, and electrons. This was quite concerning, considering they should have at least learned that most fundamental aspect of chemistry in high school before starting college. Student 5 admitted, “Personally, I don't really know what an atom looks like. All I know is that they are extremely small and naked to the human eye.” Nearly all the students incorrectly believed that scientists know the structure of an atom because it had been viewed under a microscope, not realizing the inference required based on experiments. Student 26 wrote “They use actual pictures of what an atom looks like under a microscope to provide evidence.” The students seemed to make the assumption that what we know about atoms is based on viewing them directly, instead of using other kinds of empirical evidence to draw conclusions using inference.

In the pre-test Student 1 freely admitted, “I'm not too sure, I remember learning about atoms a couple years ago but I'm a little rusty unfortunately.” This student, however, made remarkable gains in the post-test, and gave a very insightful explanation of the process of inference scientists utilize to describe what we cannot actually see: “An atom looks like a sun in the center with orbiting planets. However, even though we have illustrations of atoms, we still can't see them. They are so small that we can only really detect the electrons within the atom, not the atom structure itself. I think this is the evidence used to determine what an atom looks like, similar to a black hole, since we can't actually see the black hole, we can now photograph the material and other things around it to help get a visual.”

Five of my students showed improvements in the post-test, moving from naïve to adequate/informed. Most of the other students did not show a major change, perhaps unsurprisingly because I covered chemistry the very beginning of the semester and they took the post-test at the very end.

While many students understood the tentativeness of theories, many were unable to differentiate between a scientific theory and law, let alone give an example of either, and I coded half of my students' responses as naïve in the pre-test. I was not surprised because I know there are many misconceptions about this topic. In fact, I was pleasantly surprised and impressed when the other half of the students provided an adequate/informed response.

Student 2 expressed a common misconception in their pre-test, "I think that scientific theory is more of a hypothesis based on observations, while scientific law is more concrete based on facts and calculations. An example could be Newton's Laws and how they apply in physics." They then accurately and beautifully wrote in their post-test: "Yes, there is a difference between scientific theory and law. Laws describe a narrow set of conditions whereas theories are based on the inferences that scientists have made based on observations and they describe how and why natural phenomena occur." Their response was nearly verbatim what I taught in my NOS lecture.

Student 4 wrote in their pre-test, "I'm going to take a guess a scientific theory is an idea not proven and scientific law is something proven," a common misconception. The provided an improved explanation in their post-test, however: "a scientific theory is an explanation used with data experiments and scientific law is a universally accepted fact or an equation that is used to make accurate decisions."

Only four of my students changed their responses from naïve in their pre-test to adequate/informed in their post-test. While I think I succinctly described the differences between theory and law in my NOS lecture at the beginning of my class, I believe I could provide a repeated explanation in my evolution lecture near the end of class. Admittedly, I don't think I spent too much time discussing laws in my biology class, but instead focused on how scientists are not 100% certain of anything, yet we come very close to it when it comes to theories.

I coded about half (sixteen) of my thirty students as naïve when I asked them to compare and contrast science and art in their pre-test. I was not surprised because while this question seems simple, it's actually very difficult to answer, because neither art nor science are easily defined, let alone compared. As Student 13 wrote, "I think it depends on what someone thinks art is. Art has a very flexible definition." Of those sixteen students, nine showed improvement in their post-test, moving to adequate/informed.

Student 5 made a major change when they wrote in their pre-test "Science and art are similar in the way that there is always something to be found/created with both science and art. They are different in the fact that one is based on statistical evidence while one is based on creativity and imagination." They then changed their idea completely in the post-test, writing "Science and art share similarities such as both can utilize creativity and imagination. Without either of those two things we wouldn't have planes or crayons and etc..." They changed from originally thinking that imagination was exclusive to art and absent in science, to admitting that science takes creativity and imagination as well.

Student 6 similarly changed their mind when the originally thought, "I guess science is a way of looking at the world. It tries to make sense of it. Art can be used to look at the world in a more creative sense. Possibly to even critique it." In the post-test they wrote, "They both need a fair amount of creativity to follow through with." The appeared to initially think of art as the more creative endeavor, then changed to accepting that both art and science require creativity.

In contrast, Student 11 began class believing that science required creativity, but instead believed that art was subjective while science is not. They wrote, "I think both science and art are creative. They both simulate our senses and are based on our observations and perception. It is not bound by rules, and is a limitless concept that we are forever exploring and trying to understand. The difference would be that art is more free and up to interpretation. Science is somewhat bound by our physical world. It is not unrestricted and there are patterns to everything that happens and we cannot manifest something in it that breaks those rules." They seemed to hold the common misconception that nature obeys the rules humans write, instead of understanding that nature doesn't follow any rules, but rather science is used to help humans understand nature.

Interestingly, most of the students provided responses in their pre-test that I scored as adequate/informed when I asked them if science is a creative and imaginative process. Only six of the thirty I coded as naïve. Of those six, five gave responses that I coded as adequate/informed in their post-test, indicating remarkable improvement.

Student 1 wrote in their pre-test, “I think it's important to use a little creativity when either doing a hypothesis or brainstorming, however when collecting data I think you should only go by what you find, so it's concrete data. When you start to use creativity too heavily then I think it can cause the data to become a little skewed.” They provided a different response in the post-test, “I think there is a form of creativity and imagination needed in order to come to a conclusion on an experiment or an investigation. It is important to use your creativity to find the solution to a problem, find the best way to get to the end goal effectively. Being a robot when it comes to regulations won't get you as far because odds are you aren't being creative and enjoying the task.” They originally believed that creativity only belonged in the beginning stages of designing an experiment, not in the data collection analysis part, implying that they hold the common misconception that data speaks for itself. Their beliefs changed, however, expressing that creativity specifically is required in the concluding stage of the experiment. They also emphasized the necessity of humanizing the process and not being robotic.

Student 7 wrote in their pre-test, “I don't feel that scientists are very creative with their data collection as they are usually close-minded in trying to make the experiment result in their wanted hypothesis.” They also changed their response in the post-test, writing, “Yes, to figure out the results and why they happened can take creativity to imagine what the reason is.” While their answers were succinct, their beliefs changed completely. Whereas they initially believed scientists were not creative, they changed their mind believing they were, even in the concluding stages of experimentation.

Student 10 wrote in their pre-test, “I think creativity and imagination shouldn't be included in Scientists' experiments/investigations. Science consists of some logic and boundaries which don't let scientists use their creativity and imagination during and after data collection. In other words, scientists have some primary goals which they attempt to achieve during their scientific experiments, and creativity and imagination have nothing to do with those goals.” They changed their mind in their post-test, stating, “Science often begins with observations and collecting information while using the senses. Also, scientists are humans. therefore, I think their creativity and imagination would affect during the data collection." This student's response was more verbose, but demonstrated a similar belief. They, too, initially believed that creativity had no part in science which should instead rely on logic. They seemed to come to realize that scientists are indeed human, and their creativity and imagination would affect how they perform experiments.

Student 20 began class believing the old line that data speaks for itself, writing, "I don't think there is much creativity other than planning and designing experiments. One plugs in the input and an understandable output should come out." However, in their post-test, they wrote "Yes, because there are many ways to analyze data. If a scientist is not creative when looking at data, then there is a good chance that they will miss something important; a pattern for example." This student displayed a remarkable shift in perception. Initially believing that data analysis was straightforward, they later expressed that data can be analyzed different ways depending on the imagination of the scientist. They even gave an example of why this is important, extolling creativity as a way scientists can make important discoveries.

Student 26 initially thought, "I do not think scientists use imagination during or even after data collection. I believe they take the facts as is and write or describe what actually happened rather than assuming. Like if they were collecting data on plant growth scientists would write down the actual growth of the plant and not the height it will potentially grow too." Then in their post-test wrote, "Scientists use creativity when coming up with anything that has not already been done. Like the first person testing gravity had to have creativity when trying to test it. Imagination comes in after when your ar analyzing result and making conclusions." They, too, changed their beliefs that scientists never use creativity nor imagination, then changed their beliefs that they are used during the entire process.

When I asked my students to differentiate scientific knowledge versus opinion, it yielded perhaps the most disconcerting responses of the entire study. I coded twenty of the thirty students' pre-test responses as naïve. I do not address the concept of facts/knowledge versus opinion in my class, but after analyzing my students' responses, it's evident that I (and other educators) need to add it to the curriculum. While I did not include this concept in my class lectures, I expected my students' responses to be informed because I assumed it is basic concept that everyone would understand, regardless of experience in science. The responses were, however, very troubling. Most students would state that something they believed was right could be defined as knowledge or fact, and what others disagreed with them was a wrong opinion. They largely completely missed the differences in these two words.

Student 4's first attempt at describing the differences stated "an opinion is limited knowledge for example one can have an opinion of the world being flat because it just appears flat, while scientific knowledge is full understanding and proof probably. So the scientific can probably show a diagram showing how the earth is not flat." Instead of describing the Earth being flat as 'incorrect' or perhaps 'ignorant,' they described it as an opinion one can have. In the post-test, they again conflate opinion with ignorance: "the opinion is not having any background knowledge while scientific knowledge is an actual scientist who has been mastering his or her craft giving information."

Student 12 similarly wrote that something that was right was a fact/knowledge, while opinions could be wrong: "There is a difference between the two. Scientific knowledge is something that is true. Scientific opinion is something that is not factual and can be very biased. An example of a scientific fact is the theory of evolution. An example of scientific opinion is climate change." They likewise conflate 'incorrect' with 'opinion' in their post-test: "Scientific knowledge is that a person is informed with specific knowledge on a particular subject in the field. Scientific opinion is more biased. For example, the landing on the moon. There are opinions that it never happened, but the scientists at NASA are sure it happened because they have more knowledge and facts that deal with it." Student 25 aligns similarly, but uses a different example: "Scientific knowledge sounds like a fact or argument that cannot be disproven whereas an opinion can be an argument from a peer that presents a situation/experiment in a different light, but isn't proven or backed up with evidence. An example of this would be climate change. It's proven that climate change such as the planet having rising temperatures, the burning of fossil fuels and increasing sea levels as a result of glaciers melting, we know this as scientific knowledge to support the concept of climate change. However, someone could opt out and create the opinion that climate change doesn't exist and that it's just getting hotter as time goes by." They seem to describe what is their own understanding with knowledge/truth, and the label the dissenters' position as mere opinion. Student 29 similarly conflates ignorance with opinion: "Scientific knowledge is taken from facts or has evidence to support it where scientific opinion may be true, but ultimately lacks the evidence to support its claim."

Student 18 stated that knowledge is true, but opinions could be either true or false, instead of the more correct description that an opinion is neither true or false: "Well, the difference between knowledge and opinion is that knowledge must be real, whereas opinion can be real and nonreal. Knowledge is true and factual, and opinion is/ can be true and false, which changes its truth value. In this case, I would say there is a difference between scientific knowledge and scientific truth. I don't really know any examples to help me, nor do I have a reason." They maintained this description in the post-test. Student 24 wrote similarly: "By definition, scientific knowledge is always true. Scientific opinion can be true and false. For example, we have knowledge that there are 7 continents on earth. But people may have different opinions on what is at the bottom of the ocean." This is firstly incorrect because knowledge can turn out to be incorrect, and opinion is neither true nor false. The example they gave is particularly puzzling, because it would be more accurate to state there are six continents, since the land mass Eurasia is divided into Europe and Asia for social reasons. Furthermore, what is at the bottom of the ocean is not a matter of opinion, what is there does not change depending on anyone's opinion, we either know or we don't.

Student 6 naïvely wrote that a consensus determined whether something was knowledge or opinion: "Scientific knowledge would be something that everyone considers true and a fact. A scientific opinion would be an opinion that only a few share. Everyone in the field may not hold that information to be correct." They maintained that notion in the post-test: "Yes. Observation would be knowledge while an explanation if not widely accepted would be an opinion." Student 21 wrote something similar: "Scientific knowledge is known as factual and accepted by everyone while an opinion is an opinion so people might disagree."

I took it as some consolation that seven of the twenty students improved their responses in the post-test, moving from naïve to adequate/informed. Nevertheless, I would hope that all of my students (and indeed, everyone) would possess such a foundational understanding of the most basic logic.

One of the best responses came from Student 3, who initially stated "Scientific knowledge, although everchanging, is based and rooted in tested theories and hypothesis with recorded outcomes, usually tested multiple times. Opinion is how my personal thoughts and experiences influence the statements I make, usually based in anecdotal evidence."

Another great description came from Student 30 in their post-test: “Scientific knowledge is a given. It is information provided to the general public under the assumption that it is correct and can be agreed upon by others, even if there are those who refuse to acknowledge it. Opinions are formed by the minds of people whether or not they have any logical reasoning to it. They can differ per individual and are offered from the person rather than the other way around like it is for scientific knowledge. For example, blue is a color and science can prove that which anyone can believe. An opinion would be that blue is a good color, but not everyone will agree because good is subjective.”

Most students were of the belief that knowledge was “right” whereas opinions could be “right” or “wrong.” This contradicted many of their earlier responses that accepted the tentativeness of knowledge. This also clearly demonstrates that most students are unaware of what an opinion actually is.

While many students admitted in other responses that science was subjective, many had a difficult time articulating why that could be so when presented with a real-world example of scientists reaching different conclusions when presented with the same evidence. There was not much difference between the pre- and post-test responses for this question, although five of the eight students who I initially coded as naïve in the pre-test showed improvement, as I coded them as adequate/informed in the post-test. Many students freely admitted their extremely limited knowledge of astronomy, yet nevertheless demonstrated their understanding of the subjectivity of science.

Student 7 initially wrote that the discrepancy was because there was a lack of evidence: “Through individual interpretation, which is used when there is no scientific evidence to back up a true answer.” They then changed their response in the post-test, acknowledging subjectivity: “There are many different ways to interpret what data shows and there are many different opinions for theories that are not set law.” Student 16 similarly wrote how the same data can be interpreted differently by different people: “These different conclusions are all possible even with the same experiments and data because science is still somewhat opinionated and data can be interpreted differently across different people.”

Student 30 gave a stellar analogy that I will use in my own teaching: “These scientists are interpreting the experiments and data differently based on how they’re able to perceive the new knowledge. For example, a ball becomes smaller. One might hypothesize that the size is reducing or perhaps the observer is becoming larger and the ball becomes smaller in perception. Another might believe it is moving further away. They could all be right or wrong since there is no other data available to confirm." They brilliantly described how different people could be looking at the same data but reach different conclusions.

Do my students actually watch my pre-recorded asynchronous lectures?

I was surprised and delighted at how many of my students watched my lectures. I was assuming the worst-case scenario, and I had originally feared that none of my students actually watched my lectures. On the contrary, of the 279 consenting students, the vast majority 166 (60%) claimed to watch all of my lectures. Second most common, 84 (30%) watched most of them. These combined totaled of 250 (90%) of students watched all or most of my lectures. 20 (7%) selected that they watched about half of my lectures. 7 (2.5%) watched less than half, and only 2 (<1%) admitted to watching none of my lectures. According to this self-reported data, I believe that a huge majority of my students spend a considerable amount of time watching my lecture videos.

Do students of different majors hold different views of NOS?

Within the sample of student responses I analyzed, there does not appear to be a big difference in NOS understanding between students of various majors. There were both students with mostly adequate understandings and those with mostly naïve understanding within the same colleges. No one type of major appeared to have a better understanding of NOS than the other.

Discussion

How do my students' view of NOS change after completing my class?

There was quite a wide variety in understanding of NOS between my students. In the post-test, some students demonstrated at least an adequate understanding in every single question, whereas others maintained a mostly naïve understanding of most questions. Twenty-five of the thirty students sampled developed a better understanding of NOS in the post-test compared to their pre-test responses. Of the five without any improvement shown, one student already had nearly a complete adequate/informed understanding of NOS so did not have much room for improvement, and another admitted to watching none of my lectures. I would take this as a very good indication that my class successfully teaches students NOS.

Many of my students understood the creative and imaginative aspects of the scientific process, with quite a few developing more informed their views from pre- to post-test. Though many had a hard time defining both art and science, which are, I can even admit, pretty difficult to define. Nevertheless, many students saw at least some similarities, whereas they are usually pitted as opposites in our society, without any overlap at all.

While many students had a difficult time understanding how scientists could come to different conclusions while looking at the same data, many students were able to articulate that scientist are people with their own perspectives.

Most of my students appear to have a good understanding of the tentative nature of science, although I would like to do further study to see how this relates to students’ trust of science. If students use their acceptance of the tentativeness of science to disregard or condemn things that are accepted by the scientific community, they do not have a full understanding of science. Conversely, someone may have complete unwavering trust in science and be blindsided when a paradigm shift inevitably occurs. Further study is needed on how the understanding of the tentativeness of science influences students’ decision-making, such as vaccines, or thoughts on politically charged scientific topics such as climate change.

What I found most concerning in this study was that most students did not seem to know how to differentiate knowledge from opinions. It is my opinion that this is the most urgent thing to address in schools and will have overreaching consequences not just in science, but in decision-making for other real-world applications.

There was quite a diverse range in understanding of laws versus theories. Many students understanding did not change much from the pre-test to the post-test. This is unsurprising since I did not spend a lot of my lecture discussing theories, basically only mentioning it at the very beginning of the term and again in my evolution lecture. Furthermore, I don’t teach laws at all for my class content. So, they only time they learned about it was at the very beginning of class in my NOS introductory video. I could add additional videos to my class in which I provide specific examples of laws and theories.

Do my students actually watch my pre-recorded asynchronous lectures?

I was pleasantly surprised by how many of my students watched so much of my lectures. Not only did it make me feel like my time and effort was appreciated, but it adds validity to my study. Since this course was fully online, if my students were not actually watching my lectures, that would mean I was not truly teaching them. But since they for the most part actually watched my lectures, in which I do teach NOS, I can more accurately say that my lectures are what has an impact on their understanding of NOS. The limitation of this, however, is that this data was self-reported. In future studies, I could explore methods to acquire data more accurately on lecture viewing.

Do students of different majors hold different views of NOS?

I was a little surprised that there was not a clear delineation in responses between students of different majors. I would have assumed that students who are part of the College of Science or who are in a STEM major to have a better understanding of NOS, but that did not appear to be the case. This may be due to the small sample size of this qualitative study, which does not function to provide generalizable results. Future studies using quantitative data on a larger sample may show different results.

Conclusion

Other NOS Teaching Methods to Explore

While I had plenty of time to interact directly with my students when I taught small, face-to-face classes, this is simply not feasible in my current massive online classes. Fortunately, interacting with peers has been shown to facilitate student learning (Tenenbaum et al., 2019) and understanding of science in particular (Ford & Forman, 2006). There may be challenges to incorporate discussion in an online learning environment where students do not meet face-to-face, such as my class. Fortunately, Canvas has integrated discussion boards where students can interact with one another, despite vast distances. By sorting students into small groups within Canvas and requiring multiple posts, there is opportunity for students to interact with one another in a meaningful way.

College students are obviously more familiar with online interaction than students were in years past, with the advent of social media. By posing prompts for their discussions focusing on NOS aspects, students should be able to better synthesize class content and relate it to NOS aspects. By learning from peers, they may gain different perspectives on NOS they had not considered. In this way they can not only reflect on NOS aspects but actually put them into practice in their discussion as they work together to solve a prompt.

Starting NOS Education Early

Nature of Science should be included in student education early, so as to provide a foundation upon which further education can take place (Akerson et al., 2011). Even very young elementary school children can develop an adequate understanding of NOS through explicit-reflective instruction (Akerson et al., 2014a; Akerson & Borgerding, 2010). While I teach college-level classes, of course not everyone will attend college. Teaching NOS to children, starting when they are young, is critical for this reason. Because a K-12 science education will be the only science education many people receive, it is imperative that early instruction it is adequate.

Students' Naïve views of NOS may be influenced by the similarly naïve views held by their own teachers (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008; McDonald, 2010). Traditional school science could actually do more harm to students' views of science (Kang et al., 2005). Naïve conceptions of NOS can even be disseminated in secondary science textbooks (Abd-El-Khalick et al., 2008). For this reason, it is imperative that teachers both understand NOS and utilize effective instruction so that their students have what may be their only opportunity to learn NOS, so that they may lead informed lives. In the words of Carl Sagan, "Every kid starts out as a natural-born scientist, and then we beat it out of them. A few trickle through the system with their wonder and enthusiasm for science intact"(Sagan, 1996). With adult students, the challenge could be to help students "unlearn" the misconceptions that have been perpetuated by their teachers, friends, family, and the media. Challenges may arise when students are dead set on retaining their flawed conceptions, so I hope that I am viewed as a reputable authority on science whom they can trust as I attempt to change their views.

This study adds to the literature on NOS because it provides insights into how a diverse array of students view NOS. I used a fairly large sample for a qualitative study to gain a deep understanding of many different students' perceptions of NOS. Furthermore, my student population is incredibly diverse in terms of race and socioeconomic background, adding new voices to the literature that have historically been neglected.

I consider my teaching of NOS in this class a success. Many students showed improvements in their understanding of the aspects of NOS after watching my explicit lectures and participating in my reflective assignments. I conclude that a explicit-reflective instruction and curriculum is an effective way for students to gain a better understanding of NOS.

Recommendations

Because this was a small qualitative study, results of this study are not generalizable. I may explore this in future manuscripts upon my analysis of the rest of my data of my remaining 249 consenting students. However, I was able to glean important recommendations for how to approach my future teaching. I recommend incorporating explicit-reflective NOS instruction and curriculum in all science classes. Furthermore, I believe that students should be taught to differentiate knowledge/facts from opinions in all classes, not just science. I believe this will have positive impacts in all aspects of society, not only in science. I also recommend including NOS questions in exams as another indicator of student understanding of NOS.

Laboratory classes could potentially be a fantastic situation for students to engage in activity-based NOS instruction, a teaching practice that has shown to increase adult learners understanding of NOS (Akerson et al., 2000). In the future I would like to collaborate with laboratory supervisors to incorporate reflective, explicit, activity-based NOS curriculum in our laboratory sections. I could start in my own biology department, then work with other departments in the College of Science. I hope that this will have an impact on a large number of students, especially those whose lecture instructors do not incorporate NOS into their curriculum. This will lead to opportunities for studies on the efficacy of activity-based NOS curriculum for college students majoring in science.

In my future research, I am interested in exploring the entire spectrum of various responses amongst my students. I would like to compare my students' responses with other data about them, such as their majors, class participation, grades in my class, and other demographic data such as religion, race, 1st generation college student, and grant status. I am interested in hearing how different cultures have shaped my students' perspectives of science and I want to collect as much data as possible, so that I don't miss any voices. As my study progresses and I learn more about my students' perspectives, I may follow up with opportunistic sampling, especially since I am interested in the long-term effects my class has on my students.

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Chapter 7: A Case Study Exploring the Efficacy of Explicit-Reflective Nature of Science Instruction in an 8-week Asynchronous Online College Life Science Course

Eric Wiederhoeft

Chapter Highlights

- Asynchronous online class discussion boards provide an adequate environment for students to learn and discuss aspects of Nature of Science with their peers.
- Explicit and reflective Nature of Science instruction can be incorporated successfully into 8-week asynchronous online college science courses.
- Asynchronous online learning environments make student/teacher interactions more complex than traditional face-to-face classroom settings.
- Specific Nature of Science instructional strategies and thoughtful open-ended questions both help to produce meaningful discussions in online learning environments.

Introduction

One of the goals of science education in the United States is to produce scientifically literate students who are capable of making informed decisions with a proper understanding of what science is and what it is not. Generally, it is agreed on that science refers to the “epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development” (Lederman, 1992). However, there remain disagreements about the nature of science and what it entails from the viewpoint of historians, scientists, and philosophers of science alike. The generally agreed on tenets of NOS addressed within this survey are listed below (Lederman, Abd-El-Khalick, Bell, & Schwartz 2002):

-The empirical nature of scientific knowledge
-Inference and theoretical entities in science
-Nature of scientific theories
-Scientific theories vs laws
-Creativity in Science
-Subjectivity in Science
-Social and cultural influences in science

Through several decades of research, it has been shown that both students and teachers alike do not show informed understandings of NOS (Abd-El-Khalick & Lederman, 2000). As a result, several studies have been carried out to determine if, and to what extent, NOS can be effectively taught to students, pre-service teachers, and teachers with various years of experience through an explicit-reflective approach (Scharmann, Smith, James, & Jensen 2005; Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick 2002; Smith & Scharmann 2008). An explicit approach to NOS represents an instructional strategy that focuses on teaching aspects of NOS directly as opposed to an implicit style of teaching through which it is hoped that aspects of NOS are picked up from the study of scientific content alone (Billeh & Hasan, 1975). The reflective piece of the explicit reflective instructional strategy seeks to give students and teachers a chance to engage with scientific content that allows them to reflect on and articulate their views in the hope of developing an overarching NOS framework (Khishfe & Abd-El-Khalick, 2002).

Over the last twenty years, and especially because of the COVID-19 pandemic, there has been an upward trend in higher education offerings of online courses in both synchronous and asynchronous modalities, as well as an increase in the amount of research focused on virtual education (Martin, Sun, & Westine, 2020). The shifting learning environment from a face-to-face setting to a virtual setting may impact the way that NOS is effectively taught. Virtual learning has several advantages to offer both the institution and the student. The educational institution benefits from a broader exposure of different student populations that were not possible before the advent of appropriate technology, while also being able to potentially reduce the travel costs for staff (Dung, 2020). For the student, virtual learning provides flexibility, potential cost savings, and the convenience of not having to travel to in-person classes which can save on time and transportation costs. Additionally, adult and continuing education students benefit from being able to attend classes and complete assignments on their own schedule amidst other work and family responsibilities. Students also benefit by being able to take courses from universities that are not possible to attend in a face-to-face setting due to either the distance or travel cost (Dung, 2020). Virtual learning also has its disadvantages, such as the lack of intimacy and rapport that is often created in face-to-face environments, the loss of motivation to complete assignments when the teacher is not physically present, and the general lack of socialization as students are not provided as many opportunities to interact with their peers informally, hindering relationship building (Julien & Dookwah 2020). The advent of virtual learning has posed new instructional challenges to educators as they must adapt their classroom skills to a virtual environment where they may never see their students in person. Some of these required skills include knowledge of online learning managements systems, a working knowledge of computers and related technology, good communication skills of the educator, the effective use of multimedia resources, and the focus on student interaction, especially in asynchronous environments (Danchikov, Prodanova, Kovalenko, & Bondarenko 2021).

There are various approaches through which virtual learning can take place including blended learning where there are both in-person and virtual components, synchronous online learning in which teacher and student meet virtually together at appointed times, and asynchronous online learning where the educator primarily acts as a facilitator and students participate and complete coursework individually on their own time (Amiti, 2020). Arguably, the asynchronous learning environment can be the most challenging when it comes to building positive teacher-student relationships and social interaction which have the potential to negatively affect student motivation and overall student success if not carefully monitored by the instructor. To alleviate these concerns, discussion boards are frequently utilized in asynchronous environments to help bridge the communication gap between student and instructor while also allowing students to interact with one another, creating a positive impact on the learning experience (Ringler, Schubert., Deem, Flores, Friestad-Tate, & Lockwood 2015). Asynchronous learning is also a shift from traditional lecture-based instruction and information dissemination. Instead, the asynchronous learning environment requires that meaning making and comprehension be gained through collaboration and reflection (Sloan, 2003). It is important in this context that students can create connections and be cognitively engaged within the community of their peers (Sloan, 2003). One of the ways in which an instructor can build this cognitively engaged community is through frequently using discussion boards in online courses. It has been shown that discussion boards in the asynchronous learning environment, along with clarity of design and instructor interaction, showed a significant increase in both student satisfaction and learning (Swan, 2001).

In addition to explicit-reflective NOS instructional strategies and asynchronous online learning environments, there exists another parameter to this research: the length of the course. An abundance of research that compares how learning outcomes differ between traditional 16-week courses and compressed course terms of 4 weeks – 8 weeks does not currently exist. However, some research has indicated high overall student success rates in compressed course terms. A study comparing 8-week vs 15-week online chemistry courses involving laboratory work showed that students enrolled in 8-week terms outperformed students enrolled in 15-week terms on the final exam (Bannier, 2017). Through combining best practices in asynchronous online education with that of explicit-reflective instruction of NOS, it is reasonable to think that student understanding of NOS can be increased over a shortened 8-week course timeline.

Objective

This case study seeks to understand if, and to what extent, NOS comprehension can be increased in an 8-week asynchronous online environment when taught in an explicit and reflective fashion using discussion boards.

Background

This study took place during the second 8-week term of the Spring 2022 term at a small midwestern community college. The course chosen for this study was an asynchronous online introductory Biology 101 course for majors and nonmajors. This course was selected for the study due to the nature of the topics of study and course objectives, in addition to the ease of incorporating NOS competencies into the units of study. The course objectives are broad and introduce topics including the scientific method and data collection, cellular structure and function, animal and plant biology, genetics, ecology, energy transformation, phylogeny, biotechnology, evolution, the cell cycle, and global issues and their effects on the field of biology. These course objectives focus heavily on content knowledge and no explicit references to NOS are listed, though in a couple objectives, namely the scientific method and data collection, they can be assumed. This biology course is self-paced and students work their way through several interactive modules using a third-party software program known as Bio Beyond. Over the course of the 8-week term, students read selected chapters covering the content, work through the interactive modules at their own pace, and complete a short multiple-choice quiz over the readings for that week. The author of this study acted as the instructor for this course.

Methods

The data collected throughout the study involved the Views of Nature of Science (VNOS) survey, weekly discussion board posts, and semi-structured interviews. From a total of 26 students enrolled in the course, only two students voluntarily agreed to participate in this study. These two students who will go by the pseudonyms John and Sally volunteered their data to be collected and analyzed after the completion of the 8-week course. During the first week of the course, students were asked to complete the VNOS-B open-ended questionnaire (Lederman, 1999) prior to completing any other coursework to capture their current views of NOS before any instructional intervention occurred. The VNOS-B survey is a validated open-ended survey focused on the complexities and tentativeness of science (Lederman 1999). Specifically, this survey centers on human creativity and subjectivity in science based on scientists' backgrounds, human imagination, the difference between scientific theories and laws, observation and inference in the development of scientific knowledge, and the empirical nature of science.

Because this online course was taught in an asynchronous fashion, class discussion boards acted as the primary instructional intervention strategy to explicitly teach NOS competencies.

Students were tasked with completing one discussion board topic per week over an 8-week period that focused on one NOS competency each week. For every discussion board topic, the students were required to make an initial post in response to the topic of that week and reply to a minimum of two of their peer's discussion posts for that week. The discussion topic for week 1 served as introduction to science and gave students a chance to think about the answers they provided on their VNOS surveys. The discussion topic for week 2 focused on the empirical nature of science. The discussion topic for week 3 focused on the distinctions between observation and inference. The discussion topic for week 4 focused on forming a proper understanding of the scientific terms "hypothesis," "theory," and "law" as they pertain to scientific investigations and knowledge. The discussion topic for week 5 focused specifically on the differences between scientific theories and laws. The discussion topic for week 6 allowed students to determine if creativity and science coexist or act as mutually exclusive entities. The discussion topic for week 7 explored whether subjectivity exists the field of science or not. The discussion topic for week 8 ended the term with an exploration of the societal and cultural influences on the field of science. For further detail regarding the discussion prompts please see the Appendix.

At the conclusion of the course, students were asked once again to complete the VNOS-B survey. Additionally, semi-structured interviews were held to clarify any ambiguous answers provided on the questionnaire as well as provide further insight into the thought process of student responses. The interviews were voluntary and provided data triangulation that helped to support the data analysis. After the final grades for each student were finalized and the course was closed, the VNOS-B questionnaire data was collected, and the author was provided with the list of participants that volunteered for the study. Out of a total of 26 students enrolled in the course, 4 students volunteered to participate in the study. Of those 4 participants, 2 of them withdrew from the course early on and meaningful data could not be extracted. Two students, John and Sally, completed the entire course and represent the data sources for this case study. While the reasons for such low participation are uncertain, a possible cause may have something to do with the difficulty in fostering meaningful student relationships and interactions in the asynchronous online learning environment. Both John and Sally were undergraduate students that were not majoring in a scientific discipline. John is a Psychology major who, at the time, was in his first semester of college, and was enrolled in this introductory biology course to satisfy the science credit requirement for his Psychology program. Sally is an early childhood education major in her second year of college. Sally owns a daycare business and has been out of school for several years. She was also taking this introductory biology course to satisfy the science credit requirement for her academic program.

Results

The pre- and post-VNOS-B questionnaires collected from John and Sally were analyzed for evidence of an increased understanding of NOS through a coding scheme that labeled each participants response as naïve, transitional, or informed. These coding terms are the same terms utilized by the creators of the VNOS series of surveys (Lederman et al., 2002). The participants responses on the VNOS-B questionnaire were compared alongside their discussion board responses and their interviews, if applicable, to elucidate a more accurate assessment of each participant's views of NOS and how those view changed over the 8-week course. Table 1 and 2 show the coding scheme assigned by the instructor for each participant's Pre- and Post-VNOS questionnaires.

Table 1. Comparison of Sally's VNOS Responses

NOS Aspect	Pre-VNOS NOS Assessment	Post-VNOS NOS Assessment
Question 1: Empirical Nature of Scientific Knowledge	Transitional	Transitional
Question 2: Inference and Theoretical Entities in Science	Naïve	Naïve
Question 3: Scientific Theories vs Laws	Naïve	Transitional
Question 4: Creativity in Science	Naïve	Transitional
Question 5: Creativity in Science	Naive	Transitional
Question 6: Subjectivity in Science	Naïve	Transitional
Question 7: Social and Cultural Influences in Science	Naïve	Transitional

Table 2. Comparison of John's VNOS Responses

NOS Aspect	Pre-VNOS NOS Assessment	Post-VNOS NOS Assessment
Question 1: Empirical Nature of Scientific Knowledge	Informed	Informed
Question 2: Inference and Theoretical Entities in Science	Naïve	Naive
Question 3: Scientific Theories vs Laws	Informed	Informed
Question 4: Creativity in Science	Naive	Transitional
Question 5: Creativity in Science	Transitional	Transitional
Question 6: Subjectivity in Science	Naive	Naïve
Question 7: Social and Cultural Influences in Science	Transitional	Informed

Sally's VNOS- B Responses

Sally's response to question 1 revealed a similar transitional level of NOS competency in her pre- and post- responses, "Yes I am sure it does change. I think as time changes and as we receive more information on things, we better understand. We want to see how things work, figure out the issue and fix it" (Sally, pre-VNOS). Compared to

> Yes I believe a theory can change. A theory can be proven or not. A theory will change, be improved or modified as the scientists gather more information on the subject. We bother to teach scientific theories for newer predictions that can be evaluated, like electricity (Sally, post-VNOS).

While Sally is able to articulate in both responses that scientific theories do change and with time passing, new information can lead to a revision of the existing theory, she fails to correctly answer why we bother to teach theories and uses the term "Proven" instead of a more accurate term such as "supports" in her post-survey response. Nothing can ever be fully proven within the field of science as we never know if we have all the information to describe a scientific theory perfectly, nor do we know with full certainty that we are interpreting all of our known information accurately. Sally's interview discussion echoed similar thoughts to both her pre- and post VNOS responses for question 1 during which she states, "It (a Theory) is like a thought-out explanation," and "They (scientists) get more information and… work towards it… and then we understand it better." Sally's Pre- and Post- responses for question 2 both show a naïve understanding when she responds, "small solar system. I don't know" for her pre-survey, and "Atoms are tiny units of matter that cannot be seen even with a microscope. An atom is just smaller particles of protons, neutrons and electrons. Scientists use microscopes to detect the number of protons, electrons and neutrons" for her post- survey respectively. While she is able to reflect an accurate representation of how atoms are composed in her post-survey response, she fails to describe why scientists believe atoms to be composed of those sub-atomic particles. When interviewing Sally over question 2, she reiterated a similar response found in her pre-VNOS response when she replied "Well, I mean honestly I don't know what an atom looks like. Is it just like waves and is it determined by like, the number of protons and the balance and the weight and stuff like that?" The third thru seventh questions on the survey show where Sally begins significant improvements between her pre- and post- survey responses. For question 3, Sally's first response reads, "I am sure there is a difference," but does not support her statement and shows a naïve understanding of the concepts of scientific theories and laws while her second response reads:

> Scientific law is an observation of the phenomenon the theory is attempting to explain. It is a statement based on repeated experiments or observations. Where a theory is an applicable explanation for a wide range of phenomena. Gravity is an example. The scientific law states that when you drop something, it will fall straight down to the floor. A theory is the explanation as to why every time you drop something it falls straight to the floor. (Sally, post-VNOS)

Sally is able to correctly differentiate between a scientific theory and law, but provides an incomplete and partially incorrect example to support her statement. Considering this, it shows her moving from a naïve to a transitional view for the NOS aspect dealing with theories vs laws. When discussing question 4 with Sally during her interview, she was able to list an example of a Theory, Dalton's atomic theory, and a Law, Newton's law of universal gravitation. She also reiterated how Theories do not become Laws and Laws do not become Theories. On question 4, Sally's pre-survey response indicates a naïve understanding of NOS when she says, "They are both showing us everything around us in a different way. They are different in a way where science is looking for knowledge and art expresses it." This response fails to expand on the similarities between science and art, namely creatively, but does make a partially correct distinction between the two. Her post-survey response still mentions a distinction between science looking for knowledge and art expressing that knowledge but she elaborates on her former response by adding, "Both art and science are attempts to explain the world around us. Both can cause us to see things in a different light. Both an artist and scientist have to be very creative." Understanding that both artists and scientists utilize creativity in what they do brings her to a more transitional understanding. Sally again reiterates the same sentiment during her interview when she states, "Both of them (science and art) are creative." In question 5, Sally's pre- and post- responses both contain attributes that initially imply a naïve understanding of NOS: "Sure. They must be problem solvers," and "Scientists use their imagination to now come up with explanations. They must do experiments, make observations to test a hypothesis." Looking at Sally's response to question four when she mentions that scientists and artists both have to be creative in their endeavors and hearing her discuss this question during her interview where she stated, "…When they try to design an experiment they have got to be creative… Without their imagination, I don't think there would be science." These additional details provide evidence of a transitional view that considers the need for scientists to use their imagination and creativity to carry out scientific processes.

Sally's pre- and post - responses for question six include, "Yes, knowledge must be the real thing and opinion may be or not." And "Yes. Knowledge is based on facts and evidence, while opinions are based on anything. Knowledge is the real thing and opinions can or cannot be" respectively. Her latter response reveals a notable difference in that Sally is acknowledging that knowledge is based on evidence while opinions may or may not be. This shows a movement from a more naïve to a more transitional perspective as she could not provide the same level of detail in her former response, instead stating knowledge is the "real thing" without elaborating on what that meant. For the last question on Sally's VNOS survey, she first mentions, "It is how they all choose to look at the data. Not everyone sees the same." Sally does not fully answer this question and a clear definition for her use of "It" is uncertain. In her post-VNOS response, Sally is able to expand upon her first answer by stating,

> It all depends on how they choose to look at the data, Some scientists decide to change their minds after looking at the experiment and data over and over. Some scientists use their background knowledge and other experiences to interpret data. (Sally, post VNOS)

Additionally, in her interview, Sally makes the statement, “Just because you and I are looking at the same picture doesn’t mean we see the same thing,” when responding as to why scientists might interpret data differently. This shows a move from a naïve to a transitional understanding. A more informed view of the cultural and societal influences on science would make mention of the cultural differences in perspectives, as well as the individual biases all scientists have, and how those forces play a role in our interpretation of the natural world which Sally does not mention in her response.

Sally’s Discussion Board Responses

The week 3 discussion board required students to participate in a NOS activity called the “Checks Lab” (originally created by Steve Randak with the current version by Loundagin, 1996). Throughout this activity, students attempt to create a storyline based on a series of fake checks written over several years. This activity requires creativity and subjectivity when using the available evidence of the checks to form inferences as to what the “correct” storyline might be. During this discussion board, Sally noted the following observations,

> 1. Some valuable information on the checks would be the dates the checks were written and who wrote them.
> 2. Some useless information on the checks would be the amount they were written for.
> 3. Some misleading information was all the names. You have William, William Jr. Bill and W.A. It was hard to figure out who was who. (Sally)

As a result of this discussion board, Sally was able to discern how both creativity and subjectivity are involved in scientific processes and this knowledge is later reflected on her post-VNOS response for question 5 where she mentions how scientists use creativity and subjectivity when coming up with explanations. Furthermore, in Discussion board six which dealt with the similarities and differences between science and art Sally writes, “I do believe that creativity exists in science. Scientists need creativity to help generate hypotheses. Being creative will help a scientist come up with new ideas and be able to solve problems.” When discussing the use of creativity in scientific investigations with a peer in the same discussion board Sally responds,

> I'm glad to see one of your takeaways from the video was when the scientist was talking about working backwards from a problem. I had to stop the video, think about what he was saying, and replay again. I am sure many people have actually done this before and maybe did not even realize it. You know the final answer is going to be XYZ but you're not sure how you got that so you work yourself backwards to find the solution, I can see doing that. (Sally)

This response to her peer is evidence of a shifting thought process and one example of how Sally was able to acquire new insight regarding NOS through discussion with other students within the course.

Sally also improved in her ability to correctly identify what theories and laws are and accurately distinguish between them. This topic was addressed in the fourth discussion board post in which students participated in a short quiz over scientific terms in addition to first writing their own definitions of the terms "hypothesis," "theory," and "scientific law," followed by looking up the actual scientific meanings of these terms. In her discussion board post Sally stated,

> A hypothesis to my understanding is when you come up with ideas on events and make guesses about them. A Theory is when you come up with an actual result on a hypothesis. it is done after tests and research have been run. Law is when a theory is finalized.
>
> Revision
>
> Hypotheses are proposed explanations for a fairly narrow set of phenomena. Theories are broad explanations for a wide range of phenomena. They are concise, coherent, systematic, predictive, and broadly applicable.Laws are statements, based on repeated experiments or observations, that describe or predict a range of natural phenomena. (Sally)

She went on to say in discussion board 5,

> I believe my answers were accurate I just couldn't tell you what the difference was at

> the time. Now I know that there is a difference between a scientific Law and Theory. I also had thought that once a theory had been tested enough it would become a scientific law. Now I was able to learn and see the difference between each. (Sally)

In discussion board seven, students were required to look back at their stories from the Checks Lab in discussion board three and discuss whether or not they could identify bias or subjectivity in the created storyline. Sally commented regarding this topic,

> In any kind of discourse in life, there will be a form of subjectivity and bias. based on personal belief, opinion, or experience. In science it's necessary. Scientific theories are subject to change over time after the discovery of new facts or simply a change in belief. Subjectivity is important in science even though being objective is the key… Everyone has a bias. I find it fascinating that you concluded that an accident occurred. I never thought of that. it's interesting. i think there would also be a check for some kind of physical therapy if an accident was assumed to have happened. there was no right or wrong answer, just what we can all come up with. (Sally)

Again, the components to Sally's responses in these discussion posts were missing from her pre-VNOS survey responses indicating the possibility that these discussion boards are eliciting changes in the way Sally views NOS. This helps reinforce the idea that an explicit reflective approach at teaching NOS can be successful in virtual settings.

John's VNOS-B Responses

John, on the other hand, showed less improvement when comparing pre-VNOS to post-VNOS scores alone. In the first question John shows evidence of having more informed views of the empirical nature of scientific knowledge as both of his responses include the idea that scientific knowledge changes when new evidence is collected. John's Pre-VNOS response to question 1 reads,

> The theory absolutely does change. After a new theory has been observed for a while, inevitably new information will enter the playing field and challenge the current views. Adjusting the theory to be able to accompany this new information is easier said than done but is a never-ending process of refinement. Without learning that information

> changes over time as new data and studies are performed, it can be easy to get stuck with the same viewpoint throughout your entire career (John, pre-VNOS).

John's second response reads,

> I'm not sure if theories change, so much as new theories are presented to account for differences. Like if a theory works very well based on current research and seems to paint an accurate picture. But a new breakthrough starts to make it seem like it doesn't really fit the new model very well, one could pivot from that theory, but I would imagine most of the time if a theory isn't fitting anymore, one would look to produce a new theory entirely. (John, post-VNOS)

John's responses to question 2 are as follows.

> There are models that have been developed, but I don't think they're entirely accurate. They're maybe a bit of a placeholder until we can be certain that's how they look. It's nearly impossible to really take a picture of something so small. (John's pre-VNOS)

> There are microscopes that can see atoms, but looking at pictures available on the internet, it's still not really clear. I believe the model shown for education purposes isn't what it really looks like, but it's presented in that way because it's close enough and makes it easy to visualize what composes different elements. The idea that Electrons aren't actual orbs, but instead are a sorta electric energy that radiates around individual atoms means you likely can't see them on a microscope, but they instead have to be measured. And this measuring is how the model has been formed over time (John's post-VNOS).

While John accurately describes atoms being too small to take a picture of and the discrepancy between the model of the atom and what it actually looks like, he makes mention of "measuring" atoms but doesn't describe how that would take place, and mentions that the current models used to describe atoms are placeholders until we can be "certain" of how they look indicating a transitional instead of informed understanding of the inferential and evidential nature of science. John's responses for question 3 indicate an informed understanding between scientific theories and laws for both his pre- and post-survey answers. In both cases John correctly describes the difference between a theory and a law by stating, "Laws are widely observed phenomena, a theory would be a proposal on why these phenomena happen." Regarding the similarities and differences between art and science, John's first response illustrates a naïve understanding: "Both are crafts that people seek to perfect and improve upon. But science is much stricter and more academic in nature than the arts." Because an interview with John could not be scheduled, it is hard to determine what John meant by the word "crafts" without making any inferences. John lacks the inclusion of science requiring evidence while art does not, and that both science and art are human endeavors, but science requires the interpretation of evidence in order to form understandings. while his second response listed below indicates a transitional view.

> Overall science and art are very similar in that they are individualistic, and the same two people painting the same landscape from the same angle at the same time, may have very different looking paintings. You can formalize the process all you want, but when faced with situations that require some subjectivity, the human element is presented and causes variation. (John, post-VNOS).

The transitional nature of John's post-VNOS response shows evidence of the subjectivity involved in both science and art when he points to the "individualistic" nature of interpreting what John refers to as a formalized process (scientific methods). John's response to question 5 which deals with the creative nature of science, both show evidence of a transitional view and no improvement in NOS understanding was perceived. John's first response to question five reads,

> I would imagine so. Without much imagination, it's hard to see anything outside of what is right in front of you. Coming up with an idea as to why your data isn't telling you what you were expecting is an important skill and requires imagination. (John, pre-VNOS)

> Yes, ideally all science is done through positivism means and confirmed through measurable, typically mathematical equations and measurements. But that's idealistic and not entirely realistic. A lot of the time, in many areas of science there are humans present in the equation at one point or another, and you must account for behaviors and such. Which requires subjectivity, understanding and a bit of imagination to account

> for such a factor. There are other examples I'm sure, but this is the one that came to mind. (John, post-VNOS)

John is able to include a description of creativity being a necessary component of scientific investigations in both of his responses, but neglects to mention that this creative aspect is present in all forms of an investigation and is required in order to generate scientific knowledge from their creative interpretations of data. John answers question 6 in a similar way with both responses falling into a mixed transitional category that contain accurate and inaccurate statements. John's Pre-VNOS response reads, "Scientific knowledge is well-established fact, kind of like Scientific Law. Opinion is more like Theory in the sense of you taking a jab at what you think is the purpose of a certain phenomena." While he is correct that there is a difference between scientific knowledge and opinion, he naively describes theories as opinions. His post-VNOS response contains similar sentiments when he says, "Yes, but I'm not sure how to explain the difference aside from the words themselves. I think scientific knowledge is kind of a general understanding of something, where scientific opinion is one's own interpretation or skepticism of that knowledge." Again, while John acknowledges a difference between scientific knowledge and opinion, his supporting details show naïve understandings of the two entities.

John again shows an improvement in NOS understanding when answering question 7 pertaining to subjectivity in science. John's first response reads,

> The data right now is vague and there's plenty of holes, therefore making all these explanations reasonable in some sense. As more data and information is collected, they will be refined and eventually there may be more settling on 1 or 2 options instead of the many other options out there (John, pre-VNOS).

This shows a transitional view where he accurately presents the idea of refinement as more data is collected, but he does not allude to the subjective nature of the scientists that may see the same data differently based on their cultural bias, worldview, or life experience. John's post-VNOS response elucidates a more informed knowledge of the subjectivity of science when he answers, "Imagination and subjectivity. Everyone has their own perspective and ways of looking at things, and even if presented with the same data set, it can be interpreted in different ways, leading to different results." In this response, John is able to describe how imagination and subjectivity play a role in our interpretation of data which can lead to different results.

John's Discussion Board Responses

John was able to improve his understanding of NOS in the areas of creativity in science and social and cultural influences in science, while all other aspects of NOS remained unchanged. Questions 4 and 5 on the VNOS overlap regarding the comparison of art and science and the use of creativity in science. While John was able to maintain the same position in his post responses for question 5 stating that the use of imagination was an important part of scientific processes, he initially struggled to articulate how science and art are similar and different from one another. He was able to define his thought process more clearly when responding to two peers in discussion board six where he states,

> I also really liked when one interviewee pointed out how he notices styles in scientific experimentation and writing, like he would notice a style from a particular artist at a museum. It really seems that creativity is at the root of science and progress. (John, Discussion Board)

> We're definitely on the same page. Creativity is critically important at every step of the way when doing science. From initial thoughts to figuring out how to run experiments, to interpreting data. Every step requires some critical thinking skills and a fair amount of imaginative thinking skills as well. Science can be often viewed as a strict practice where you must abide by certain guidelines, but I think as you expand your scientific knowledge and experience, things become somewhat less rigid. Kinda like when you've been at a job for a while and you have a good understanding on what policies actually serve any purpose. (John, , Discussion Board)

In the above responses, it is evident that John has been able to take something away from the discussion board that has resulted in a modification of his through process when discussing how art and science are similar from the standpoint of creativity. In discussion board seven, John is able to further articulate on his position of subjectivity in science and additionally, social and cultural influences in science, when looking back at the stories created during the Checks Lab discussion board in week three of the course. He states in his full post and response,

> Looking back on the original stories, I found that I disagreed with a lot of others takes on what was going on behind the scenes with those transactions. I've got some life experience in EMS and have a tendency to lean towards the worst case scenario. Quite a few people deduced that there was likely a car accident and someone got seriously injured, incurring a large hospital bill. I assumed that someone died in the car accident. And I think that's a sign of my own bias. As long as there are humans drawing conclusions from data and experiment results, there will always be some sense of subjectivity that bleeds into scientific works. The science itself, such as data and statistics is ideally completely objective and unbiased, but often times a vigilant mind will notice subtle biases, such as who was selected for a survey, double blind study but they only selected participants from a single city in a certain area, therefore skewing the results. But I don't think it should be eliminated entirely. Often times context paints a clearer picture than without, and by eliminating subjectivity, I feel that you would, consequently, eliminate context as well (John, Discussion Board).

> I agree that subjectivity should stick around in certain contexts, especially in the social sciences like the professor highlighted. Sociology and Psychology are inherently subjective and rely heavily on context to draw conclusions. Subjectivity is the human element and telling someone to toss that aside is a perfectly reasonable request when looking for good science, but I think it's unrealistic to expect it to actually disappear (John, Discussion Board).

> (In response to a peer) Ooh that's a good point! It reminds me of the previous discussion post about imagination and creativity in science. I don't think you can realistically have imagination and creativity without the presence of personal motivators, experiences and biases. Subjectivity will always be present and it would likely be a better approach to find ways to account for subjectivity instead of attempting to eliminate it (John, Discussion Board).

In his response, John is describing the extent to which bias and subjectivity can play a role in scientific processes. His post and peer replies in discussion board 7 are also reflected in his post-VNOS response for question 7 where he again the use of imagination and presence of subjectivity that can allow for scientists looking at the exact same data to have varying conclusions that explain the data.

Discussion

Between the two students, Sally showed the largest increase in NOS competencies when comparing pre- vs post-VNOS responses with significant changes in 5 out of the 7 aspects of NOS compared to John who showed significant improvement in 2 out of 7 aspects. Sally's pre-VNOS responses were all coded as naïve with the exception of her first response which was coded as transitional. In Sally's post-VNOS responses for questions three thru seven she increased her NOS competency to a transitional view. The aspects of NOS in which Sally showed improvement include scientific theories vs. laws, creativity in science, subjectivity in science, and social and cultural influences in science. I believe the discussion board topics each week that explicitly focused on these aspects of NOS were responsible for these increases.

In both John and Sally's VNOS surveys, questions 1 and 2 which deal with the empirical nature of scientific knowledge and inference and theoretical entities in science show no significant change. This may be due to the nature of the question's students were asked to discuss in which the directions, questions, or both directions and questions may have not adequately addressed the empirical nature of scientific knowledge and inferential and theoretical entities in science. Additionally, it is plausible that students already thought they understood these aspects of science and may not have thought the information in the discussion boards was useful to enhancing or improving their views of these two entities.

The data acquired and analyzed from John and Sally is useful in the ongoing research of strategies and instructional practices that can be incorporated into online asynchronous courses and, if taught in an explicit reflective style, can result in more informed understandings of NOS. While not every discussion board topic appears to have been useful in enhancing the understanding of NOS in every category, several discussion topics, specifically discussion boards 3-8, appear to have given students a chance to interact with content that addresses several tenets of NOS and allowed students the opportunity to describe, discuss, and enhance their understanding of NOS through peer-to-peer interaction. This research also supports the idea that the educator does not need to be the individual primarily responsible for teaching NOS directly in an explicit reflective way, but the use of open educational resources, videos, and various other multi-media can also act as the vehicle that delivers NOS content with efficacy.

The results from this case study, in addition to the online asynchronous learning environment itself, appear to align with the current research. Online asynchronous environments are unique in that they do not naturally allow for the same extent of instructor-student interaction (Julien & Dookwah 2020). The lack of student rapport possible in this learning environment may describe why it was so difficult to recruit willing students to participate in this study even after multiple appeals for participation and attempts made on the part of the instructor to help create a positive relationship with each student. It was also shown in this case study that an explicit and reflective instructional strategy for teaching NOS can indeed increase student understanding of NOS, at least to some degree, as it was initially shown by Khishfe & Abd-El-Khalick (2002). This study utilized discussion board prompts as the primary mechanism to allow for students explicitly and reflectively engage with NOS competencies in an online environment. Bannier showed that it was possible for students in an 8 week chemistry course to outperform those enrolled in the same course for 15 weeks (2017). Likewise, this study has shown that it is possible to increase student comprehension of NOS in a shortened 8 week course setting.

This study is not without its limitations, however. First, the small sample size of two students cannot be adequately used to make any generalization as to the effectiveness of this instructional strategy within this context. Second, while it was stated that students should complete their pre- and post-VNOS surveys without the use of any materials and answer according to their own current understandings, a way to monitor this was not enforced and students could have used outside materials when writing their responses which would then invalidate what was attempting to be measured, namely their personal and current understanding of NOS. Third, when dealing with the application of subjective codes (naïve, transitional, and informed) to student responses, it is possible that other individuals reading the same student's responses would have coded those responses differently than the author thus leading to a different analysis. Fourth, an interview was not conducted with John. Had an interview been conducted, some of John's vocabulary usage could have been clarified which might have changed the way his responses were perceived and coded by the author. Fifth, the instructional strategies utilized in the discussion boards for this study are not exhaustive and there could be several other strategies that could be used to increase NOS competency.

It also worthwhile to note the difficulty in student engagement and eliciting student participation in asynchronous online environments. Even though the teacher presence and interaction in the course occurred frequently each week, and multiple attempts were made to invite students to participate in the study, student participation was quite low and only four students out of a total of 26 students agreed to take part. Of those four students, two ended up withdrawing from the course and were thus eliminated from the study as no usable data was extracted. As Traynor-Nilsen (2017) pointed out, it is easier for students to ignore the instructor and the instructor has less sense of control in the online learning environment.

This research supports the notion that an explicit reflective instructional approach can enhance the understanding of students perception of NOS in an asynchronous online learning environment. Open-ended discussion board prompts that allow students the opportunity to engage in explicit NOS content, and a reflection on what they are learning in a discussion with their peers, can result in a positive increase in their understanding of what science is and what it is not. This research is an important facet of science education in light of national reforms that have been mandated which are geared towards building a proper understanding of science and the importance science has in a student's general education (Rhoton, 2001). As the need for scientifically literate students increases, and as the trend for online courses continues its upward trajectory, more studies are needed that study additional explicit reflective NOS instructional strategies in asynchronous, synchronous, and hybrid online courses.

Conclusion

The intent of this research was to uncover the effectiveness of explicit reflective NOS teaching in a shortened 8-week asynchronous online course. The open-ended VNOS survey created by Lederman et al. (1999) is a valuable tool in assessing the perceptions and understanding of students regarding the various aspects of NOS. In light of the sparse research regarding NOS instructional practices in various learning environments, this study, though limited in the amount of data collected and analyzed, has shown that it is possible to increase students understanding of NOS through the use of open-ended discussion board prompts and various multimedia and internet resources. More research is needed to validate these findings and further elucidate the role of explicit reflective NOS instructional strategies in the online learning environment.

Recommendations

It is recommended that further research be done to uncover more explicit reflective strategies in online learning environments, as well as further research into the inclusion of explicit NOS instruction in other life science courses. Furthermore, it is necessary to perform the same research with larger data sets that may be able to provide more insight into the efficacy of explicit NOS instruction in asynchronous online science courses to validate the findings of the current research.

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Appendix. Discussion Prompts by Week

Week	Discussion Board Prompt
1	For the first part of your discussion board post, look over the 7 questions of the VNOS Questionnaire and your responses to those questions and answer the questions below: 1. Where there any questions that seemed easy to answer? hard to answer? If so, what were those questions and what made them easy or hard for you? 2. In your own words, what do you believe "science" is? Clickto watch this video on nature of science: https://www.youtube.com/watch?v=TkvjDZseD4k 3. What do you believe are reasons for individuals to become scientifically literate? (scientifically literate: having a proper understanding of what science is) 4. Compare the attributes of science presented in the video to your responses on the VNOS Questionnaire - If you were able to go back and answer any of the questions on the VNOS again, would you answer any of them differently after having seen the video?
2	Click on the link below and watch the video on the empirical assumption of science, then respond to the following prompts: Part 1**:** https://www.youtube.com/watch?v=6fTqQRSMwOo (Links to an external site.) 1. Science is based on an assumption of being empirical, which means it is based on sensory observations and what can be measured and experienced through the senses. With this assumption in mind, do you think that science is able to discover/uncover absolute truth? Yes or no, why or why not? 2. Can you think of a question that we could not answer using scientific methods. Describe why you believe that question cannot be answered through scientific means. If you think science can be used to answer ALL questions, explain why you believe this.

	Part 2: Click on the following website link (https://www.shapeoflife.org/nature-science-scientific-knowledge-based-empirical-evidence (Links to an external site.)) and select any one of the videos that seems the most interesting to you then answer the below prompts. 1. Write a brief (2-3 sentence) summary of the video you watched. 2. In the video you watched, list the conclusion of the scientist and the empirical data that was used to support their conclusion.
3	Below you will find four pages of checks and a worksheet to help you organize your thoughts/storylines. I want you to pretend you are something akin to a detective who is trying to piece together the information on the checks to come up with a storyline that ties all the checks together. 1. Start by clicking on page 1 which contains 4 checks, and come up with a story based on your observations of the information contained on those 4 checks. Write down your summary somewhere (it doesn't have to be on the worksheet, it can be notes typed in a word document if you wish). 2. Next, click on page 2, look at the information found on the 4 checks on page 2 and add this information to your existing storyline. Does this information force you to change your story or does it simply add details to your existing story? Write down your new storyline somewhere, either on the worksheet or in your word document. 3. After that, click on page 3, look at the information found on those 4 checks, and further work out your storyline with this additional evidence. Record your new version of your storyline considering these details. 4. You will notice there is also a "page 4" in black text that is not a hyperlink like the other three pages... Think about why I am not letting you see the information from the checks on page 4? 5. For your first discussion post - write down what you believe the best/most accurate storyline is based on your observations from the three pages of checks you were able to see and answer the three questions below. -What bits of information on the checks were valuable to you in formulating a tentative explanation?

	-What information was useless? -List any misleading information that was presented. 6. For your two additional discussion posts, look at two other classmates' posts with their storylines and see how your story differs. You may wish to engage in a (friendly) debate as to why you think you might be right or they might be wrong, or you may like the storyline that your classmates came up with and wish to adopt some of their explanations to your own story if you think they make a good case based on the available evidence. The goal is to try and create the most logical and accurate storyline based on the information available on the checks. CHECKS LAB WORKSHEET (Links to an external site.) PAGE 1 (Links to an external site.) PAGE 2 (Links to an external site.) PAGE 3 (Links to an external site.) PAGE 4
4	This week I want you to think about your current understanding of the following words: 1. Hypothesis 2. Theory 3. Law For your first discussion post I would like you to write your own definition of these words based on your CURRENT understanding (Don't look up what these words actually mean in science, I'm interested in what you think right now!). After you write your own definitions of these words based on your CURRENT understanding, I want you to go to the link below and read "Science at multiple levels" click next at the bottom to read "Even Theories Change" and click next at the bottom of the page again to read "Summing up the process", then revise your definition of hypothesis, theory, and law as needed. https://undsci.berkeley.edu/article/0_0_0/howscienceworks_19 (Links to an external site.) For your second discussion post: Go to the following link and take the short quiz. In your discussion post record your score on this quiz and which

	questions (if any) you missed: https://www.visionlearning.com/en/library/Process-of-Science/49/Theories-Hypotheses-and-Laws/177/quiz (Links to an external site.)
5	First, check out this video that includes a good summary of theories vs laws: Theories vs Laws (Links to an external site.) Next, go back to your VNOS survey that you completed at the beginning of our course and look at your answers for questions 1 and 3. For your first discussion post, summarize your answers to questions 1 and 3 from the VNOS survey that you answered, then compare your answers to the information you viewed in the above video and answer the following question: Do you think your VNOS answers were accurate? If so, why? If not, why not? Was there any new information that you learned regarding theories and laws from the video that you did not previously know? For your second discussion post, List one scientific theory and one scientific law and describe how they are conceptually different.
6	I want you to start out by asking yourself this question: Is creativity present in scientific endeavors? You may want to go back to our VNOS survey and look at your answer to question #5 that dealt with the same topic. Next, check out this video: Is Creativity Important in Science? (Links to an external site.) For your first discussion post, summarize your answer to question #5 on the VNOS survey that you completed at the beginning of the year. Then, Consider the video you just watched and list 1 or 2 takeaways you got from it regarding science and creativity. Finally, write down your current opinion of whether you believe creativity exists in science and why you believe what you do. For your next two discussion posts, reply to at least two classmates regarding their takeaways from the video or their viewpoints on the presence or absence of creativity within science.
7	This week I want you to look back at our week 3 discussion on Observation vs. Inference. This was the discussion in which I gave you the same checks to look at and asked you to come up with a storyline to explain these checks.

	Read through 2 or 3 of these stories that your peers came up with and compare them with your own. Can you identify your bias in your own story? If you can't, think about how you came up with some of the details of your story? What did you need to know, experience, or understand in order to create your storyline? This would be part of your bias. After doing this, answer the questions below. Some definitions that may prove helpful for this discussion: Bias: an inclination of temperament or outlook especially: a personal and sometimes unreasoned judgment: prejudice. b: an instance of such prejudice. c: bent, tendency. (Merriam-Webster dictionary) Subjective: Based on or influenced by personal feelings, tastes, or opinions Objective: Not influenced by personal feelings or opinions in considering and representing facts. For your first post: Answer the following questions - Do you think subjectivity in science can be completely eliminated? Do you believe subjectivity should be eliminated? Provide some examples to back your viewpoint if possible. For your second and third post: Reply to at least two of your peers. You may wish to challenge their viewpoint in a respectful manner (if you do this you should provide evidence if you can), or you may wish to expand upon their answers and add some details that enhance or support their view. Maybe there are areas where subjectivity is beneficial? Maybe there are areas where we must main as objective as possible? Think about where those scenarios might be preferred in our scientific study.
8	For your first post: I want you to watch this video (Links to an external site.) to witness one example of how culture and science are influenced by each other. You might also want to check out this document (Links to an external site.) and this document (Links to an external site.) to read some further examples of this cultural/scientific interplay. For your first post I want you to do some research and identify an example of how culture/society has influenced or is currently influencing the process of science.

For your second post: Since this is our last discussion I am also interested in hearing about what you have learned or gained through these discussions. Please write a few sentences on what your biggest takeaway has been in our attempt to grasp a better understanding of science. Maybe this was something you learned explicitly through our discussions, but it also could have been a change in your overall view of what science is.

For your third post: Please reply in a few sentences to at least one other classmate in a substantive way. Try to veer away from simply praising their views or disagreeing with their views to expand on the overall conversation.

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Commentary: Action Research Studies on Online Nature of Science Teaching and Learning

We defined "action research" per Wells (2018) in the commentary of the previous section on action research on in-person learning contexts. The authors in this section conducted action research studies on how they embedded nature of science (NOS) within their online teaching contexts. All authors in this section were teaching college students and taught their courses fully asynchronously. Londino-Smolar states that there is a paucity of research on NOS taught in an online asynchronous context.

While the collective measures of NOS learning differed, all authors found that students' conceptions of NOS improved after taking their course per the VNOS-B (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). Indeed, Lodino Smolar indicated that her unit on fingerprinting (contained within her fully asynchronous online forensic science course) supported deeper understanding of the Empirical Nature of Scientific Knowledge, the Social and Cultural Embeddedness of Scientific Knowledge, the Creative and Imaginative Nature of Scientific Knowledge, and the Theory-Laden Nature of Scientific Knowledge. Both Rothman and Wiederhoeft found that their students' conceptions of NOS improved after taking their fully asynchronous online life science courses, despite a rather large range of ideas with the determinations of inadequate, adequate, and informed on each of the tenets of NOS.

The valuable insights each author gleaned allowed them to reflect on their own teaching and on future ways to further support the development of informed conceptions of NOS. Both Rothman and Wiederhoeft indicated that their online discussion boards supported their students' understanding of NOS. Wiederhoeft's life science course was formatted as an 8-week intensive course, yet his case study of two students still showed gains in NOS understanding. Rothman and Lodino Smolar both recommend embedding NOS across students' educational careers and in other science courses; Rothman suggests embedding NOS college-level science laboratory courses. Lodino Smolar notes that administration of the VNOS-B was a challenge in an online environment, as the instrument was developed as an in-person assessment of NOS understanding. One may infer that an exploration of administration of the VNOS-B through online means is needed to examine its validity and reliability in this new context.

The fully asynchronous online context in which to teach NOS to college students is not only rather new, but also an important area for exploration. As the Covid-19 pandemic further opened up possibilities for online learning and working environments, additional research is needed to delve more deeply into how students can learn NOS in fully online, synchronous courses as well as how students' conception of their NOS learning can be measured.

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SECTION III - SELF-STUDIES ON BECOMING A TEACHER OF NATURE OF SCIENCE

Chapter 8: A Science Teacher Looks in the Mirror

K.D. Lane , Mary F. Johnston

Chapter Highlights

- Barriers to learning for rural youth living in poverty.
- What is Nature of Science and why is it important?
- How can self-studies help teachers become better teachers?
- A science teachers journey through self-study.
- Explicit Instruction

Introduction

Problem Statement

Teaching and learning about NOS has long been a desired part of science education (Jenkins, 2013). The value of teaching these tenets is evident by the vast availability of NOS scholarship available in educational literature about this very topic (Olson, 2018). An effective education in science requires students to develop an understanding of NOS. The development of this understanding is of the utmost importance (Abd-El-Khalick, 2006; Lederman, Abd-El-Khalick, Bell, & Schwartz 2002). Possessing an understanding of NOS by all citizens, urban or rural, leads to a society that is better aligned with critical thinking, enhanced decision making, and more engaged with matters of social-science (Torres & Vasconcelos, 2019).

By understanding the aspects of NOS, we see that science is tentative; scientific laws and theories are subject to change. Scientific laws and theories are not hierarchical, one is not based on the other nor more significant than the other. There needs to be a strong correlation between observations and inferences. Science is cultural and subjective; observations of natural phenomena are dependent on our perception and our framework of thought. Science relies on empirical data; science is observable and therefore inferable. Scientific knowledge is creative, and it is limited by the imaginations of the scientists and the extent of current technology (Lederman, 2006). Science is fallible, we learn from our mistakes, in fact the more falsifiable a hypothesis the better (Chalmers, 2013) If students have a basic understanding of each of these notions, they will be able to participate in the world as well-informed people who can make decisions based on evidence. This view of NOS is a consensus view, non-controversial, and comes from the way that scientific knowledge is developed (Torres & Vasconcelos, 2019).

Many studies have shown that teaching NOS effectively requires time for explicit reflection (Akerson, Abd-El-Khalick, & Lederman, 2000). Activities need to be designed with chances for this explicit reflection in mind. Simply doing hands-on science is not enough, there must be explicit instruction anf reflection on the characteristics of science, the knowledge of science, and the enterprise of science. Activities alone are not sufficient to allow for this level of knowing. Some researchers have shown that linking elementary school science process standards to NOS may be effective (Bell, Toti, McMall, & Tai, 2004). Even the youngest of students are taught how to make observations or predictions, followed by meaningful discussions and reflections about NOS.

Research provides evidence of a middle-class advantage in schools. The educational level and income level of parents are the largest predictors of student success in school (Duncan, Yeung, Brooks-Gunn, & Smith, 1998; Reardon 2011). Students from more privileged families tend to receive higher grades and test scores, go further in school, find more stable employment, and earn more than those from less privileged families (Calarco, 2018).

This study began with an interest in the ways poverty and lack of equity present barriers to learning Nature of Science (NOS) for rural American youth. This research about equity as it relates to rural youth living in poverty is necessary today because over half of the schools in America are in rural areas and nearly one quarter of all students attend a rural school, according to “Leveling the Playing Field for Rural Students” (Minichello, 2017). Across the nation there are pockets of rural poverty. For example, 80% of schools in South Dakota are in rural areas, compared to only 6.5% of schools in Massachusetts (Johnson, Mitchel, & Rotherham, 2014). This uneven distribution of student population means that the needs of many students in rural areas are not being met—needs that are different from their urban peers.

People often equate higher levels of poverty to urban areas and are thus not aware of the level of poverty in rural areas. In fact, more than half of the rural student population comes from a low-income family in 23 states (Showalter, Klein, Johnson, & Hartman 2017). “Leveling the Playing Field for Rural Students” states that even though one in five students across the nation attends a rural school, only about 17% of state funding goes to rural schools. Additionally, socioeconomic status serves as the strongest indicator of student outcome (Chandler, 2014). This means that we are ignoring the needs of millions of students.

To further complicate matters, there is little research specific to rural students living in poverty and the barriers this presents to learning NOSC. Often these teachers do not live in the community and don’t understand the culture of the community. This makes it difficult to establish meaningful relationships with the students and the families. Teacher attrition is worse in rural areas of sparsely populated states for many reasons. Novice teachers, teachers from minority backgrounds, STEM teachers, and special education teachers are the most likely teachers to quickly turnover.

Rural districts often pay less, offer less professional development, have lower value benefit packages, and require teachers to perform more duties. The high rate of turnover for novice teachers is particularly alarming simply because many of these teachers work in rural districts. Not only does this affect relationship building with students, but it also affects the quality of education.

Research Questions

- How can I support rural elementary students living in poverty in learning key points of NOS?
- Can "Canned Lessons" be augmented into something that can allow for deeper NOS learning?
- How do I need to reconsider my approach to teaching when communicating to elementary learners of NOS?

Background

When using the term "rural" it can mean different things to different people. For the sake of this study, I am using the term rural as defined by the U.S. Census Bureau. The Bureau defines rural areas as areas that are located outside of urban areas. Urban areas comprise three different areas: cities, suburbs, and towns. Cities are subdivided into three other divisions: large, medium, and small, depending on population. Suburban areas lay within urbanized areas but are outside of city boundaries and are also broken into sublevels like cities. Towns are located outside of urban areas but are within urban clusters. Anything not included in these areas are considered rural, according to the Health Resources and Services Administration (updated March 2022).

Rural areas are subdivided into three categories: fringe, distant, and remote. The rural fringe areas are closest to urban areas followed by rural distant areas and finally remote rural areas. The remote schools in this study are located in the distant rural and the remote rural areas. The distant rural locations are more than five miles but less than 25 miles from an urban area. Remote rural areas are more than 25 miles from an urban cluster (Malkus, 2018). This research focuses on both distant rural and remote rural areas located within the United States and includes students living in poverty.

We know that middle class parents approach child rearing differently than parents living at and below the poverty line. This difference in raising children follows the children throughout their education and lifetime (Matsuoka, 2016). The term "concerted cultivation" was first used by Annette Lareau to describe the cultural logic of a distinctive middle-class parenting pattern (Matsuoka, 2019). This parenting style is renowned for being highly structured. These middle-class parents fill their child's days with extracurricular activities and places limits on media time. Lareau (2011) covers this in detail in her book "Unequal Childhoods" and draws a simple conclusion: these unequal childhoods lead to unequal success in educational achievement.

Issues around rural poverty are multifaceted and vary from region to region. For example, rural kindergarteners' math scores mirror patterns that become more significant in later grades. The scores of students in the rural South are lower than those of their peers in the Midwest, which in turn are lower than those in the Northeast. Most differences are relatively small at this level but tend to grow as grade levels increase (Malkus, 2018).

To further complicate matters, there is a higher number of special-education students in rural schools in the Midwest and Northeast than found in the West and South (Malkus, 2018). Chandler (2014) showed that pre-referral interventions for struggling students were minimal. In some cases the only intervention offered was a daily check in with the student, well below the Response to Intervention Criteria (RTI) set forth by the Individuals with Disabilities Education Act (IDEA) 2004. Additionally, parents were being left out of decision making and only invited to case meetings after the students' status had already been determined by the school (Chandler, 2014).

Students who struggle deserve to receive interventions when the first signs of difficulty emerge. Rural students should have the same quality of programming as middle class and upper middle class urban and suburban students. This means that rural schools need to invest in training teachers in the framework of RTI. Educators also need to work in environments where they feel safe and encouraged to seek help from colleagues to meet the needs of their students. Additionally, teachers in rural areas often have stereotypical beliefs about students who live in poverty. Included in these beliefs is the notion that hard work can overcome poverty, that schools can and should fix issues of poverty, and that, even in really challenging areas, the situation is not that bad (Chandler, 2014).

Furthermore, social class does matter in the classroom. Calarco (2018) presents evidence that the actions of teachers often serve to reinforce existing inequalities. He/she explains that middle-class students have unfair advantages in schools in large part because their parents are more likely to intervene than a working-class parent. Middle-class students ask for more help more often and they will keep questioning teachers until they understand. Calarco (2018) indicates that "teachers often underestimate the capabilities of less privileged students and discipline them more harshly" (p.159).

This shows that there is still much work to be done within high poverty rural schools. Teacher turnover is high in poor rural areas which further hinders student outcomes. High turnover means that schools must spend more money training new teachers, and there is less comradery between teachers, leading to less collaboration. Schools with high turnover also disproportionately serve economically disadvantaged children. If turnover harms student achievement, and better student achievement has been shown to improve long-term outcomes, then reducing teacher turnover can help promote the upward mobility of the county's disadvantaged children (Blizzard, 2021).

Carey (1986) states that "...students listening to a science teacher must gain understanding by relating what they are reading (hearing) to what they know, and this requires active, constructive work. This is the cognitive rationale for making science lessons relevant to students' concerns" (p.1123). As an educator, I must be able to reach students where they are in order to elevate their level of understanding. In my opinion, this is perhaps even more crucial in the teaching of NOS, as understanding science is key to understanding the world around us. However, before we can learn science, we must understand NOS.

There is still debate among scholars about what students should learn about NOS and if there is truly a consensus (Olson, 2018). Some scholars argue that the current tenets of NOS are oversimplified and actually misrepresent the NOS, while Lederman and Lederman suggest that the tenets are not intended to be taught as declarative lists but are to be taught to help summarize deeper understandings (Olsen, 2018). Regardless of which school of thought is correct, we know that understanding science results from understanding NOS.

Instruction needs to be modified to meet all learners where they currently are, because every learner has different strengths. According to Akerson et al. (2013), "Learner needs can differ depending on socioeconomic status" (p.6). This is just one reason why all teachers need to know who their students really are as individuals. If students are English Language Learners, then teachers need to find the best way to communicate with the student. If students come from food-insecure homes, then snacks might be needed during class time. If science class is first thing in the morning, then the teacher may need to lead movement activities to wake students up. It is our job to know our learners and to engage with them where they happen to be.

Theoretical Framework

This research is guided by an examination of relationships between concepts. This type of framework is known for assisting the researcher in both the identification and construction of a worldview on the phenomenon that is being studied (Grant & Osanloo, 2014). This approach allowed me to decide how best to explore this issue. I was able to decide the direction I want to take along the way and to examine the variables in a way that made sense to me. Conceptual frameworks are based on concepts that are the main variables of the study (Adom et al., 2018). The overall aim was to eventually develop a theory that will be useful for other researchers and practitioners in this same field (Adom, Hussein, & Agyem, 2018).

The idea of using an emergent design framework along with a self-study felt like the way to go for me. I had done enough research about the background of teaching NOS that I felt comfortable. However, I knew that things in a classroom can change quickly. I also knew that my experiences would hopefully change as well, emergent design allows for this flexibility.

Positionality within self-study is vital. As a former dual credit biotechnology, life science, and general science educator, I believe that education serves an intrinsic purpose to improve lives, thus boosting the overall health and well-being of society. A healthy society is one filled with confident, informed, and creative critical thinkers, people who are active in their communities, can form their own opinions and make solid arguments to back up their decisions. The onus of education should not fall on the student but on trusted professional educators. I believe that the job of an educator does not end or begin within the walls of a classroom.

In qualitative ethnographic research, there are insiders and outsiders (Creswell, 2019). Insiders are perceived to have had the experience growing up in a community, having a shared racial or ethnic membership, or having another kind of shared experience that increases the quality, legitimacy, or value of research (Lareau, 2021). Others suggest that outsiders can bring a fresh perspective to the research study and offer insights that can be missed by those on the inside. In this study, I am both an insider and an outsider. I live in a poor rural community, I taught in this community, I volunteer in this community, but I was not born here. By virtue of not being born here, I will always be seen as an outsider to the people whose families go back multiple generations living and working in the hills and hollers, we call home.

Whether or not you are working as an insider or outsider it is important to understand how your knowledge and perceptions will shape a study. This is a part of the acknowledgement of positionality. Before the research even begins the researcher needs to ask if the research should even be done (Parson, 2019) and how the researchers own bias will skew the findings. A researcher's positionality is the sum of their personal social location, personal experience, and theoretical viewpoint (Parson, 2019). Researchers need to be acutely aware of their positionality. Positionality plays an important role in framing research questions, interprets data, and understanding potential harm that can come from doing research on marginalized groups.

I found it necessary to remain mindful of my positionality during this self-study. I am a first generation college student from a lower middle class background. I started elementary school long before people were testing for learning disabilities, so I was simply labeled as “slow”. School, for me, was terrible. People made fun of me, I had to leave the regular classroom to go with staff members for speech lessons which I hated. While my classmates were earning grades, I was earning squirrel stickers, I felt dumb. On top of these challenges, we also moved several times meaning that I would have to start over trying to make friends, I always felt like an outsider. The memories of these feelings are things that I keep in mind when working with students and I also think it is key to building meaningful student/teacher relationships.

Procedures

As a former high school and junior high school teacher, I imagined every day in a classroom would be much the same; after all it was for me. In the school where I taught it was common to only teach single grade level classes, like 8th Grade, Freshmen, or Juniors. If we did have a second-grade level added to our schedule generally it was just one class of a different grade. Each day we had the same rotation of students at the same time of the day throughout the semester. Once the bell rang and the class started, you would do a fast review and pick up where you left off the day prior.

I spent one school year working as a Title 1 paraprofessional in an elementary school located in our community. This was before I became a teacher and is what ultimately brought me into a classroom of my own. The teacher that I worked for was a language arts teacher. The majority of my days were spent one-on-one with students helping them develop reading and writing skills or assessing their reading levels. My experience at this school was vastly different from the experience that I was about to have.

The elementary school where I worked had undergone many district-wide elementary level changes. Our district was shrinking quickly and many changes have taken place in a relatively short period of time. In my 9 years working in the district there have been three different superintendents and more personnel changes than I can count. The teacher I worked with had students from K-5th, often all in one day! What a vast difference in planning and implementing this must require. Personally, I cannot imagine having five vastly different levels of human development to teach. Elementary teachers go from having students who may not be able to read and write to young readers who are voracious readers.

Since my teaching career was spent with high school and junior high school aged students, I felt the need to experience elementary school once again. I believed if I wanted to work with pre-service teachers or conduct research, I needed to gain as much experience with different age levels as possible. My personal stature is large, I am a former professional football player and race car driver, however, I was afraid of lower elementary level students. They are tiny, energetic, full of questions, and largely innocent.

The last thing I wanted to do was hurt their feelings or trip over one of them. I appreciate their sense of wonder and curiosity; I find it endearing at least for the first thirty minutes and then I am ready for quiet. For me, order is important, the type of order that one would find on a military post, for example. This type of order cannot be found in an elementary school setting. I cannot stand sticky fingerprints, runny noses, constant motion, and classroom quarrels. I found that at least in the upper grades there were fewer sticky fingerprints to deal with in the classrooms.

When I first met with the teacher who graciously allowed me into her classroom, we discussed scheduling. The only day that she had more than one 4th grade science class back-to-back was on Tuesdays. She also had one of the Tuesday classes again on Wednesday, but the other Tuesday class did not return until Friday. So, I decided that Tuesdays and Fridays would be best for gaining the most access to this grade level of students. I wanted to spend as much time as possible with the students, so I devoted the next month to working with these classes.

Before starting that week, I looked over the lessons that were selected by the classroom teacher to be used for this mini unit on energy. I specifically looked for places to embed more discussion and reflection about NOS. The lessons selected are what I call canned lessons, they are premade lessons that are available from a website called Teachers Pay Teachers. Many of the lessons available on this site are average, meaning they cover the basics of the standards. However, several lessons and units are high quality that were developed by educators who are passionate about their subject areas. The canned lessons that I had to work with were average, in my opinion.

Into the Lion's Den I Go

The first day's lesson was an engineering design challenge that explored potential and kinetic energy using a balloon, a straw, a piece of string, and tape. The goal was for the students to find a way to get the balloon from one end of the string to the other without using their hands. I found this to be a good place to offer reflection and instruction about the creative nature of science. The defined learning outcome was to be able to distinguish between potential and kinetic energy. As I brainstormed with each team, we talked about how creativity was necessary in gaining scientific knowledge.

Scientists first imagine new technologies and then create ways to make them work. Most teams were shocked to think about science as being a creative endeavor. And as we chatted their designs became more intricate, and the groups became more excited. And as the excitement built each group pushed and tried various ways to achieve their goal.

After I got home, I was able to process the day. I realized just how terrified of young students I am; they seem so innocent, and I was afraid I would say something the wrong way and hurt their feelings. Additionally, they are so little compared to the high school and junior high students, most only came up to about my chest. If I had to guess I would say that sixty percent of them came into the room first thing in the morning appearing happy and full of energy, much different than the morose teens that I am used to having in class. Honestly, I was ill-prepared for this type of energy.

Day two started with a quick Post It Note session where I asked each team to recap what they learned the previous session about how science is a creative endeavor. Each team had three minutes to chat and then write out what they thought was the best response and then share it with the rest of the class. I was hopeful that this would add another layer of reflection in order to help them remember the connection to creativity in science. The next ten minutes were spent discussing potential and kinetic energy while working on a sorting worksheet that the teacher had prepared.

Finally, the students were introduced to their next challenge. They were to design a "blaster" to use to launch three different objects with different masses at different levels of applied force. This lesson was designed to show the effect of mass and force on motion and required them to make observations. I used this lesson as a way to cover creativity and to discuss observations and inferences. As I moved around the room and spoke with the teams there was clear consensus about how creativity is important in science. One student even mentioned that without creativity nobody would have discovered rocks under the dirt!

As I began to ask about observations it was clear that they all understood aspects of observations, however inferences were not understood. I tried to change my approach to how I posed the questions and statements, but I was not getting very far. I asked each student to complete an exit ticket, this exercise serves as a quick assessment of knowledge. This showed me that the next session needed to have even more time for explicit reflection and instruction about inferences.

After class I spoke with the teacher to see if she had any feedback for me. She suggested that I try to meet the students at their level. In all honesty I thought that was what I was doing, however the discussion with the class showed that I was not. This teacher is so good at understanding the mindset of elementary students and knowing just how to probe to elicit substantive responses. I felt a bit defeated. In the end she said that I was doing, "great." I gathered my stuff and headed out, but I could not stop thinking of ways to better engage.

When I got home, I looked online for ideas or videos to help me get my message across. I decided to make a Google Slide presentation to share with the class. After presenting this to the class, on my third day, I realized that it had made a difference. I don't know if it was because I gave them information in writing as I read the slides to them, if it was because I selected images that I thought they could each relate to in some way, if it was because it served as a way to reflect, or all of the above. But at the end, each student was able to make an observation of an image and then infer or draw a conclusion about what is happening in the image.

Once we finished this task the teams got busy finishing the construction of their "blasters." As I made my way around the room, I asked specific questions that would require students to infer a response. The vast majority of the responses were correct, I then congratulated them on making a correct inference. It made my heart happy to see joy and a sense of victory in their eyes. They were shocked that they actually knew what this large tricky word was. I knew they could grasp the idea behind inference. I just needed to find a way to make it apparent.

On the fourth day we discussed ways that force and mass would change the outcome of the blaster. I asked students to infer what would happen if they used less force and more mass, and they were able to correctly answer that prompt. I feel that this was a success simply because we slowed down and discussed and reviewed the material. I allowed for explicit reflection during this task.

We ended the mini unit by giving an assessment that was a basic vocabulary check. Students were given a word bank and they used it to fill in the blanks in the sentences. After this I wanted to complete a K-W-L (what I know, what I want to know, what I learned) chart to check for a deeper level of understanding. I viewed the results with favor, the students had gained knowledge and had some fun along the way.

At the end of this I was exhausted. Elementary students require so much energy and constant reassurance. Despite being tired I felt good about my experience, it was trial and error for sure and stressful. I was not accustomed to not feeling comfortable in a classroom or with students. I have always had a great rapport with my classes, we could joke and learn; but this was different. I felt stiff. I did not feel well versed in pedagogy enough to explain it to kids the first time around. That fact bothered me the most.

Plan for Critical Friend

Since I was planning to do self-study, I knew that I would need to find a critical friend to help me along the way. I also knew that I needed to find a school to work in, because of COVID and policy changes this may become an issue. The schools in our district were not allowing visitors in the schools like they had before, and I needed access. I reached out to a friend, and she was willing to allow me into her elementary school and set up a meeting with her science teacher for me.

I wanted to gather information from the classroom about the different classes that I will be working with during this time. Not only did I want to make sure that I had an understanding of the content, but I wanted to make sure I understood from her point of view what my role would be. I also wanted to know a few things like: will there be paraprofessionals or other aids in the room with some students? Are there groups of students who should not work together? Are there students who need lots of hands-on help during labs, students who have special needs that I need to be aware of?

She shared the documents with me that we would be using for the mini unit on energy. These lessons were “canned” meaning that they came from Teachers Pay Teachers (TPT) and had nothing built into them to help increase the level of understanding for NOS. She was open to allowing me to alter them in any fashion that I deemed appropriate as long as she had a copy several days prior to the start. I am grateful by the way I was welcomed into her classroom with open arms. This was her last year before retiring and was a wealth of information about working with this age group.

After getting back home the first thing I did was to think about where there would be a natural fit for discussions about NOS within the lesson itself. I knew that activities need to be designed with chances for this explicit reflection in mind. Hands on science is not enough to allow for gaining knowledge of NOS. My thought was that if I could draw enough connections between the assigned lab and NOS it would serve as the explicit reflection necessary for learning (Akerson, Abd-El-Khalick, & Lederman, 2000,; Akerson, Carter, Pongsanon, & Nargund-Joshi (2019). At this time, I felt pretty comfortable with my thought process entering my initial approach.

Now I needed to consider my choice of a critical friend. According to Alan, Sariyev, and Odabasi (2021), critical friends help provide rigor and trustworthiness in research; this strengthens the research process. Next on my list was to reach out to my critical friend to set up a meeting for laying out groundwork. We agreed that she would offer me feedback on pedagogy, strategies for discussing NOS, and reflections. I created a Google Drive Folder and uploaded the “canned” lessons, my lesson plans that included areas for NOS discussion, and a running document for notes and questions that we could both comment on during this process. There is also time for Zoom or phone conversations along the way, if needed.

At this point I started to doubt myself and my processes. The more I thought about the journey on which I was about to embark, the more uncertain I became. I did not enter the education profession in a traditional way. My background is diverse. At one time I nearly became a registered nurse, I have worked designing sensory gardens for adults living with autism, I have worked as a chef, I have driven a race car and played professional football. I came into my first high school classroom with an emergency license four weeks after the start of the school year. The school was located in my community and had lost three of their four science teachers just prior to the start of the year. I was hired to replace a substitute teacher who had started the year in the classroom. I was hired because they needed a body that knew something about science. Was I hired because I was the only choice? I will never know the answer to that question that is always in my mind.

I have a master’s degree in environmental studies, a lifelong love of science, and had the desire to teach but no knowledge about how to teach. I was asked by the school board and superintendent if I was willing to take licensing exams and I said yes. According to them I was a perfect fit for the job! Once I got home from being told the good news it occurred to me I didn’t even know where my future classroom was located, where to park, how to get into the building, what time to show up, or anything else. All I knew for sure was that the substitute teacher had agreed to stay for one week to train me and then I was on my own. It then became apparent to me that I was their only choice. This made me feel even more inadequate and those feelings of inadequacy stuck with me the whole time I worked in classrooms.

What I Saw in the Mirror

In truth, I was in way over my head in my high school classroom. I had no idea how to teach, or anything about any of the paperwork involved. The term IEP meant nothing to me, I had no clue how to write a lesson plan, or even what to try to teach. I did not understand how to enter grades in the software program that the school used, I had no idea how to create a teacher website and upload assignments, and heck I had no assignments. The other two newly hired teachers only had a six week jump start on me, so they were just trying to survive as well. They were both first year teachers in a community that was not home for them, at least I had that going for me. I just knew what made some of my former teachers good or bad in my opinion. So, I decided to embrace the traits of good former teachers and hope the rest would fall into place.

I was afraid of the critical friend relationship; afraid I would be found out. Afraid that someone who has been in a classroom longer than I had would see right away that I am not a “real” teacher. Afraid that she would quickly realize how much I don’t know about teaching, even after years of doing the job. Afraid that my approach to embedding NOS into canned lessons would appear unimaginative and futile. Afraid that when I looked inside, I would see a fraud trying to make a go of life in academia.

What I needed to do was to take a deep breath and realize the result of this would do nothing but make me better (if that is what I allowed). It honestly was difficult to get my head space in line to allow this to happen. I needed to quiet the voices of self-doubt and of the inner child that was never enough. Once I was able to do this, the critical friendship proved to be helpful for me in many ways. One, it gave me another voice when I was trying to frame and make sense of my observations. Talking with my critical friend allowed me to reframe my observations and thought processes. Often during this process, I found myself too caught up in a single detail and my critical friend was able to remind me to look at the larger picture or remind me of why I am doing what I am doing.

Key to a critical friend relationship is dialog, not just talk (Alan, Sariyev, & Odabasi, 2021) and to have this you need to find someone that you respect and who respects you. You need to not take things personally and trust what you are told is coming from a place of mutual respect and desire for improvement. The person I selected to fill this role for me was someone from my cohort, or class peer group. I have not known her long, but I trust her personally and professionally. She works hard to be the best version of herself that she can, and I like that about her. I knew she was someone who would push me. My critical friend challenged me to be better and for that I am grateful.

When I first started to make comments on the Google Doc, they lacked insight. I would simply say "things went well" or "they didn't understand this." My friend called me out on it. She would post comments like "How did it go well, give me an example?" or "What exactly did they not understand and how did you try to explain it?" After a conversation I realized that my comments were blanket comments because I was afraid that I would somehow appear to be someone who had no idea of what they were doing; I was afraid to be open. Once I was aware of this, I realized that I have every right to be where I am today, I was able to dive deeper.

One of the changes in my feelings that I noticed was my confidence in presenting information related to NOS. I have done so much reflection in this area as a student, that I am finding that I am becoming more comfortable with the tenets of NOS. I have read countless articles and books by experts in the field of NOS. I have looked at what used to seem true to me, such as a scientific law holding more power than a scientific theory, and learned the error in my belief. Scientific laws describe an observed phenomenon while theories explain the phenomenon. One is no more or no less important than the other. I can see how these tenets relate to the study of science. I also noticed that I really do like little kids, I do have a soft place in my heart after all.

Perhaps the two single most effective strategic changes I made was to slow down the pace of the lesson and offer time during the lesson for reflection. This entailed me stopping the class from time to time to have quick chats about aspects of NOS and then return to the specific lesson. I feel that this offers extra time for explicit reflection about how an element of NOS fits into the rest of the lesson and can be seen throughout science. And by slowing down the lesson pace more students were able to remain engaged. All of this supports the literature that I read as part of my research. It is my hope that other educators can learn from my self-study the importance of allowing time for explicit reflection.

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Chapter 9: Embedding Nature of Science Explicitly Within an NGSS Chemistry Classroom – A Self-Study

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Chapter Highlights

- Self-Study incorporating NOS within an NGSS classroom.
- The use of Appendix H exemplars as an instructional resource.
- The impact of NOS action research upon belief system of in-service educator.

Introduction

During the past eight years, New Jersey has acted as a Lead State in the development and implementation of Next Generation Science Standards (NGSS), (Lead States, 2013a). Experienced science educators were tasked with learning about and and then developing novel instructional practices to deliver lessons alighend with *The Framework,* as outlined by NGSS. The adjustments were facilitated by attendance at multiple professional development seminars, from summer programs to multiple day long seminars (Science Education Institute, Raritan Valley College) and in-district peer training. During coursework within my doctoral program, I was introduced to the importance of nature of science (NOS) and its explicit inclusion in the delivered science content (Akerson et al, 2000). However, there had been no emphasis upon NOS within professional development or educator training on either NOS comprehension nor instructional strategies for its explicit inclusion within the classroom prior to or during NGSS implementation. The omission of NOS by those preparing training sessions may be due a deficit in specific directions by NGSS itslef regarding NOS incorporation (Lederman, 2016).

The continued growth of educators within the classroom is an important aspect of self-study. Nilsson and Loughran (2012a) suggested that teachers should be involved in the development of their own pedagogical practice. An educator's development should continue in response to changes in either educational research or new state or national standards (Nilsson & Loughran, 2012a). Simply stated, the authors suggested that an educator should adjust pedagogy over time. In this self-study, adjustments will reflect insights regarding NOS comprehension, instructional strategies to embedd accepted science aspects within a unit lesson, and the specific nuances of implemantation within an NGSS classroom. Finally, the impact of action research upon the educator's belief system regarding NOS and NGSS Appendix H (Lead States, 2013b).

Background regarding Nature of Science and NGSS

Student development into informed citizens, capable of making educated and scientifically based choices in both personal and global contexts, requires an understanding of Nature of Science (NOS). For this reason and others, NOS is considered an essential concept to learn in science classes. (Lederman, 2007; National Science Teacher Association [NSTA], 2021). Although there is no absolute consensus on the defnition of NOS, it is described by Lederman et al (2013) as "the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992, 2007).” (p.140). The characteristics of science may be summarized by target aspects or tenets which may include: observation versus inference, distinction between laws and theories, scientific knowledge is partly empirical, scientific knowledge is subjective (theory laden), science is a human enterprise and scientists are a product of culture, scientific knowledge is tentative (Lederman, 2007. pp. 833 – 835). It is not only the students who may be lacking in their NOS understanding. Often, educators or university students who are late within their content studies have inadequate understanding of NOS. Research has demonstrated that explicit and reflective embedding of the tenants within the delivered content (Akerson, 2000; 2014 and 2019; Karakas, 2008; Lederman, 2007; Wahbeh, 2014), significantly improves the comprehension for students, pre-service and in-service educators. However,it is not enough for a teacher to understand NOS tenets. Educators who have developed NOS comprehension are frequently unable to transfer what they have learned in their delivered instruction without appropriate explicit and reflective training to that end (Lederman, 2007). The current study exemplifies growth in both comprehension and pedagogical abilites. As discussed previously, self-study is an effective component in an educator’s individual development.

The educator’s process and reflection promotes the development of new knowledge or understanding, while challenging pre-existing notions of themselves as educators (Schuck & Russel, 2005) and is ultimately transmitted to a greater audience. Hauge, (2021) suggests that an essential reason for completing self-study is to respond to critical questions and ultimately respond to the silent knowledge and understanding about our practice. That is, to influence educational practice beyond our own classrooms and into the general educational and research communities for critique and implementation (p.155). The sharing of knowledge gained during the self-study may lead to the meaningful incorporation into the practice of other educators in the field (Nilsson & Loughran, 2012b). The action research and subsequent self-study have been designed to review not only NOS tenets explicitly delivered, yet to do so within the context of an NGSS classroom. The Framework implimented relies upon three dimensional instruction: science and engineering, crosscutting concepts and the disciplinary core ideas. The standards and their effectiveness have been questioned by many reputable authors within the body of scientific researchers (McComas (2016), McComas and Nouri (2016b), Akerson et al (2019), Lederman, N and Lederman, S (2014)). Insights gained in this study will be shared to assist other educators and potentially teacher educators regarding the specific pedagogy utilized to incorporate NOS within the three dimensions.

Purpose

This primary author has completed this self-study to chronical the impact of the preparation for, completion and then analysis of, an action research study. The action research was designed to examine the explicit and reflective incorporation NOS tenets within a unit on the gas laws within each of five college preparatory chemistry classrooms. NOS was embedded by the use of reflecion questions requiring that students select and explain how specific grade level exemplars from Appendix H (Lead States, 2013b) appplied. The reflections were completed independently, within cluster groups and followed with whole class reivew. The self-study reviews how the preparation of lessons, adaptations to plans and analysis of pre-established questionaires, as well as field notes impacted my understanding of both NOS and the delivered content itself. It reviews the efficacy of using pages 5&6 of Appendix H (grade level exemplars) to explicate the science tenets. By reviewing her reflections and overall pedagogy an increased understanding of the improved practices for the effective implementation of Appendix H and exemplars, when following previously established methods. Finally, the study served an opportunity to form an independent opinion of *The Framework* and use of its Appendix H when embedding NOS within the delivered curriculum.

Research Questions

Q1. What is the impact of an action research study upon my individual identity within the classroom? Doctoral student, educator, educational researcher and beyond.

Q2. *What is the impact of explicit and reflective embedding of NOS within an NGSS a unit lesson impact upon instructor comprehension of NOS tenets as specific exemplars and the delivered content?*

Q3. *How have my views on The Framework and its inclusion of NOS via exemplars changed?*

Method

A self-study design was implemented concurrent with an action research study. The action research data analysis and findings were completed prior to the current chapter. The pedagogical design incorporated within delivered instruction reflect previously implemented frameworks regarding an explicit and reflective discussion of NOS (Akerson et al., 2000; Lederman, 2007; Peters, 2012) in addition to sample NGSS lessons which emphasize explicit

NOS incorporation (Fanning & Adams, 2015 and Griffith et al., 2021). The conceptual framework introduces NOS tenets by direct student interaction with grade level *exemplars* located on Appendix H (Lead States, 2013b). The study was conducted within five high school college preparatory chemistry classrooms and lessons were taught by the primary author. These lessons were part of an action research study in which there was "thinking new, experimenting and trying new approaches" (Hauge, 2021 p. 144). The new thinking and approaches included adjustments in established lessons as well as belief systmes, and allowed for additional adjustments during the course of the unit lessons.

How was the educator and educational researcher impacted by this action research? To respond to this question, the self-study design was incorporated. The data reviewed for this self-study extended from her initial exposure to NOS tenets as a doctoral student and through the action research study on a unit lesson and the compilation and analysis of the data for said study. During the action research study, daily or weekly field notes aligned to predetermined questions which may include: "*What were the strengths of the lessons?", What changes would you make next time?", "Did the students appear to understand the lesson or did you need to respond to more questions than usual; were there more insightful questions?" and "Did you have new or unexpected insights.?"* At a minimum, adjustments to pedagogy and general reflections for future analysis were recorded either in the instructor notebook or electronic journal or occasional voice memos, which will then be transcribed. Smith and Krumsvik (2007) outline the use of video recorded lessons. Although video recorded lessons were not permissible due to a lack of permissions, the participant did utilize voice recordings of memos to self, as well as recorded zoom meet with her critical friend. As a reflective educator, the lessons were outlined in depth within reflections and also as part of the chapter on the action research (Johnston & Akerson, 2022).

The primary author of this self-study was a second-year doctoral student and a veteran educator. The school district in which the study took place was located in New Jersey. New Jersey participated as a Lead State and the district implemented Next Generation Science Standards (NGSS) (Lead States, 2013a) between the years 2014 -2015 and 2015 – 2016. Multiple professional development training seminars have been attended, from a week long summer program to multiple days and professional development at the district level. The instructor is proficient in NGSS delivery and comprehension, yet has not previously incorporated Appendix H (Lead States, 2013b) in her instruction prior to this self-study.

Research Context

The context of this self-study is within high school college preparatory chemistry classrooms, with students ranging from grades 10 through 12. There are a total of five college preparatory chemistry classes that received the instruction described in this self-study. The classes are generally student centered and follow the NGSS framework. During this period, there were occasionally students who joined the class via a zoom platform due to COVID-19 quarantining and others who missed classes due to multiple field trips and State Testing makeup days, which had been moved due to unanticipated school closures or delays. This was the first year in which students met live for the majority of the year and during this unit lesson, the first opportunity students had to be seated within cluster groupings of two to three. During the self-study the instructor completed an action research study regarding the impact of explicit and reflective embedding of NOS within an NGSS classroom, via the use of grade level exemplars listed on Appendix H (Lead States, 2013b). The content being discussed included each of the three gas laws, as well as the Kinetic Molecular Theory.

Data Collection

Data collection consisted of general reflections made prior to, during and after the action research unit lesson. Daily lesson plans submitted for each of the five college preparatory chemistry classes (block schedule) spanning the 14 days of the action research study. An electronic journal was created from transcribed written notes and audio recordings, as well as the electronic daily record of reflections. Post study reflections were also added to the electronic record. Finally, applicable transcripts obtained during discourse and reflection with a critical friend is part of the data.

Lesson Plans

The lesson plans were created well in advance of the unit lesson. A written copy was created and included multiple iterations of planning. The electronic lesson plans submitted to the district were then outlined at the beginning of the study. Adjustments to these lesson plans may be considered secondary data for adjustments made during the study. The lesson plans included specific curricular standards, goals and objectives, NGSS science and engineering practices, cross cutting concepts which are implemented in the lesson. The lesson plans also include specific activities and assessment strategies employed for each class, each day. This "daily activities" section was utilized to emphasize nature of science exemplars.

Voice Memos

Voice memos were created before the action research study was started. During the study, voice memos were created in addtion to written or electronic notes. Following the study, voice memos were created as well. The memos were then emailed to the primary author and transcribed onto a Google Document, using *voice typing* tool. The memos were then copied into a final document.

Instructor Journals

The instructor has consistently maintaned a daily record and reflection after each class. In addition to her regular instructor journaling, a notebook which is specific to the study was utilized to record reflections just prior to, during and post unit lesson. To assist with the transcription process, the written journal was adapted to an electronic record onto which daily reflections were recorded. The reflections from the aforementioned journals were then combined onto the final document described above.

Student work and Action Research

Although no student work will be cited in this self-study, the field notes made regarding student work as well as their overall growth of student comprehension, the artifacts collected during the action research component of the self-study are also part of the analysis. The impact of student progress or struggles upon instructor comprehension and their overall growth regarding both NOS and the gas laws, and the impact upon the instructor are noted.

Critical Friend and Colleagues

Email and Zoom discussions between the primary author and a critical friend, an expert in the field, and cohort members may be included in the data for this section. The Zoom interaction with the expert in the field was not recorded, however, written notes were created following our collaboration. The Zoom interaction with the critical friend occured after the action research had been analyzed, and self-reflections had been reviewed. The Zoom was both recorded and transcription enabled. Additional questions and analysis resulted from the discourse.

Data Analysis

First, the data were summarized by an overall review. Yin (2016) outlined the uncoded analysis of qualitative data (Yin, 2016). The process included first organizing data onto a single document. Notes were then taken as the entirety of data was reviewed, the data was organized and reviewed for patterns or potential themes. Yin suggested procedural checks of the notes which were taken to ensure no data had been ignored or underused (Yin, 2016). The process was reviewed with a critical friend who served as a check of the patterns derrived from this uncoded review. Additional questions, responses and perspectives born of the collaboration with the critical friend were then incorporated within the analytical method employed. Here, novel insights, patterns and / or inferences were approached.

Field Notes and Reflections

The field notes and reflections were in the form of audio voice memos which were transcribed onto an electronic document, daily instructor notes from which any pertinent data was extrapolated onto the same electronic document, and final the ongoing daily reflections taken in the midst of the action research study. Finally, post action research study notes were added to the electronic document to note the impacts of the study itself, and formulating the student driven data, as it impacted the participant's understanding of NOS and role as student / researcher.

Action Research Chapter

The action research paper study which was completed concurrently with the self-study may be used as part of the ongoing reflections made post study. The reflections include the separation of or detachment from the results, positionality and ethics. The reflections made during the preparation of the study were also analyzed for the impact of sections such as data analysis upon the overall confidence of the participant regarding increased proficiency, and identity as doctoral student, educator and educational researcher. Specific attention was made to statements about coding and the collaborative nature of inter-rater reliability.

Critical Friend

A Zoom recorded meeting with the critical friend was conducted to discuss findings the study, go through method and analysis employed. The analysis was outlined to ensure credibility. There were no additional suggestions or recommendations regarding the analysis. During the Zoom, additional questions posed and comments made are incorporated into the results. The interaction included my asking about how her questions related to self-study. Examples of questions posed included inquiry about how the lesson had been delivered in the past, how scaffolding had been employed, why I was attempting to avoid politics when science and politic are related in NOS tenets, and why identity was part of my overall study. In addition to the discussion with a critical friend, brief discourse with peers about patterns observed and the insights from professors may be included.

Results

Shifting Identity

A review of the data regarding the impact of explicit and reflective embedding of NOS within a unit lesson on the gas laws demonstrated that the initial delivered instruction was challenging and then a clear shift toward the benefits of this delivery were noticed. There was an incorporation of a researcher concurrent with that of educator identity, in a synergistic manner. As the study was being developed the role of doctoral student was more prevalent outside of the classroom; during the study and within the classroom that of educator and educational researcher were prevalent, however, an influence from outside beliefs such as spirituality or roles including scientist, partner, friend, daughter and sister and employee were noticed. The post action research and analysis and outside of the classroom, roles shifted again to doctoral student and educational researcher while balancing contributing and salient roles as ethical member of science and society.

As the study began I was very aware of my positionality, yet unaware of the ability to shift seamlessly between the two roles:

> I had to be very clear (with students) to not tell me one way or another about

> participation ... they started saying "sure I will" or "we have decided not to…" despite discussions about positionality. So, I adapted my script to remind students to please not tell me one way or the other due to positionality - ... I was *the teacher first*. (Instructor's electronic journal)

Within the first few days, however, I began to notice that the concerns regarding shifting to the researcher identity may have been incorrect.

> ... the biggest things to note this week are that in the moment of doing the work, *I ebb and flow between feeling like a researcher and then educator and really just want to remain in the identity of educator and simply take field notes* – the first time I do a lesson I am making notes more frequently than I would usually only because [before I took them because] I want[ed] to deliver better lessons – and am listening *even more closely* to comments within groups. [I want to take better notes and be able to adapt the novel lesson and record my own reflections, aka – there is more self and student observing recorded]

On occasion there were moments where I was educator, as well as educational researcher. What I was unaware of was how often I incorporated the role of scientist within the classroom. Previous experience within the field science appear to benefit the science educator as well as educational researcher. Adjustments to student activities and / or experiments are readily implemented. A scientific mind and approach within the classroom assists with suggestions which may be scaffolded for students.

> When we reviewed the exemplars one student had used "*in light of new evidence*" – I found this to be an important and reasonable error. So, I thanked the student and walked over to where we had been doing the laboratory. I mentioned that there was an expectation of what might happen … because the experiment had been done many times yet what was observed was "*unexpected*" – I then reminded the students that *I immediately asked for someone to bring me an ice bath* and *we added one step* (placed the flask into the ice) – the balloon immediately entered the flask. I explained that while we had *all noticed* something didn't go quite right, I had brought a *bit more experience* with me into the laboratory and was able to ... make a quick adjustment. Just like other

> students made adjustments when they had issues with balloons breaking at the openings. I explained I was able to make this adjustment based *upon my understanding of gases*, and that although the student was learning (yay) there *was not new information* being placed into the body of scientific understanding. *A terrific exchange!*

One of the aspects of identity which I had not considered, yet which was apparent within the context of the action research reflects my trepidation to include my own beliefs (as a public school educator, this is a reasonable level of ambivalence) and also when providing examples within a lesson, I may include references to a sibling who is also an educator. I do not frequently discuss friends or family, yet as an educator my sister may appear to be relevant to instruction? The unease experienced while attempting to hide the public identity (non-educator) with political beliefs was also evident.

My reflections included references to unease which is experienced when incorporating social and cultural impacts upon science. First, when preparing for the action research study and then in the midst of the study itself it was evidence that I currently more reluctant to incorporate examples about the impact of society or culture upon science than previous years. The reflections also indicate the lost opportunities to stress the previously mentioned NGSS goal of students becoming educated citizens.

> Looking at McCombas' book and noticing strategies that I can incorporate in lessons or possibly next year as I am recreating how I am going to deliver nature of science... *I feel a bit constricted when discussing social cultural aspect of science*...

During the course of the action research study, the lesson was adapted to incorporate the historical significance of Boyle's experimentation on the ability to create a vacuum. We discussed the significance of Boyle disregarding scientific experts of the time and the societal expectations in research. The history was discussed prior to discussing his law. After the students had been exposed to the history I asked them to reflect upon how they would have proceeded in a similar circumstance. Students were confused about how religion or society could impact science and why.

> The history [Boyle] was well received, I am not certain that they can grasp the true impact of going against accepted science and making scientific statements which are

> contrary to the experts, but we did discuss it and we did locate exemplars reflecting social and cultural impacts upon science... I did not go into the discussion deeply, yet did discuss how politic, religion, mores of society influence or at times keep science "in check" I explained the impact society has upon science and vice versa [always cautious as there are generally students whose family members may have health concerns and it must be acceptable discourse]

The *critical friend* asked why I had been so cautious regarding social and cultural impacts upon science, as it was part of science tenets. Here, I felt that it was important to emphasize that we, as public school educators, are and should be accountable for what we bring into a classroom environment. Although there have been missed opportunities in the recent past, due to heightened political sensitivities, appropriatley placed statements allow students to arrive at an understanding without impacting their belief systems. For myself, I found that I am not afraid to speak about what I believe. More importantly, I am a role model to students about how one may remain open minded and rely upon science. My place is not to do any more than present the content in an engaging manner which allows students to connect to the science as well as the content. This connects with my spiritual beliefs as well as my identity of impartial and objective scientist.

The impact of explicit and reflective embedding of NOS within a unit lesson impact upon instructor comprehension of NOS tenets, appendix h and / or the delivered content

The data demonstrated that despite an intuitive appreciation for and knowledge of nature of science aspects, as well as previous experience within the field of scientific research, explicit and reflective incorporation within a unit lesson was beneficial to both content and NOS comprehension. The action research provided the insights regarding how to deliver the concepts of both science tenets and the gas laws in an explicit and reflective manner. Adapting lessons is a normal aspect of both meaningful instruction and the action research process. The evidence demonstrated these changes. The growth from a reluctant delivery to that of a confident and finally delight in delivering and observing the impact of lessons was also noted. Importantly, the data demonstrate that the author found this work to be beneficial to herself, her students and an overall motivation to share these insights with other educators has increased.

I learned about nature of science and terms such as "*explicit*" and "*implicit*" during a seminar within the doctoral program. I recall reading various articles shared by my professor, one which had been annotated in a few places with the terms "*explicit*" and "*implicit.*" I read the paper twice to find the importance of these terms, which are now incorporated regularly as part of methods followed. One reason I chose to continue my studies within the field of science education was to ensure opportunity to fill potential gaps in learning from the perspective of one who had entered the field via the alternate route teaching program. I began to think perhaps these were terms which other science educators had been exposed to. This was not the case. I also considered if exposure to bench work within the field of science or perhaps NGSS instruction had increased my NOS comprehension while also acknowledging there was a need to better understand implementation of the tenets.

> ... I started learning what the words *implicit* and *explicit* meant ... it wasn't terminology I was used to or accustomed to so I was a total novice in terms of my understanding ... [despite scoring well on the VNOS I took] I wondered ... you know well maybe I know a little bit more about nature science because I've been doing this next generation instruction which is very science based ... or maybe because I was in the field?

During the study it was evident that I moved from a place of concern about my understanding of the method required to correctly explicate science tenets within the context of a unit lesson, to one where I had acquired more confidence and finally to one which I saw the benefit of the method, and was excited about future adjustments which could be made to enhance the pedagogy.

> ...expecting them [students] to wrap their heads around it [NOS] ... new to it myself and transmitting it and never having created lessons which included...

> I am a bit more prepared for their questions, yet will still need to invest time preparing as well as I can to connect NOS and Appendix H.

Adjustment; before we move into calculations I am asking about Boyle's from the aspect of *communication of results* to stimulate discussion on why sharing results is important; it is not enough to have imagination and creativity if others cannot use or replicate work. After this move to the brief passage from the Teflon blog about its discovery (What will be important about discussing the discovery of Teflon is a) the term *noticing* (background / experience allowed to observe what others may have missed b) the term *curious* (this term is so important in being creative) c) unexpected benefit.

> *"Creating isn't meaningful without publication … without the ability for replication ..*"
> bring in Teflon again.
> "I felt good about 95% of what I saw today. *I felt students were engaged and that I was prepared to help them see there is more to science and imagination* / creativity than doing an experiment. Glad I adjusted ...

I asked the class informally how they felt doing the NOS [identifying exemplars and tenets] was impacting their content [did it help them understand the topic we were discussing] and they all said yes*… I can see why. When I had read about the connection between the two, I was unsure* (Peters, 2012) ... it is clear that by asking students to reflect and then reviewing *reflections students really see the content at a deeper level.*

> Students suggest that the method encourages thinking ... *(I am feeling good about the connection to reflection and content … beginning to make that connection about why the one influences the other because to this point I had not understood the connection*) I'm *understanding the purpose of action research more and I'm understanding nature of science more* and also *understanding coding and the importance of interviews*.. (laugh) why didn't I write that into my proposal? One big note to make to myself is how to allow for accommodations ...

The *critical friend* and I discussed this part of the study as the "buy in." During our conversation and review of the work, I stated that one of the most important impacts of the study had been my personal understanding of how reflecting upon NOS within the context of gas laws actually benefits study learning, and for that matter the educator's as well. I expressed this being one of the most important takeaways from the study. I explained that I had understood from an intellectual perspective science and its nature was important within content, but now I knew from an experiential aspect and most importantly, as an educator who insists upon best practices – this was an amazing resources for my students. There is a sense of enthusiasm for sharing what can help students, not to write a paper or to give a talk, but excitement about what one has witnessed working.

Is it a fair assessment? How have my views on Appendix H exemplars to embed NOS within chemistry content changed and how did it impact my understanding of both NOS and chemistry content?

The data revealed a shift from ambivalence bordering on a disregard for the exemplars located on Appendix H to one of acknowledgment and propensity toward proper training in their implementation. In other words, the statements about NGSS standards and the lack of NOS within them may not be completely resolved, yet perhaps the lack of effective educator training impacts the efficacy. The goal might be to educate classroom teachers first about their existence and secondly about their implementation. Still, a bit of hesitancy to fully embrace the exemplars is ongoing, as they are verbose and not always readily understood "as is."

> Puttick and Drayton thinks there should be a fourth dimension and I am agreeing [this is from reflections and included in a previous position statement written in a science seminar course]

While reviewing the literature a quote from McComas and Nouri (2016) was discovered which resembled reflections within my data. The authors stated "For example, the target aspect of observations versus inference, inference is not located in the final version of the standards (p.571).

> From my instructor reflections "I like how the exemplars are written on Appendix H, yet *the observation and inference is not clearly spelled out on the exemplars."*

I was able to recognize that there were benefits associated with the use of Appendix H, concurrent with noticing the need to enhance what was distributed to students or perhaps the manner in which the exemplars were reviewed and incorporated:

> Surprisingly I appreciated that the exemplars included creativity and imagination. Also, unless students actually read every exemplar, this may not matter… however, one exemplar is a direct statement from VNOS-B *('…theories do not with time become laws or facts'*).

> I like how the exemplars are written on Appendix H, yet the observation and inference

is not clearly spelled out on the exemplars. In addition *the syntax is not student friendly*. The term *probabilistic* is an example of terms which are not readily understood [by students] and which impede the direct use of Appendix H in a classroom. I do think using the modified version will be helpful – however, I also think they may need to review it as a whole class again – next time I will have them use colored pencils [I actually adapt that statement and have them place stars on their handouts].

Additional Insights with critical friend: Foundations needed for sucsessful implementation.

The data were consistent while reviewing the study with a critical friend. Here, additional insight included the adaptations to lessons. The critical friend brought my attention to the pedagogical strategy being implemented, and the willingness to situate the instruction. While discussing how this is part of an NGSS classroom (at least that is my understanding of them) I realize that to engage in the action research, there needed to be a level of comfort in delivering student centered lessons (these approached situated instruction). I also realized that to do so required organized cluster groups based upon student needs (hybrid groups) – which may better result in rich engagement. It occurred to me that I had established an environment in which students may have been better able to take risk within their groups so that they could be corrected or reinforce understanding. The critical friend, allowed me to see the foundations which may be required for successful implementation by asking me about the lesson designs.

Discussion

Schon, 1983, stated “competent practitioners know more than they can say” (Schon, 1982, as cited in Visser, 2010). Conversely, my introduction indicated that educators will learn through the process of reflecting upon pedagogical strategies. The self study has been conducted with honesty toward and about self, and ... involved the feedback of a selected critical friend to review insights (Clark, J. S., Porath, S., Thiele, J., & Jobe, M., 2020). The anticipated outcome of this self-study was a refined concept of self as an educator, specifically one within an NGSS chemistry classroom following nearly a year and a half away from *The Framework*, as a learner gaining insights into novel pedagogy and content, and as an author communicating to a larger audience.

When considering the first question of the study: “*What is the impact of an action research* *study upon my individual identity within the classroom? Doctoral student, educator, educational researcher and beyond."* I underscore the continual evolution of the author, previous authors and future authors within the context of self-study. It is difficult to corroborate a single identity or concept of self resulting from a self-study. In this case, the salient theme might simply be that the reflections reveal a shifting sense of self both within the frame of the study and most likely withing future contexts or studies. My own predominant identity is first that of educator, although the type of education may change as teaching moments exist both outside of and within the classroom. I might add the adjective ethical educator or open-minded educator to the identity. I appreciate the synergistic impact or confluence of the roles of educator with that of educational researcher and perhaps the underlying scientific and spiritual training which embed a sense of ethics, neutrality and compassion

As attention shifts to the second research question: *What is the impact of explicit and reflective embedding of NOS within an NGSS a unit lesson impact upon instructor comprehension of NOS tenets as specific exemplars and the delivered content?* It is apparent that when Peters (2012) suggested that the interventions utilized for explicit versus implicit connections to NOS within inquiry-based activities had a positive correlation to content knowledge (Peters, 2012), the theory may also apply to in-service educators, as well as their students. The self-study reflects that the explicit and reflective incorporation of NOS tenets was beneficial to both the students and the educator. The growth occurred via differently: the student learning from reflecting upon activities or specific questions posed during instruction versus the educator and educational researcher learning from both the preparation and adjustment of the lessons, as well as from observing student discourse or responding to questions posed. The evidence demonstrated growth in both their confidence in science comprehension and content. The primary author may have been proficient in her understanding of NOS, as demonstrated on a prior VNOS-B assessment, nevertheless, her ability to transfer the understanding required reflection and adaption of previous lessons. These adjustments and reflections regarding best practices for students enhanced both NOS and content comprehension, and in turn the more effective delivered instruction and intervention had a positive impact upon learners.

The final research question asked *How have my views on The Framework and its inclusion of NOS via exemplars changed?* remains somewhat unanswered, yet there has been a definitive shift within my own view of NGSS standards and our ability to utilize the grade level exemplars from Appendix H (Lead States, 2013b) to incorporate nature of science within the specific content. Experts who study aspects of science have suggested that NGSS has overlooked NOS within the standards. However, despite the criticism of the standards, there are occasionally positive statements from those voicing concern. For example, an attempt at a national set of standards in science education had not been revised in over a decade and McComas (2016) suggested the benefit of a shared discourse about the same document regarding science education. The flawed nature of the standards may be that they simply do not specially mention embedding NOS. For example, in their introduction to a publication on Teaching and Learning Nature of Science in an Elementary Classroom, Akerson et al (2019) described the lack of "strongly stated expectations for students to conceptualize NOS ideas within the body of the document" (Akerson et al, p.392). This statement echoes that of N.G. Lederman and J.S. Lederman (2014) in their editorial on NOS within NGSS, where they suggest that nature of science is buried within the standards, and that despite a generalized description of NOS within Appendix H, no clear outcomes are delineated (Lederman & Lederman, 2014).

The data revealed a shift in the primary author's use of and views regarding the exemplars located on Appendix H. First, there had been a need to locate the characteristics located on pages 5 and 6 of Appendix H, and then connect the grade level exemplars with NOS tenets. Next, an instructional design needed to be implemented and adjusted. As the reflections from the action research study indicated, in most cases the use of the grade level exemplars was found to be a useful tool when embedding NOS within the lessons. The reluctance toward Appendix H and grade level exemplars shifted to a need to educate classroom teachers first about their existence and secondly about their implementation.

There was a bit of hesitancy to fully embrace the exemplars, as they are verbose and not always readily understood. It should also be noted that these grade level exemplars were not simply a list which students were asked to memorize. Lederman (2014) was clear that students' explicit and reflective incorporation of NOS required more than memorization of a list (Lederman & Lederman, 2014). During the action research lesson, students were expected to describe the science observed, locate an exemplar which explained the science and then explain why or how they felt that way. The independent responses were discussed within cluster groups and finally as a whole class. It should also be noted that despite the benefit of reflecting upon each activity or demonstration completed, a complex chemistry curriculum will require a balanced and timely use of the conceptual framework described.

Conclusion

In his forward to a collection of self-studies in science education (Buck and Akerson, 2016) John Loughran re-stated (Loughran, 2010) that outcomes of the research should be presented in a manner which goes beyond the current story or research. In this self-study, the reflections and data obtained will benefit the educator, as well as those who will receive professional development regarding this work. More importantly, the outcomes apply beyond the constraints of high school science, lessons on gas laws or even an NGSS classroom. One of the most important outcomes of the study has been an increased appreciation for the importance of transmitting NOS within the classroom and ambition to refine pedagogy while sharing findings. How did this happen? Perhaps there were three steps.

First, there was the acknowledgment that the role and identity which best suits the primary author is that of educator, yet the ethics which underscore both her spiritual and scientific background appear to reinforce the need to search for best practices toward rich engagement and learning for students. According to Hauge (teacher educator 21st century), self-study is intended to search for gaps or contradictions between the educator’s personal theory or practice and how their teaching is conducted (Hauge, p. 2). İt is possible that there are fewer gaps or contradictions within my educational practice because of belief systems. The ability to speak at depth about more of the science occurring globally during the past few years, and the potential to help students rise to the NGSS goal of becoming educated citizens has been challenging. Within public school systems, we are ethically unable to present options which might challenge the belief systems of students or their families or raise controversy. Therefore, as an educator in this time of heightened sensitivities toward science, alternative approaches are suggested. We may arrive at the same understanding of science when including less controversial yet related topics. Here, confidence was gained in current pedagogical strategies and the concern regarding positionality of the combined identities of educator and educational researcher were replaced with the understanding that the two may be synergistic.

The second step in my overall outcome was overcoming my resistance to the use of NGSS standards. *The Framework* had not been received well by many experts in the field of science, especially those concerned with incorporating NOS explicitly within the content. However, with a willingness to learn about NOS tenets and then connect these tenets to the NGSS resources, such as Appendix H (Lead States, 2013b), it is possible to acknowledge the standards and their potential. The initial training as we adjusted to NGSS standards was incremental. We initially focused upon how to read the standards, and how the then utilized Common Core aligned with *The Framework*. Subsequent training was specific to designing lessons and identifying CCC's and SEP's, finally we reviewed the meaning behind "Asking Questions" and engineering and design. It is possible for those training educators to arrive at sample lessons which also explicitly embed NOS within the delivered instruction.

The final step toward my appreciation of transmitting NOS within the classroom was that of the action research study. During the study, a previous lesson was adapted in order to both incorporate the explicit and reflective NOS within the context of gas laws. Prior iterations of the lesson were altered to allow increased student discovery. For example, terms such as "law" (gas law) or "theory" (kinetic molecular theory) needed to be removed from study guides. Lessons are generally student centered, yet the lesson was situated as much as possible, however the overall lesson may be considered social-constructivist in nature. The lesson allowed students to utilize the knowledge they were developing from their observations to arrive at understanding. This allowed me to then incorporate reflections independently and then within cluster groupings. As the study progressed, it was apparent that students needed to better understand the content to reflect upon questions and apply NOS tenets to activities, and ultimately the gas law being discovered. With any lesson, the instructor needed to present the lesson prepared for scaffolding or unanticipated questions. Here the questions may have been about either the lessons or the exemplars. The instructor also found herself adding sections to the unit lesson which reinforced NOS, as well as the content. These lessons included the history of scientists such as Boyle, Charles and Gay-Lussac. Real world examples of NOS within the context of gases were included. For example, the discussion on the discovery of Teflon allowed students to observe human endeavor, as well as discuss a specific gas (tetrafluoroethylene). Additional handouts were prepared for students with questions or interest in the content. The preparation of each lesson, the search for historical connections and connecting the work to NOS was beneficial for both the students and the educator. The following reflection was composed while considering the study and its meaning as the data were being analyzed:

> The students selected for the action research may have been the optimal group. They had been away from critical thinking due to COVID-19 adjusted platforms and although it was at times challenging to be patient while slowing down the pace from previous years. I was able to see vividly how discussing the content benefitted the students – that was a definite

> "aha" moment for me. Understanding this – that being able to identify science, to apply that to a specific content meant I had to make sure they learned the content correctly! This means time! This means that students need to *buy in* as much as the teacher – they needed to know that it was up to them to follow a plan even if it may be easier or more popular to simply give answers at certain points. But yes, this was the perfect year to see just how much reflecting made them stop and learn the content! In turn, this helped me appreciate NOS all that much more – and made me want to better deliver the content and NOS within exemplars better

Demirdöğen and Uzuntiryaki-Kondakçı (2016) conducted a study of pre-service chemistry teachers just prior to graduation. They found the belief systems of these future educators regarding the need to transmit NOS to their future students was an important aspect of instructional strategies. In their review of teacher competencies to support effective NOS instruction, Nouri et al (2021) cited Akerson et al, (2014):

> [T]eachers should expect to feel different emotions as they develop professional identities as teachers of NOS. It is a difficult process simply becoming a teacher, and it is no less difficult to become a teacher of NOS. Emotions of joy as students' exhibit successes and despair as students' struggle will be difficult, but through perseverance and attending to these emotions, professional identity will be built. (p. 2080).

The impact of believing in what we teach is important. The implications of acknowledging the need to alter my own future pedagogy, as well as share the effective strategies discovered during the course of these studies should result in an enhanced science experience for future students.

Notes

The chapter was written with data obtained during the action research study "Nature of Science in an NGSS Chemistry Classroom."

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Chapter 10: Teaching the Nature of Science: A Self-Study of a Biology Lecturer turned Doctoral Student

Stephanie Marin Rothman

Chapter Highlights

- Having confidence that I belong in my program contributed to myself continuing my studies and planning future goals.
- Examining my instruction through the researcher lens made me more critical of myself as a teacher.
- I do teach the Nature of Science in my lectures, even though I recorded them before I was familiar with the term.
- My new Nature of Science lecture covers the aspects well.

Introduction

Problem Statement: Is Teaching the Nature of Science Important?

For the last century, scientists, science educators, and science education organizations all over the world have agreed with the goal of aiding students in developing adequate conceptions of the Nature of Science (NOS) (Abd-El-Khalick et al., 1998; Wahbeh & Abd-El-Khalick, 2014). That students develop an understanding of NOS is still considered an important educational goal by contemporary science education researchers (Allchin et al., 2014; Olson, 2018). Despite this goal, numerous studies have shown that many students hold naïve views of NOS (Abd-El-Khalick, 2012; Abd-El-Khalick & Boujaoude, 2003; Dogan & Abd-El-Khalick, 2008; Kang et al., 2005; Lederman, 1992). Many science teachers also have a tenuous grasp of NOS, potentially further propagating misinformation to their students (McDonald, 2010; Wahbeh & Abd-El-Khalick, 2014).

Mistrust and misunderstanding of science can lead to dangerous repercussions, such as denial of lifesaving vaccines. Society needs to learn about what science is and what it is not, so that they can think critically and make informed, measured, practical decisions about their lives, such as how to protect themselves from deadly pandemics that have resulted in the deaths of over 1 million Americans (CDC COVID Data Tracker). School is the primary route of exposure to science for most people, and quality science education can make all the difference in people's perception of science. With a better understanding of NOS and how to effectively teach it, teachers can better help their students understand the concept as well. Hopefully, students with a better understanding of NOS will be more skeptical of scientific claims from erroneous sources.

My Teaching Methods

Because it can be difficult to understand NOS, classroom lessons and activities that help students improve their knowledge of NOS should be more widespread. Teaching strategies that help students gain a better understanding of NOS need to be created, tested, and disseminated. There have been numerous studies examining the efficacy of various interventions at improving students' views of NOS. Discovering effective ways to teach NOS is important, because while it is mandatory for a teacher to understand NOS in order to teach it, that alone is not sufficient for students to learn from them (Wahbeh & Abd-El-Khalick, 2014).

Implicit and explicit approaches to teaching NOS have been described (Abd-El-Khalick & Lederman, 2000). Students may be able to implicitly develop an understanding of NOS through participating in the action of conducting science. Conversely, explicit instruction of NOS relies on instruction that clearly includes NOS aspects in the curriculum and student learning outcomes (Wahbeh & Abd-El-Khalick, 2014). This explicit instructional framework further was advanced through the addition of reflection in the curriculum, which includes opportunities for students to reflect on NOS as a part of their learning experiences (Abd-El-Khalick, 1998). Explicit-reflective instruction has been consistently shown to improve students' conceptions of NOS in both children and adults (Abd-El-Khalick & Lederman, 2000; Akerson et al., 2014; Akerson et al., 2000; Bloom et al., 2015)

Engaging

The goal of my teaching is for my students to rekindle their childhood curiosity and wonder for the natural world. I want to inspire a love of science in my students that lasts for the rest of their lives, not just slog through a semester. Similarly, I am not the only one who believes that a successful science curriculum nurtures an interest in science that lasts a lifetime (Carey & Smith, 1993). My classes may be perceived as being "easy" because my exams are open note, however I don't see the value in having students cram for exams to memorize information which they view as unimportant and irrelevant. Furthermore, it is likely that that style of learning will not lead to long-term memory, but instead be forgotten at the conclusion of the class. While cramming has been shown to increase student exam scores because it is a form of short-term memory, it is not an effective way of learning for long-term memory retention (Cepeda et al., 2008). My priority is for my students to learn to think critically, rediscover their childhood curiosity, keep learning about biology long after the class ends, and share their passion with their friends and family.

Teacher Questioning

If you want answers, you need to ask questions. I have always encouraged my students to ask questions because they are in my class to learn. Unfortunately, many of my students have been belittled by other teachers for asking questions, making them hesitant to do so again. I emphasize that there are no stupid questions and that if they ask questions, I will actually be impressed with them since inquiry is the first step in discovery. To facilitate an environment of inquiry, I frame every unit, module, and submodule in the form of a question, and pose questions throughout my lectures.

Embedding NOS Teaching Within Curricula

Amazingly, despite my earning both bachelor's and master's degrees in Biological Sciences and a decade of college-level teaching experience, I was not familiar with the term NOS before starting my doctoral program. Fortunately, my education was not inadequate, because I have been familiar with the aspects of NOS, if not their categorization as such. Having a science teacher who understands NOS is critical for students to thusly learn NOS, but that alone is not enough (Wahbeh & Abd-El-Khalick, 2014). I believe I have been inadvertently teaching my students NOS, although implicitly, since I started teaching. Nevertheless, by contrast, an explicit teaching method has been shown to better help students increase their understanding of NOS (Abd-El-Khalick & Lederman, 2000). For this reason, I started the Spring 2022 term with a new lecture explicitly listing the aspects of NOS, and provided accompanying documentation for students to reference. I also added a new reflective note-taking assignment in which I ask my students to connect lecture content to the NOS aspects I taught at the beginning of the term.

Visual Aids

Being a visual learner myself, my online classes are very visual, with a pleasing aesthetic that makes navigation intuitive. I have an interest in instructional design, and my classes utilize universal design for learning. I describe the NOS aspects orally through a lecture, written in simple text, and with images. Other studies have already shown that visual aids can effectively support understanding in adult teachers, and I anticipate similar results with my adult students (Akerson et al., 2008).

My Science Classes and Students

I am a Lecturer (non-tenure-track/adjunct) at two public universities in Southern California, full-time at my main home campus and part-time at another campus. In my position, I am the instructor of roughly one thousand students per year for online asynchronous General Education biology courses. I have also taught at two Southern California community colleges in the recent past. Lately, the classes I teach have been Life Science/General Biology and Human Sexuality, both taught online in the asynchronous mode.

The overall population of students on my campuses are incredibly diverse. At the campus where I conducted my action research, as of Fall 2019, 57% were first-generation college students. 69% of students received aid, 44% were Pell recipients, and 33% received federal loans. 49% of new students had transferred in, the other half were first-time freshman. In terms of racial diversity, representation is Hispanic 47%, Asian 21%, White 15%, Other (American Indian, Alaskan Native, Pacific Islander, multiracial, and unknown race/ethnicity) 7%, International 6%, and Black 3%. (Office of Institutional Research Planning and Analytics, 2019). Representation at the other campus where I teach the same class but have not yet studied is 64% Latina/o, 10.6% African-American, 8% Asian, and 6.6% Caucasian, 2.6% two or more races (*California State University Dominguez Hills*, 2020).

My students are also diverse in terms of interests, with many different majors represented. At my main full-time campus, I usually teach three sections of my introductory-level general education Life Science class, with usually about 120 students per section. Many of my students are freshman, although all levels are represented. My Life Science students are non-biology majors. Other STEM majors (Science, Technology, Engineering, and Mathematics) are well-represented in my class, particularly engineering and computer science are well-represented, although a diversity of majors is included overall.

Background/Theory: My Own Views on the Nature of Science

What is Science?

Science is not easy (or perhaps, even possible) to define. The definition may rely on the historical context in which it takes place, further complicating the issue (Chalmers, 2013a). The simplest way I can define science as I see it, is a method of discovery. It is a process by which humans attempt to understand the universe, and it differs from other ways to attempt an explanation in that it involves uncovering new information and creating new explanations. In this way, science is progressive, but also accepts that we will never have all the answers due to the amazing complexity of the universe.

While there is a lack of consensus about what exactly science is, there are several aspects of the Nature of Science (NOS) that are non-controversial and generally agreed upon. However, like science itself, there is no ubiquitous definition of NOS, and any definitions are liable to change in the future (Abd-El-Khalick & Lederman, 2000). NOS has been described as the epistemology of science, that is to say, science as a way of knowing, and includes the values and beliefs that are inherent to the development of scientific knowledge (Lederman, 1992). Aspects of NOS that are relevant to my context as a science educator are that science is empirical and there is a distinction between observation and inference, that science is tentative, subjective/theory-laden, imaginative and creative, and social and cultural. Furthermore there are similarities and differences in the function and relationships between scientific theories and laws (Abd-El-Khalick et al., 1998).

Science is Empirically Based

Science often begins with observations, with collecting information, and that information is collected empirically using the senses we as humans possess. Regardless of the conclusions scientists may ultimately make, initial observations are thusly empirically based, based on and/or derived from observations of the natural world, using the senses. Furthermore, it is important to distinguish the differences in observation and inference. Observation is information we empirically collect, whereas inferences are assumptions we make based off the observations we have at our disposal. Inferences are a crucial aspect of science, especially considering no one has all the answers available to them. Inferences, such as deduction, can be a logical tool we can use to explain phenomena when we do not have exhaustive empirical observations. The caveat is that inferences, like assumptions, can be shown to be incorrect. However, this does not reduce their importance, because likewise even empirical observations can be shown to be incorrect. Furthermore, if an extensive amount of empirical data is collected, our faith in inferences can be reliably (if always tentatively) accepted.

There is a Distinction between Scientific Laws and Theories

Another confusing point for people to understand about science is the difference between scientific theories and laws. It is my opinion that much of this confusion is simply semantic, what with both "law" and "theory" having different layperson definitions than their scientific definitions, and that much confusion could be ameliorated by simply changing the words we use. If I had a dollar every time I heard someone say evolution is "just a theory" I could probably retire from teaching. Hyperbole aside, I believe using a word that is synonymous with uncertainty to describe what scientists are *most* certain of is a recipe for confusion. Instead of taking people head on, why not simply use a different word? This misunderstanding is further perpetuated when science teachers themselves do not understand laws and theories, as students' naïve views of NOS may be influenced by the similarly naïve views held by their own teachers (Abd-El-Khalick & BouJaoude, 1997; Dogan & Abd-El-Khalick, 2008; McDonald, 2010).

The simplest way I can describe them, is that laws are based on empirical observations and describe a narrow set of conditions, and theories are the inferences scientists have made based on those observations to describe how and why natural phenomena occur. Of course, one must understand what observations and inferences are to understand what laws and theories are, and that is probably another reason people find it difficult to understand. (You would almost think we were intentionally trying to confuse people.) Further adding to the complication is that there is no hierarchy between laws and theories, they both are accepted by the scientific community, and both have the potential for being rejected if new evidence disproves them.

Science is the Product of Human Imagination and Creativity

As much as society tries to delineate the sciences with what they perceive as more "creative" pursuits such as the fine arts, science and art actually have much in common. Both art and science are ways in which humans attempt to understand and explain the universe. As such, they both are the absolute manifestation of human imagination and creativity. Creativity and imagination are part of the entire scientific endeavor, from formulating questions, to designing research, to interpreting results, and finally in how we share our discoveries with others in the form of the written and spoken word, and visually as graphs, tables, and illustrations. Any person can create art and any person can conduct science, regardless of age or education. Just while children can create finger paintings, children use science to learn about the world around them. Both the child and the famous scientist use prior knowledge to build upon what they know, formulate new ideas and try new things. Both art and science exist within the context of the creator, and neither would exist without human imagination and creativity.

Science is Subjective and Theory-Laden

Throughout my life I have constantly heard the assumption that scientific researchers need to distance themselves from their studies and be impartial. Indeed, I have been taught that "good" science shouldn't allow their judgment to be "clouded" by influences in their pursuit of the "truth." However, this way of thinking is in contrast with the very NOS which states that science is actually, in fact, both subjective and imbedded in the social and cultural context. Scientists are people, and people are individuals who have their own backgrounds which will influence how they perceive and interact with the world, including how they conduct science. The beliefs or theories that scientists subscribe to will influence what they believe is important and how to design and interpret scientific research.

Science is Socially and Culturally Embedded

Everyone, researchers included, has prejudices, biases, and perspectives, and pretending that researchers don't is deceptive and inaccurate. As we look at the history of science, it's important for us to view the work of scientists with the social and cultural context of the researcher. After all, as much as we extoll science, we cannot ignore the fact that people have used it for nefarious reasons. A racist person conducting science may very likely make racists conclusions through their research. Just because this researcher followed the scientific method doesn't mean that the conclusions they draw are accurate, rather their conclusions are based on their own perceptions of reality. As much as scientists pursue "truth," they are pursuing something unattainable, because one could argue philosophically that universal truth does not exist.

While this flawed idea that knower and known are independent is common to those outside of the natural sciences, I suspect it may be common among scientists themselves. After all, all research I have been exposed to in the natural sciences utilize the quantitative mode of inquiry, characterized by assumptions that reality is single and social facts have an objective reality and inquiry is objective, with the role of the researcher being one of detachment and impartiality and objectivity (Glesne & Peshkin, 1992). The qualitative mode of inquiry, characterized by the assumptions that reality is socially constructed and that inquiry is subjective (Glesne & Peshkin, 1992), I have personally observed only in the social sciences and not at all in the natural sciences. I think it's important for the reader to understand the perspectives of the author so that they may contextualize what they're reading and ask their own questions. As the sciences become more "decolonized" and more diverse voices are heard, I wonder how perceptions of this NOS will shift as well.

Science is Tentative

A seemingly contradictory aspect of science is that it is always subject to change. It may seem paradoxical that society reveres science, yet it must always accept that what we assume may be disproven, yet this is a critical aspect of NOS. Indeed, when I teach my biology classes, everything I teach is "…as far as we know." I actually tell my students that if they ever see on an exam the possible answer choices "always" or "never" then those choices cannot be correct because science doesn't allow that kind of certainty and there is an exception to every rule. Tentativeness is an important aspect of NOS, and like the other aspects, it part of what separates science from other ways of knowing. Science is progressive, and progress is a kind of change. Because what we assume to be true about science is theory-based inferences, as we gather more information and make new discoveries, our ideas and explanations are likewise subject to change. A hallmark of being a scientist is uncertainty. Because science is a pursuit of learning, it makes sense that it follows the maxim that the more you know, the more you realize you don't know. The more we learn, the more uncertain we become, because with our learning comes an understanding of how complex things are and how much more there is to know.

My Teaching Philosophy

I view learning through the lens of the constructivist theory. I do not believe that students come to class as a blank slate or shapeless clay I am tasked to mold. I believe that they come with their own unique perspectives which includes prior knowledge, experiences, and beliefs. This view fits with NOS itself, because one of the aspects of NOS is that science is influenced by the perspectives of scientists. In my student-centered classroom, students are encouraged to relate the course content to their own lives, work together to solve real-world problems, and choose what assignments to complete from a list of options, including first-hand experiences with nature. At the conclusion of class, my goal is for students to reflect on what they knew before and after class, build new knowledge onto the knowledge they came to class with, and rekindle their curiosity of the natural world. New additions to the curriculum of my class Spring 2022 include explicit-reflective lessons and assignments on NOS. Interestingly, I have been teaching NOS all along for the past decade, although without explicitly referring to it as "NOS" or having read anything within the field of NOS. My understanding of the nature and philosophy of science has come from my viewing of PBS as a child, my studies as an undergraduate and graduate biology student, interactions with my university scientist colleagues, and only very recently in my studies as a Doctor of Education student.

Purpose

I am both a teacher and a student. I am teaching a *natural* science while studying *social* science. In the microcosm of academia, I have a foot in two different worlds. Am I a part of both or neither? These are the thoughts that have ran through my brain since starting my doctoral program. Ten years before starting my EdD in Science Education, I completed my M.S. in Biology and began my career as a university lecturer. Surrounded by tenure-track professors with PhDs, I experienced imposter syndrome before I had ever heard the term. I asked myself if I was still a real scientist if I am not actively conducting research; and if I could really teach my students science if I wasn't a scientist myself. In this self-study, I will reflect on what kind of teacher I am, and how my studies are helping me develop into the teacher I want to be. I will reflect on my own feelings of being a scientist and researcher, teaching in the natural sciences, while being a student of the social sciences. I will specifically reflect on how I am teaching the Nature of Science (NOS) to my students. This **self-study** project will focus on *my own perceptions of myself as an educator and scientist*. My related **action research** project will focus on *my students' perception of NOS*.

Research Questions

Research questions I hope to address in my study are:

- How do I identify as a scientist? Researcher? Teacher?
- What is my own understanding of the Nature of Science (NOS)?
- How have I been teaching the Nature of Science (NOS) in my pre-recorded biology lectures?

Critical Friend

My critical friend for my self-study and action research project is my colleague Paul Beardsley, Professor, Center for Excellence in Math and Science Teaching, and my mentor for my Chancellor's Doctoral Incentive Program Fellowship. Since we are both faculty at the same institution, he can observe my online asynchronous Life Science class ran through Canvas, where he can see my lectures, including my NOS introductory video, and peruse my class curriculum and assessments.

Method

Data Collection

In this study I evaluated three sources of data: assignments I wrote for my Science Education seminar in which I reflected on my own thoughts, experiences, and feelings; my new Nature of Science Lecture that I recorded after my first Fall term as a doctoral student which I added to my Life Science class; and my Class Lecture videos that I recorded in 2014, before I was familiar with the science education field or NOS.

Seminar Reflective Assignments

The classes I have taken as a doctoral student have been very reflective. I wrote my weekly assignments for Educ-Q 612 Topical Seminar in Science Education class in the style of stream-of-consciousness, rather like a journal. I used these assignments to evaluate my own perceptions of my identity as a researcher, scientist, and teacher as I started my doctoral program.

Nature of Science Lecture

New this semester, I added a NOS lecture video for students to watch at the beginning of the term which I explain several aspects of NOS. Aspects that I include are that science is empirically based, there is a distinction between scientific laws and theories, science is the product of human imagination and creativity, science is subjective and theory-laden, science is socially and culturally embedded, and that science is tentative. In their skeletal notes assignment, I ask students to reflect on the aspects I covered in this video as they watch my class lecture videos throughout the term. My critical friend Dr. Beardsley and I viewed my lecture video independently before we met to discuss and analyze it together.

Class Lecture Videos

I recorded the lecture videos for my class in 2014, before I was familiar with the term “Nature of Science” although I believe I was teaching the aspects all along, having, what I believe, was an understanding of NOS without knowing that's what it was called. I reviewed my lecture videos and copied from the transcripts instances in which I relate an aspect of NOS to the content I cover in the lecture and compiled these excerpts in a separate document.

Data Analysis

Seminar Reflective Assignments

I reviewed the reflective assignments I wrote nearly a year ago at the start of my doctoral program. I looked for patterns and looked to see if the patterns changed over time. I looked specifically for evidence of my own conceptions of being a scientist, teacher, and student, and looked for correlations.

Nature of Science Lecture

In several meetings over Zoom, Dr. Beardsley and I discussed my methods for teaching NOS. I requested that we not use too much structure for him to analyze my lectures, because I wanted his own perspective with original feedback. We both analyzed my new recorded lecture in which I teach the aspects of NOS. I also include with this lecture a Word document summarizing the aspects in bullet points for my students to use when studying and completing their skeletal notes.

Class Lecture Videos

I perused my lecture videos to look for instances in which I teach aspects of the NOS. I originally recorded my lectures in 2014, eight years before this study. While I have taught my class both in-person and online the past eight years, I had not reviewed any of my pre-recorded lecture videos since I first recorded them in 2014. I used transcripts of my lectures to code them for instances in which I taught the different aspects of NOS. I methodically poured over the audio and transcripts of my entire collection of course lecture videos. When I observed an instance in which I teach an aspect of NOS, I copied the text from the transcript into a new Word document and flagged it with the code for the particular aspect. At the conclusion of perusing my entire collection of lectures, I looked over my data to look for patterns in how often I taught each particular aspect. Dr. Beardsley also reviewed my first lecture on science, Unit 1 Module 1 Lecture Video "What is Biology?", to analyze it for instances in which it taught NOS. We met via zoom to share our findings.

Results

How Do I Identify as a Scientist? Researcher? Teacher?

Fall 2021 Week 1 reflection

I began my doctoral program eager to learn and ready to make improvements. I love my current job and admitted to going back to school and getting my doctoral degree for fun and for professional development:

> "I was inspired to enroll in this program more for my own personal growth than for any other reason, so I am looking forward to challenging myself and rethinking what I believe I already know."

I had never heard of the term 'Nature of Science' before starting this program but was eager to learn more. While I hadn't heard term 'NOS' before, the aspects themselves were something I was already familiar with:

> "I think many people treat science as analytical and irrefutable, and everything else is subjective and unimportant. For instance, I think many science-minded people would scoff at the notion that there is faith involved in science. However, there is a lot of faith involved in science. I'm curious to find out why some people place such unshakable faith in science while others deny it completely. I think we can use that information to help us teach our students."

I also expressed tentativeness in my confidence of my own teaching. Despite my many teaching awards, I constantly worry that I'm doing something wrong, or that I could at least be doing it better:

> "I've been teaching science for so long, that I've been building on what I've done for years. It will be interesting to see if there are flaws in the foundation of my teaching practices. I am excited to more closely examine my teaching methods, and to consider why I am using them. I am interested in studying my methods and determining if I am

having the impact on my students that I hope I am."

Fall 2021 Week 2 reflection

While I started my program thinking I was learning brand-new concepts, my worry was assuaged the more I learned about what NOS is:

> "Well, the readings for this week have been very affirming. While I have only heard the term 'nature of science' for the first time in this class, I have apparently been teaching it for the past decade."

I never called the aspects the 'Nature of Science' in my classes, but I have been teaching them to my students, nevertheless. I also related what I learned in my seminar class to my inquiry class:

> "This past week in Y520 we have also been covering epistemologies (a term I had also never heard of before). We had to select the epistemology that we most closely align with, and I selected Postmodern because of my lack of certainty in anything, a common theme in my entire biology class. I think that the common notion that science produces absolute truths leads to distrust when science inevitable makes new discoveries and scientists form new ideas. I also believe it's important for everyone (including researchers) to realize their own biases and consider how that may affect what research they do and how they do it."

I seem to freely and easily relate different subjects together, as demonstrated with relating NOS with social science inquiry. I think this will help me as I reconcile being both a natural sciences teacher and social science researcher. Even this early on in my program, I felt a sense that I fit in my new field, because my beliefs and values aligned with other researchers:

> "In 'On Understanding the Nature of Scientific Knowledge' by Carey and Smith, I was instantly struck by the declaration that a successful science curriculum nurtures an interest in science that lasts a lifetime (Carey & Smith, 1993). This is my number one priority for my students in my classes. My colleagues may think my classes are easy because my exams are open note, but I just don't care for students to cram for an exam

to memorize information that isn't important to them and which they will instantly forget. I just care that my students learn to think critically, rediscover their childhood curiosity, and keep learning about biology after the term ends."

Furthermore, I felt that this field was a good fit for me because of the ease at which I read the articles:

> "I am very confident that I chose the right field and the right program for me. I easily understood everything I read, and I can imagine myself writing my own journal articles like the ones I read."

I was very inspired to represent the interdisciplinary field of science education research. I was relieved to read about other researchers extolling the need for collaboration:

> "I was inspired by the final section in 'Cognitive Science and Science Education' and agree with Carey that cognitive scientists and science educators need to work together (Carey, 1986). There is a shift happening in academia right now, and I think it's critical that we keep moving towards more interdisciplinary research and collaboration."

However, the article I site is from 1986, thirty-five years before I read it. I wonder how much headway interdisciplinary research and education has made. Even this very early on in my program, I already am planning my research:

> "Based on the reading, I believe my asynchronous video lectures (recorded in 2014) emphasize the nature of science, but I don't know how they affect my students' views of the NOS. I would also like to conduct a pre- and post-survey on the NOS, although I would like to see how it correlates to students who actually watched my lectures or not."

Using a pre- and post-test on students' perceptions of NOS is a study I developed in my companion paper. I also mention other ideas for studies I may implement in the future, such as following up with past students:

> "I believe that I am a successful teacher purely based on my teaching reviews, but I

> would be very curious to do a follow-up survey with past students. I could ask them what they remember or what was their biggest takeaway from my class they took years ago. I would also like to ask them if in their lives they experienced a perspective change to think more 'scientifically.' I would like to know when this happened and what caused it. I could do a qualitative study with interviews/open-ended surveys."

I am also very interested in real-world application of my course content to students' lives:

> "I would also like to look at students' views of the NOS and compare them to their vaccine rates. I have always been most concerned with real-world implications in my biology classes. If a student memorizes the phases of mitosis but doesn't believe in vaccines, then their biology class was a waste of time in my opinion. I would also like to compare students' views on the NOS to their other beliefs, like religion and political ideologies and their trust in science and medicine."

Fall 2021 Week 3 Reflection

I learned about philosophy in both my Q612 seminar and Inquiry class, a field with which I had zero experience before. I had never heard the term epistemology before and was unaware of the many other different ways of knowing when reading about the philosophy of science, and I had trouble delineating it from the Nature of Science.

> "To me, the Nature of Science seems like the acceptance that we can't really be certain of anything, which seems like a type of epistemology (or philosophy) in itself. In my Y 520 class I aligned myself with the Postmodern because of the tentativeness, which parallels Nature of Science…" (Chalmers, 2013b)

I was alright planning to use VNOS for my upcoming action research project, but expressed interest in utilizing a mixed-methods approach to also use quantitative data:

> "I will probably end up doing both qualitative surveys like the VNOS extoled by Lederman, et al and quantitative selected-response surveys, perhaps like the Views on Science-Technology Society (VOSTS) questionnaire developed by Aikenhead, Ryan, and Fleming (1989) mentioned on page 503. It could be interesting to compare the

> different kinds of data." (Lederman et al., 2002)

At this point I start to feel conflicted between quantitative natural science research and qualitative social science research and really start to understand the delineation between the two. When it comes to utilizing any two seemingly conflicting techniques there is a group that may claim it's the best of both worlds and another that claims it's the worst of both worlds. Whereas I felt initially comfortable in my new field, I start to learn the differences and have a difficult time picking a side:

> "I will probably request responses from a smaller portion of students in the Spring for our Inquiry Linkage class. I just have to quell the experimental scientist in me screaming to get as much data as possible."

Fall 2021 Week 4 Reflection

After four weeks I feel more confident reading the literature in my field, which will help me in my own research. In particular, seeing how other researchers have influenced one another helped me contextualize my own research within the field:

> "I found this paper in particular very helpful because of all the new sources it cited. Right in the first paragraph of the introduction the authors listed nine papers that showed students still hold naïve ideas about the nature of science (Wahbeh & Abd-El-Khalick, 2014)."

I start to feel more confident doing my own background literature review because of the exposure to foundational papers through my advisor, giving me confidence in my program and mentor. If I had not been guided to these foundational pieces, I wouldn't have known where to start and would have felt overwhelmed and dejected and I'm sure I would not have continued in this field.

> "I started off completely overwhelmed searching for literature because there is just so much out there, but these foundational and influential papers we've been reading have been very grounding and have helped me know where to start. The more I read, the more confident I feel searching for papers on my own and understanding them."

This confidence appears to affect my entire attitude, and even when confronted with discouraging evidence, I am not dissuaded from pursuing research:

> "I thought it was interesting that the authors noted that while it's mandatory for science teachers to understand the NOS in order to teach it, that alone is not enough. As with most things, the problem is much more dynamic and there are a host of other factors that contribute to effective teaching. Instead of feeling dejected about this though, I felt inspired that there is a way I can contribute to solving the problem by finding new ways to help teachers teach the NOS to their students."

Having confidence in myself may have, I believe, inspired me to continue pursuing research and advancements in my field. I assume that if I did not have confidence in myself, I would be dejected and be less inclined to work towards progress in science education. I even start to dream big and imagine myself contributing to the field by writing textbooks:

> "I was also shocked to read on page 16 that naïve conceptions are often spread through science textbooks. I am often pestered by textbook publishers asking if I want to write for them, maybe I should take them up on it."

At this point I am still grappling with the differences between quantitative and qualitative research:

> "I am still finding it surprising to read studies with such small sample sizes. I teach experimental design to my freshman biology majors and I emphasize that they need at least 30 subjects in their experiments. I know this is not the case for other kinds of research methods, but it still surprises me every time I read it."

The concept of quantitative research and importance of statistics is so ingrained in me that I had trouble believing there is any other way to do research. This is particularly interesting because I have struggled with math my entire life. I have always been more of a "words" person than a "numbers" person, and yet I had no idea that research using words instead of statistics was even an alternative type of method I could utilize. In fact, when I have taught my biology students in the past, I emphasized the importance of looking for large sample sizes and statistics when deciding if a study is legitimate science or not. So this bias for quantitative research that I had was not only ingrained in me from my own studies in the natural sciences, but I passed along this to my students as well.

Fall 2021 Week 5 Reflection

While the issue of scientific illiteracy is no doubt a dynamic issue, the papers I have read lead me to believe that the way education is taught is both largely responsible for the problems with science education…:

> "Reading about teachers' understanding of the nature of science is very important, because it is mandatory for them to teach it effectively, although the issue is multifaceted (Wahbeh & Abd-El-Khalick, 2014). Most students learn about science from their teachers and reading every week how little teachers understand about NOS certainly explains why the amount of scientific literacy leaves much to be desired in our country."

…Yet I also think that education, specifically teacher education, is the key to fixing scientific illiteracy:

> "I totally agree with the authors that teachers will continue to have naïve views about NOS if there is no systemic reform in college science education (V. L. Akerson et al., 2000). At least in my experience, NOS hasn't been a part of any official "student learning outcomes," which instead include just topics we are required to cover. We need to break the cycle, or else inadequate NOS will continue to be taught from professors to teachers to students who become teachers, etc…"

My confidence in the field continues to increase with every paper I read:

> "This paper will be very helpful for me for many reasons. I'm becoming more and more comfortable reading these studies, and each week I read them with quicker and with deeper understanding."

Since I recorded my online lectures in 2014 and hadn't even taught in-person in several years, I have a difficult time comparing my teaching to others that I have read about in studies. I start to finally see myself as not only a budding researcher, but a teacher to be researched:

> "I'm not really sure how to categorize my own introductory biology class in terms of how I teach NOS, whether it's explicit or implicit. I recorded my lectures in 2014, before I had even heard of "NOS," although many of the principles of the NOS are a common thread throughout all my lectures (particularly tentativeness and culturally embedded) and I use historical examples. I'm curious about how my action research will play out next spring, where I can verify if I've been effectively teaching NOS all along or not."

While I gain more confidence in being a researcher as I progress in my program, I start to doubt if I am as an effective instructor as I thought I was. I start to see myself through my new lens of a researcher, although looking in a mirror at myself. At this point, I'm still thinking more like a quantitative researcher, looking for ways to make generalizations using large data from my classes:

> "I'm also curious to examine many variables with my students such as their major and how many science classes they've already taken. My classes are large (>100 student) lectures where I am the "sage on the stage" ('sage on the screen'?) and only about half of my students enroll in lab, so that will be another variable to delineate, although labs are taught by many different Teaching Associates."

Although I have been reading qualitative research papers and claim to feel more confident reading and understanding them, I am still thinking like a quantitative researcher in terms of research design. As I learn more about how to conduct qualitative research, my understanding will improve, and I will start to design qualitative research.

Fall 2021 Week 6 Reflection

While I wholeheartedly agree that teaching NOS is of paramount importance, I start to wonder at this time if understanding NOS and trusting science are actually correlated:

> "I think science has become very politicized and black/white, with people either blindly trusting or distrusting science. When I ask my students for more information to draw

> connections with their VNOS responses, I will ask them how they personally feel about science and if they trust it. I wonder if there will be a correlation. I actually wouldn't be surprised if the people who "trust" science don't actually understand NOS and if the people who don't trust science accept it's tentativeness but see that as a reason to justify their distrust."

This is something that warrants further study, especially in light of the current pandemic and political unrest, with the two inexplicably linked. For example, someone could align liberally and use their opinion of "trusting science" in their decision to receive a vaccine, making their choice because of politics rather than their own understanding of science. Conversely, someone may fully understand NOS yet reject vaccines ostensibly because of their conservative attitudes and distrust of scientists. This begs the question, is it more important for people to understand science or to trust it? Are the two linked or independent? This real-world application is of critical importance especially considering the very real risk to life the pandemic has posed, and the political reasons driving people's decisions in whether they protect themselves and their community or not.

Fall 2021 Week 7 Reflections

In the final reflection of my first term, my confidence as a budding researcher only grows:

> "Every week I'm reminded that I'm in the right field. I'm both nervous and excited to write my own papers, and I'm grateful I have examples to emulate."

Yet as I gain confidence in research, my confidence in my teaching decreases:

> "This paper, as well as the one a few weeks ago (V. L. Akerson et al., 2000) focused on the benefits of reflective explicit activity-based teaching. I am planning on conducting action research next semester, but I don't know exactly how to categorize my class. I teach around 500 students asynchronously, and I definitely don't interact with most of them, nor do I have them reflect on NOS. It's similar to implicit in that students receive science process skills instruction and science content coursework, but also explicit in that my lectures include history and philosophy of science (V. L. Akerson et al., 2000). I don't have them do specific NOS activities (I hadn't even heard

> of NOS before this class). It's clear from this and previous papers that K-12 students respond better to reflective explicit activity-based teaching, but I wonder if my adult students will react differently. I am kind of torn. The campus where I teach (and attended) is a polytechnic university with the motto "learn by doing," so I'm a firm believer in activity-based teaching. But at the same time, while my class is *not* activity-based, I still think it's an awesome class. I would feel bad if it turned out I've been wasting my time all these years and my students don't learn what science is in my class."

As I learn to see through the lens of researcher, I am learning to be more critical. Since I am researching my own teaching through action research, it is unsurprising that I would be more critical of myself and lose confidence as I examine my shortcomings.

What is my Own Understanding of the Nature of Science (NOS)?

Over multiple meetings, Dr. Beardsley had many positive things to say about my introductory Nature of Science lecture. He liked how I came across as friendly, and used practical terms that students can relate to, especially non-biology majors. He thought that the content I covered was "right on." He didn't have anything negative to say about my lecture, and he thought I did a good job. He agrees that including a lecture on NOS is a great addition that a lot of people don't include.

He did offer some suggestions for how to improve my class even further. He suggested I start with active learning and with examples, which I agree will help students to wrap their head around abstract concepts. He suggested starting off with asking questions and asking, "which can science answer?" And answering, "what makes a scientific question or not?" and "what differentiates science?" He also suggested starting with specifics then generalize, instead of the other way around. Students may have a harder time relating to general principles. He suggested starting topics with a frame of reference and something practical to help students understand. Topics that are theoretical may be difficult for students to apply to real life, so I should add more examples.

We agreed it might be a good idea to add more short videos about NOS throughout my course, not just at the beginning. I could relate them to the content of the particular module. I could also add a checklist with the NOS aspects in the skeletal notes, so students see them repeatedly. When I ask my students to reflect on NOS in their skeletal notes, I could ask them where the aspect was mentioned by asking them to "reconfigure the knowledge" or "write in your own words" how the NOS aspect relates to the lecture content.

He suggested adding examples of how real scientists conducted their science. If I used examples of scientists who were also minorities or underrepresented that could also help my students see themselves as scientists.

He suggested I add that science investigations use a variety of methods. Science uses empirical evidence from data, but for comparison I could also including other ways of knowing, such as through authorities, tradition, or religion.

He thought I did a nice job explaining laws and theories, but that more examples could be helpful, as well as an explanation of models. I covered the tentativeness of science and that it is a human endeavor. I could add more about the role of skepticism and the importance of the role of peer review, as well as repeatability, and teamwork and collaboration.

How Have I Been Teaching the Nature of Science (NOS) in my pre-recorded Biology Lectures?

Dr. Beardsley offered suggestions for my Unit 1 Module 1 Lecture Video "What is Biology?" in which I break it into the submodules 1.1 What makes something alive? 1.2 How do scientists learn? and 1.3 Is it really "just a theory?" We agreed that my explanation of the scientific method was too simplistic and linear. In reality, scientists do not follow the stepwise process as it has been taught, which can give a false view of how science is actually done, which is much more cyclical and complex. I should instead emphasize that the process is not linear. He suggested using an example of a scientific problem and going through the steps, emphasizing that the process could take many cycles and iterations. This could also be an opportunity to demonstrate that different scientists might go about the process differently; that there is no one right way to do science. Throughout my pre-recorded lectures, I address all six of the aspects of NOS I shared with my class in my new NOS lecture video and asked them to reflect on in their skeletal notes assignment. However, since I recorded my lecture videos before knowing about NOS, I do not specifically name each aspect. Although if students are paying attention and fully grasp the aspects, I assume that they may be able to make the connections for their skeletal notes. I also do not teach each aspect equally, but rather focus on certain aspects more than others, and focus on certain aspects in different frequencies for various topics.

Subjectivity

The aspect I coded most frequently is *Subjectivity* (88 times). I code at least once it in every single one of my lectures. I coded it most frequently in the topics of Nutrition/Digestion, Ecology, Botany, and Zoology. Throughout my class, I tell my students that scientists are people with our own judgement. For example, In Module 1: What is biology? I say: “science, it’s not just trial and error, you know, there's judgement, there's intuition…”

In my lecture on botany, Module 13: A green world, I use taxonomy as an example of subjectivity: “I mean, if we want to be more precise we could have like 30 different kingdoms that were more precise, but who wants to learn 30 different kingdoms, you don't. I probably wouldn't want to. So, instead we just clump them altogether as protists… They're the ancestor of modern plants, but they don't quite make the cut as to our definition of what a plant is. Since it didn't make the cut, we throw it in the protists group. There's some other kinds of organisms related to animals, very closely related to animals, but even so they still they didn't make the cut as making, you know, meeting the classification of what we call an animal. So, again, we just throw it in the protists groups. So as you can see here, this is why it's such a diverse group, so it's just kind of everything that wasn't good enough, so poor protists.” It may be more correct to have many more kingdoms, but because of our own subjectivity of what we find important, we classify them in a way that shows our preference for particular kingdoms over others. I mostly often use myself as an example to demonstrate that while I am a scientist, I am still subjective, which is fine. While my lectures mostly provide scientific facts, I freely offer my own opinion and admit to structuring my class to my own and my students’ interests. I frequently use subjective terms like “cool,” “awesome,” “pretty,” and “beautiful” to describe biology.

Empirical

The next most frequent code is *Empirical* (71 times). I usually use it when giving examples of scientific experiments. I code it most frequently in my evolution lecture when I give many examples of the empirical evidence for evolution. For example, I stated "And he observed firsthand how the plants and animals differed from around the world but he also saw some similarities and these observations were like the lightbulb in his head, figure out evolution to be a natural selection…So, on this voyage, the H.M.S. Beagle he saw lots of different species and some of them, you know had never been seen before and they looked very similar to their mainland counterparts. These are some species found on the Island of Galapagos, off the South American coast and you know, they had some similarities to species from the mainland, South America but they're all very, very unique. They're a distinct species only found on Galapagos."

Social/Cultural

I code *Social/Cultural* (55 times) fairly frequently. I coded *Social/Cultural* mostly in the lecture topics of Chemistry, Energy, and Ecology. I have always tried to be socially aware, and attempted to decolonize our way of thinking in school, and shift the perspective from the "norm" of white, cis, male normativity. In doing so, I give examples of how people are placed within culture effects how they perceive and conduct science. In a lecture on climate change, I say "But it's probably not going to be good. And it's not going to be good for most living things on the earth. Maybe if you're a rich American it won't affect you as much, but the rest of the planet sure as hell will be.)

Tentative

The NOS aspect *Tentative* (50 times) I also coded fairly frequently, and also fairly evenly throughout all my lectures. I freely admitted my uncertainty with topics and shared how our understanding changes constantly.

For example, In Module 1: What is biology? I say: "What science means is knowledge and that doesn't mean that, you know, we're know-it-alls; you know some of us maybe can be but that's not really what science is about. Science is about the thirst for knowledge. It's not about having all the answers or thinking that you do. Actually scientists, ironically, are usually the first ones to tell you that they don't know something because that's good science. A scientist doesn't pretend to have all the answers; the entire point of science is to find answers to questions. It's about not knowing and wanting to find out (*Tentative*)." Instead of framing the tentative nature of science as a weakness, I make it inspiring, telling them in Module 4: How do living things obtain energy: “No idea. Nobody knows. Maybe you'll figure it out one day.” I am also careful in how I phrase facts, using statements such as: “They're *most likely* the ancestors of today's plants,” in Module 13: A green world, and “Now there are organic things that aren't alive but all living things are organic, *as far as we know*,” in Module 2: What am I made of?

Theories

Admittedly, I coded *Theories* (18 times) fairly infrequently. I mentioned it in my introductory lecture, but not again until my lecture on evolution. I explain the term theory as such in Unit 1: What is biology: “Now when people say “just a theory” it kind of drives me crazy, and but really the problem is it comes with the definition of what the word theory actually is, and the problem is that the word theory means different things to different people. To scientists a theory, that's something that really-- we really trust; we have a lot of certainty with it; it's been pretty much accepted by the entire scientific community; it's been tested, it's been shown time and time again it's really-- it shows a lot of certainty in unifying explanations, but to the general public it means something totally different. It actually implies like a lack of knowledge or just like a guess. Like, oh you know, in theory it should have worked out but it didn't or, you know, I have this theory that it should work this way but, you know, I don't know if it's really going to work. You know it means something totally different to what scientists think or what the scientific definition of theory is.So the thing is with the theory it's really been tested, it's really been put through the test, put through the test and it's been accepted. It's actually kind of what a hypothesis sort of graduates to. When people say theoretically it should work they're really saying hypothetically it should work; instead of saying I have this theory people should say I have this-- I have a hypothesis.” I also mention the tentativeness of theories in Module 1: “A theory may be disproven, totally could happen,” and also “You know, maybe one day a scientist will create a cell in the laboratory from starting from scratch and then we'll have to make some revisions to the cell theory, but as it stands right now we can't make cells from other-- from-- without having other cells there first. It cannot be done. All cells come from pre-existing cells.”

Imagination

The aspect I coded least frequently was *Imagination* (16 times). I mostly coded *Imagination* in my first two lectures on Science and Chemistry. For example, In Module 1: What is biology? I teach the scientific method: “The first thing is observation; oh that looks funny, (*Empirical*) wonder why it's doing that (*Imagination/ creativity*), something simple. Questioning what would happen if I did this (*Imagination/creativity*)" and similarly "That looks funny (*Empirical*); I wonder why it does that. Then questioning why does it do that; what will happen if I change one variable, what will happen? (*Imagination/creativity*)"

While I didn't include it as an aspect in my introductory video, I also looked in my lectures for *Model* (6 times). I use an example of a model when explaining atoms in Module 2: What am I made of?: "Is that picture to scale? Do you guys remember? No, not even close," polypeptides in Module 2: What am I made o?: "Doesn't have actually have those letters on it, but those beads correspond to the different unique kinds of amino acids," and cells in Module 3: What is the smallest unit of life?: "A general picture of a general eukaryotic cell, it's not an actual particular cell it's just to make it easier to understand."

Discussion

How Do I Identify as a Scientist? Researcher? Teacher?

I definitely feel like I am in the right program and the right field. I think the feeling of belonging in two fields (natural and social sciences) while not ever feeling truly like wholly part of either one is a common sentiment. People are dynamic; we contain multitudes. If the boxes we create are human-made anyways, maybe instead of trying to fit in, we should re-draw the lines. The confidence that I have in my program made me feel like I was in the right place; that my effort was worth it and time well-spent. This made me more confident in myself as a budding researcher and encouraged me to continue my studies and make future goals for my program and beyond. Conversely, the more confident I became as a researcher, the less confident I became as a teacher. I had to adjust to looking at myself through the researcher lens, critically looking for shortcomings. After reading literature focusing on substandard science education being the crux of the problem of scientific illiteracy, I was apt to put the blame of students' ignorance on myself. Although I am far from the only teacher my students have or ever will have, I put the responsibility of teaching NOS to my students squarely on myself, whether I am deserving of it or not.

What is my Own Understanding of the Nature of Science (NOS)?

It was a relief for me to affirm that while I had only recently heard of the term "NOS," I have had a good understanding of it when I started teaching it, and furthermore I can better articulate it now. While I am only beginning to intentionally include NOS aspects into my classes, Dr. Beardsley has been teaching NOS in his class for a long time and offered many examples of ways to include it in a science curriculum. We both agree that we should offer a class specifically on NOS or that NOS should be incorporated into more classes. I was prepared to be challenged in conducting a self-study. I recalled that a self-reflective process can be emotional and painful. As someone who, like I imagine most people, hates criticism, I steeled myself for discomfort before our meetings, preparing to reign in my defensiveness, but I instead experienced constructive and inspiring dialogue. Dr. Beardsley was mostly positive in his feedback, and the suggestions he shared I agreed with and found helpful to improving my class further. I am of the belief that we can always improve ourselves, especially in how we teach, so this may have helped assuage any defensiveness I could have experienced towards constructive criticism. I'm happy to learn new ways to improve my classes. In over a decade of teaching, I improve my classes every time I teach them. I don't feel like I'm taking a bad class and making it good, rather I still feel like I'm taking my great class and making it even better. I always strive for continuous improvement.

How Have I Been Teaching the Nature of Science (NOS) in my pre-recorded Biology Lectures?

Module 1: What is biology?

In the very beginning of my class in my first introductory lecture, I am very anti-qualitative and talk like quantitative research is the only way to do biology and other kinds of natural science research. I basically exclusively talk about experimentation as the only way to conduct research, and state that research without a control group is not science. This reflects my feelings at the time I recorded these lectures in 2014, before I knew there were other ways to do research. I rely on the simplified way of teaching students the linear scientific method, instead of acknowledging that research is cyclical, with many different yet valid ways to conduct it. Since my students are not biology majors, it is evident that my priority be that they be able to recognize "good science" versus "bad science." I don't give much indication that science is subjective, or that research could have both strengths and flaws.

Nevertheless, some studies touted as science genuinely are misleading, and perhaps we need to replace "bad science" with "non-science" or "pseudo-science." Just as life is rarely black and white, good or bad, there are mostly gray areas, but sometimes people are just simply wrong, and I want my students to be critical and learn to recognize that instead of blindly accept what they hear. From my perspective as their teacher, I want my students to be skeptical of non-scientific claims masquerading as science and equip them to recognize it. But if I want my students to recognize science, I need to better help them know what science is and is not. When I teach theory in my class lecture, I don't even mention laws, although I explain theory well. I do offer a simple explanation of Theories and Laws in my NOS lecture, however. As I reviewed my lecture, I made the notes: "After reviewing lecture module one, I'm feeling pretty confident in my teaching. I lecture more recently the same way I did in 2014. I've updated my classes in lots of ways every semester, but my lecturing hasn't really changed much, but it was always good. I didn't mention NOS, like I knew I wouldn't since I hadn't heard of it at the time, but I definitely touched on the aspects, and I noticed a tone of uncertainty, which I believe I will see more of as I continue with this review of my lectures."

Module 2: What am I made of?

I don't have too many instances in which I cover various aspects of NOS in this lecture. The most common aspect I code is *Social/Cultural* when I relate biochemistry to nutrition. I also need to add more learning outcomes.

Module 3: What is the smallest unit of life?

I barely include any NOS examples in this lecture; I am basically marching through facts about cells. However, I first notice in my third module that teaching about the history of scientific discoveries is a good way to teach how empirical evidence leads to inferences. I notice this again in subsequent lectures. I can add more examples of how science is conducted throughout my class. While I could use historical examples, like I do currently, it could be a good idea to share examples of contemporary discoveries. In this way I can show that science is modern, while also showing a greater diversity of scientists whom my students may better relate to.

Module 4: How do living things obtain energy?

I don't have many instances of NOS aspects in this lecture, I mostly tell my students facts. I don't really talk about *how* we know these things (through empirical evidence and inference).

However, I do freely admit uncertainty. I realize in watching this lecture, that I am functioning more of an authority on science rather than a teacher who is trying to develop my students into thinking like scientists. I note: "I don't really tell them how to think like scientists, I think I just want them to trust me. I think people just accept what they're told from who they consider is the authority (science or religion) and just blindly trust them. This backfires when science, which is tentative, backtracks, and breaks their trust. Super important for people to know that science is tentative." Room for improvement notwithstanding, I am pleased with what I saw, writing in my notes: "My lectures are really awesome, I think I do a good job." I do make the subject matter sound interesting, which I always thought was especially important for non-biology majors who are admittedly taking my class only because they have to. I note in this lecture and will see again in subsequent lectures that I teach overtly admitting my subjectivity. I believe that this helps students see me as a person, especially important in an online class where we never meet.

Module 5: Where do cells come from?

This module on mitosis/meiosis/cell division is tied with respiration/circulation in fewest mentions of NOS aspects. I mostly give my students facts for them to know. I only include a couple mentions of subjectivity and tentativeness, which are common in many other lectures.

Module 6: What are the instructions for life?

There are very few aspects of NOS mentioned in this genetics lecture. The most common aspect I code is *empirical*, because I give examples of how heredity was discovered, beginning with Mendel and through the modern day. Using examples of real science research has been the best way for me to show students that science is based on empirical evidence. Another thing I noticed in this lecture and my lecture on the reproductive system is that I am not inclusive to various genders. While this wasn't what I was looking for in this research, it is something noteworthy regardless, and I think I should re-record these particular lectures to be more inclusive.

Module 7: How do organisms produce offspring?

This lecture also did not have too many instances of NOS. I did note that I was "Often subjective for the sake of humor." Another example of me trying to make my class more relatable to students so that they can see it is being taught by a person. While some of the jokes I heard myself make were familiar to me, I noticed instances when I remembered teaching NOS in my in-person class but didn't hear it in my recording. I noted "I wonder if I reigned in the NOS stuff when I recorded my lectures and focused instead on the content which I thought was important for their exams."

When I recorded these lectures, I remember being aware that I wanted to record what was important, and not record any 'filler' information. I think I might have been censoring myself when I would have normally gone on tangents about NOS because I wasn't thinking of it as something part of the curriculum, and I was trying to keep my recorded lecture videos concise. Like the previous genetics lecture, I also note that this reproduction lecture is not trans nor non-binary inclusive. I should record new, inclusive lectures for my students.

Module 8: Why do I breathe and bleed?

This lecture was tied for fewest aspects of NOS that I coded. It is mostly just matter of fact about the respiratory-cardiovascular system. To improve it, I note "I think I would mention the NOS aspects if I explained HOW we know the things I'm teaching them." At this point of my review, I also get the idea to write a book about NOS for my students' required reading, instead of having them use a textbook. In my experience, textbooks are usually filled with facts and can be rather dry. My lectures are already providing my students with facts, although in an interesting and humorous way. Instead of re-recording my lectures to include more aspects of NOS, I could both include short videos that specifically teach NOS and also write an interesting book on NOS for their required text. I could perhaps make it an inexpensive paperback or eBook, and I could write it entertaining enough that they would actually want to read it and it could compliment the lecture.

Module 9: What controls my body

Not too many examples of NOS in this nervous system lecture. Although there are quite a few instances when I mention tentativeness. Not too surprising, since this particular subject is often misunderstood and there is still much we don't understand about the human brain and psyche.

Module 10: What happens to the food I eat?

Like the other organ system lectures, I mainly teach them amazing facts about their body in this nutrition/digestion lecture. I don't actually tell them how we got this information through science however, I just assume authority on the subject and expect them to trust me. This is problematic because even if people blindly listen to certain scientists, they are not thinking for themselves, and furthermore scientists often disagree! So how are people supposed to know who to trust? By understanding NOS they can make their own decisions. At least I freely demonstrate my subjectivity, as I do throughout my entire course.

Module 11: How do organisms interact?

I coded this ecology lecture with the most instances of *social/cultural*, which makes sense since it's about how everything and everyone is connected.

Module 12: Which organisms survive most often and produce more offspring?

Of all my lectures, I coded *Empirical* most often in my Module 12 Lecture on Evolution, where I gave many examples of the evidence for evolution via natural selection. I also coded *Theories* most often in my evolution lecture. My lecture on evolution was full of examples of *empirical* observations, such as the fossil and molecular record. Because my students are non-majors, I somewhat angle my lecture as if I need to convince my students that evolution via natural selection is factual and not a half-baked idea. In contrast, I assume that my students believe what I teach them in my other lectures, so I don't bother providing much if any evidence of how we made the discoveries. But because evolution is controversial to many and students may come to class already skeptical or with incorrect information, I bombard them with the mountain of empirical evidence for evolution. I note:

> "I shared more examples of empirical evidence with evolution because there is skepticism. I don't share as much evidence for other things, because students are more likely to just accept what I tell them for some reason I think, whereas I feel like I need to convince them of evolution because it is inexplicable controversial."

I finally mention theories again in this lecture. This would have been a good opportunity to more specifically demonstrate how theories are based on inferences based on empirical evidence.

In my meeting with Dr. Beardsley he advised contrasting science as a way of knowing with other ways of knowing. I would have thought religion had no place in a science class, but culture and religion absolutely do shape peoples' perceptions, and maybe I shouldn't ignore that. Teaching creationism isn't the same as contrasting science with religion, maybe I should discuss it instead of ignoring it. In future studies, I would like to explore how students' perceptions of evolution change throughout my class.

Module 13: A green world

The final unit is on eukaryotic biodiversity. In this penultimate lecture I cover protists and plants. Taxonomy is a great opportunity to discuss subjectivity because it is humans categorizing living things that don't follow any of our rules. We group things together based on our observations, but there is considerable disagreement (and fights) among scientists in how to classify things, and the process is often changing. I write again that I need to talk more about how we know things, and how we go from empirical evidence to theory.
I expected my lectures to sound more tentative as I recall being in my in-person lecture. I suspect I'm trying to sound more confident in my recording. I noted:

> "I think I talked about NOS stuff more in my in-person classes, but I felt that I was going on a tangent, and even though that's when students paid the most attention, I omitted it from my recorded lectures because I thought I was going off topic and that it was my job to cover the other material. I'm definitely more reserved because I'm on camara, as most people act I would think. I reign in the racy jokes I use when I'm live, not recorded. So, NOS needs to be included as something to specifically cover in the curriculum, not like an optional tangent. It's as important as anything else to cover, maybe the most important."

Module 14: You animal!

My final lecture covers the kingdoms Fungi and Animalia. My lecture is mostly animal facts, which, because most people love animals, I believe is nevertheless entertaining. I have many instances of coding *subjective*, in this lecture, more than any other lecture. Perhaps not surprising since we are animals, after all.

Conclusion

NOS in my Lectures

By examining my lectures, I found much evidence of my teaching NOS. While there is always room for improvement in my teaching, but I am nevertheless doing a great job. I do teach NOS, albeit not particularly overtly because I don't name the aspects specifically, but I do indeed teach them. I can and should supplement my class with more overt NOS instruction and curriculum to help my students make the connections between NOS and the course content. In my lectures I do indirectly mention NOS and I don't say anything to contradict it, but there is room for improvement. I know I spend more time on NOS when I have taught in person more recently than when I recorded in 2014. Since there's nothing actually wrong with my lectures, I think I can easily incorporate some more short videos about NOS into my class, as opposed to re-recording my lectures, which are already great. Maybe I could record a short video on each aspect, with examples included. I remember a big theme of my in-person classes was "question everything," I can have that in a short lecture about tentativeness, for example. I need to include examples of how to conduct science so that students can gain a better understanding of how science works and how to recognize it versus something pretending to be science.

Other ways to add NOS to curriculum

To improve my skeletal notes assignment, I could also incorporate teacher questioning by including specific NOS questions that are relevant to the lectures, so that they can connect NOS aspects to the lecture content. Students could also use their notes to collect their thoughts and ideas for future Discussion Board assignments that I could potentially add to the curriculum. In this way, all the class content and assignments are connected, helping students synthesize what they learn by drawing their own connections.

Other improvements to be made

While I was looking over my lectures looking for instances in which I taught NOS, it also gave me the opportunity to look for other areas for improvement. I will need to re-record my genetics lecture to make it more trans-inclusive. I may not have to re-record my reproductive lecture, because I have more recently recorded lectures for my Human Sexuality class that are inclusive. I think I should be able to share these same lectures in my Life Science class.

Recommendations

Interdisciplinary Collaboration

There has been an increase in interdisciplinary research, teaching, and degrees in higher education (James Jacob, 2015). I am in agreement with other researchers that cognitive scientists and science educators need to work together to improve the education of our students (Carey, 1986). Teachers will continue to have naïve views about NOS if there is no systemic reform in college science education (V. L. Akerson et al., 2000). In my decade of college education at two universities and two community colleges in California, I have not observed NOS as a part of any official student learning outcomes. Instead, the SLOs include topics that must be covered with a focus on knowledge of facts, and sometimes experimental design. In talking with my peers in my doctoral classes, most of whom are K12 teachers, they have often felt too focused on the pressure of covering topics in preparation for standardized test instead of teaching NOS.

I believe that teacher and scholars in the natural sciences, social sciences, and education need to work together to provide the best education possible for our students. We need to break the cycle, or else inadequate NOS education will continue to be taught from professors to teachers to students who become teachers, and the cycle of ignorance will continue. NOS needs to be explicitly taught to everyone, including future teachers who will teach any science to any grade level, and citizens who will make decisions that affect everyone.

My lectures did mention aspects of NOS, although my class could be improved with supplementary videos that specifically address NOS. The NOS introductory lecture is good, and I could record even more going into more detail on each aspect. I could also write a book on NOS for my students to read for their class.

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Chapter 11: Assessing Personal Conceptions of Nature of Science: A Self-Study of Nature of Science Instruction in a College-Level Biology Course

Nicole C. Nelson , Tina N. Stamper

Chapter Highlights

- College instructor's Self-Study of Nature of Science
- Examination of personally held beliefs and understandings of Nature of Science
- Teaching Nature of Science in a college-level biology laboratory
- College student beliefs and understandings of Nature of Science
- Use of a Critical Friend in Self-Study methodology

Introduction

"Raise your hand if you think the theory of endosymbiosis is fascinating." One student eagerly raises his hand, while a couple more reluctantly start to raise theirs. "Cells ate other cells and did not digest them. They kept them around because they were somehow advantageous." A couple students smile and nod, the rest give me blank stares. "You are all biology majors. This is the stuff that should excite you!" This is a real scene from an introductory biology laboratory course that I teach at a small liberal arts college. These are first year students who have lofty majors – "pre-med," "pre-physician assistant," "pre-optometry." Most students view this lab as another box they must check off their course requirement list, and yet, the content and skills they are learning as undergraduate biology majors are essential to solving numerous crises, including climate change, food insecurity, sustainable energy sources, and emerging diseases. The purpose of science education is not only to prepare students for specific careers within the sciences, but also to prepare a citizenry that can evaluate competing claims, make policy decisions based on empirical evidence, and use critical thinking skills to solve complex problems (Council, 1998).

Scientific literacy or science literacy (SL) is often the term used to describe the general content knowledge and skills that a person who is proficient in the sciences holds. The National Science Teacher Association states that "Nature of Science (NOS) is a critical component of scientific literacy that enhances students' understandings of science concepts and enables them to make informed decisions about scientifically-based personal and societal issues" (NSTA, 2022).

While there is not a universally agreed upon definition of NOS, The Next Generation Science Standards list the main concepts of NOS (NGSS, 2013) as:

- Scientific Investigations Use a Variety of Methods
- Scientific Knowledge is Based on Empirical Evidence
- Scientific Knowledge is Open to Revision in Light of New Evidence
- Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena
- Science is a Way of Knowing
- Scientific Knowledge Assumes an Order and Consistency in Natural Systems
- Science is a Human Endeavor
- Science Addresses Questions About the Natural and Material World

Lederman (2007) identifies tenets of NOS which include:

- Tentativeness of Scientific Knowledge
- Observations and Inferences
- Scientific Theories and Laws
- Creativity and Imagination
- Science is Theory-Laden
- Social and Cultural Aspects
- Empirical

Principles of Biology Laboratory is a required course for all first-year undergraduate biology majors at the university where I teach. One of the main objectives of this course is for students to complete an independent research project. The components of the research project consist of

1) Developing a testable hypothesis,
2) Designing an experiment to test the hypothesis,
3) Collecting data,
4) Statistically analyzing the data,
5) Writing a full research report, and
6) Presenting their findings to an audience (their class).

The educational objective of this semester-long assignment is to teach students the basics of how to conduct a scientific study and improve the students' scientific literacy. This is the seventh year I have taught this course, and each year I provide feedback on proposals, methodology, and final reports and presentations. Yet, I often wonder if the SL of the students improves and if my students' conceptions of NOS become more sophisticated through this exercise. As a doctoral student, I am looking at my classroom and students through both the eyes of teacher and a researcher, and I have started to think more deeply about my own level of SL and my own conceptions of NOS.

Abd-El-Khalick and Lederman (2000) conducted a literature review of studies aimed to improve conceptions of NOS in science teachers. The review found that effective teaching of NOS requires teachers "have more than a rudimentary understanding" of NOS. To accomplish this, they recommend that science teachers, particularly prospective teachers, have opportunities to couple science-based activities with reflection on their experiences.

Specifically, teachers need to reflect on the "various dimensions related to teaching about NOS in specific situations." Ultimately, they found that research efforts should pursue the relationship between teacher and student conceptions of NOS. Schwartz et al. (2004) found that individuals who engaged in explicit NOS "active reflection" through sharing and peer discussions showed the most growth in NOS understanding. To provide structure and focus to this self-study, I decided to narrow my focus to three items from the VNOS-C Questionnaire (Lederman et al., 2002). I chose these three items because they were the most relevant to ideas that I needed to grapple with myself as I taught students how to complete and present their Independent Research Projects. I also thought they would be the most useful NOS concepts for the students to discuss and engage with as they thought about their own research projects. The VNOS-C items I selected were:

- VNOS – C1 What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy?)"
- VNOS – C8 Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
- VNOS – C10 Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced. If you believe that science reflects social and cultural values, explain why. If you believe that science is universal, explain why.

Research Questions

1. What are my current understandings of and beliefs about the three VNOS items (listed above)?
2. Will exploring my current understandings and beliefs about NOS (specifically the three VNOS items listed above) improve my teaching of NOS to first-year biology students?
3. What challenges and successes do I have in embedding the three NOS foci in my teaching?

Reflexivity Statement

As a student, I was first drawn to the field of biology because of its exploration of living things and ability to explain so many natural phenomena. It was a way for me to organize my understanding of the world in a meaningful way. There is comfort (and a sense of control/power) in knowing how our bodies work, how ecosystems function, and how all living things are ultimately related.

In my opinion, it is also essential that our citizenry understand science so that they can make empowered decisions for themselves and at the ballot-box. As a white, upper-middle class, Midwestern woman, I have generally positive views of the field of science and how it is beneficial to society. But I understand that this comes from a privileged position and that many people have historically been abused or marginalized by the scientific institution of the West and of the United States.

As an undergraduate, I was also drawn to the field of education because I recognized the inequalities in the educational system. A statistic from the early 2000s that pulled me into education (instead of remaining strictly a biology major) was that only 20% of Black males in the Indianapolis Public School System graduated. This statistic struck me as both tragic and solvable. I realized that I could merge my passion for biology with my interest in social justice through education. This eventually led me on a path towards biology and environmental science higher education. Currently, I find myself teaching a variety of biology and environmental science courses. In all these courses, I am committed to improving my students' understanding of NOS.

Method

This self-study consisted of the introduction of an intervention, a data collection period, and data analysis. The intervention consisted of first answering the three identified VNOS-C questions and then introducing those concepts to my biology students. Data collection occurred through journaling my reflections and conducting meetings with my Critical Friend. After the data was collected, the data analysis was completed using a VNOS-C coding scheme and thematic analysis.

Intervention

A self-study methodology was selected to investigate my own conceptions of NOS and whether they developed and/or changed as I taught first-year biology students to conduct their own independent research study in a college-level biology laboratory course. I specifically focused on three NOS concepts that are outlined in the VNOS-C Questionnaire (C1, C8, C10) (Lederman et al., 2002). While this is the seventh year that I have taught this course, it is the first year that I have taught it with a focus on understanding my own conceptions of NOS and how my own understandings of and beliefs about NOS are impacting my students' learning. To develop a better sense of my conceptions of NOS and how I could better integrate them into the laboratory curriculum, I introduced each of the previously listed VNOS-C questions to my two laboratory classes as group and classroom discussions.

Data Collection

The site of the study was a liberal arts, Catholic university in the Midwest, United States with enrollment of approximately 2,200 students. Currently, I teach 40 first year biology students in both a lecture and laboratory setting. This study focused on the laboratory aspect of the course, specifically the Independent Research Project.

Data collection occurred during a three-week period in late March and early April of the Spring 2022 semester. During this time students were completing their independent research paper and preparing to submit their final papers and final presentation. In addition to teaching, I was engrossed in providing feedback on the first draft of students' Final Independent Research papers. The data I collected was from my personal research journal which consists of reflections of the NOS (focusing on the three areas listed above), the transcripts of reflective conversations with my Critical Friend, and my own reflections after the critical friend meetings.

I used the VNOS-C questions (1, 8, 10) as discussion prompts at the beginning of two weeks laboratory periods for two different sections each week, starting with just table groups and then as a large group discussion. Students were asked to contemplate and discuss C1 and C8 during week one and C10 during week 2. There were approximately 16 students in each section. This occurred in the second half of the semester, so I had already built a relationship and sense of community within the class.

For the personal research journal entries, I started by attempting to articulate my own views to the three selected VNOS-C questions, used those same questions as discussion prompts in my laboratory sections (over the course of two different lab meetings), and then wrote a post-laboratory reflection on how my views were challenged or became more nuanced through the class discussion and a general sense of my class's understanding of the VNOS questions.

My Critical Friend, Tina Stamper, is a Curriculum and Instruction – Science Education doctoral student, and classmate from the Q612 Topical Seminar in Science Education Spring 2022 course. The purpose of the Critical Friend meetings was to help clarify my conceptions of NOS, while also providing feedback on my pedagogical strategies for teaching NOS. I met, via Zoom, with Tina a total of four times, but I did not include the fourth meeting transcript in my data analysis because the purpose of that meeting was to primarily discuss Tina's study and the next steps of the writing process.

Therefore, I included three Critical Friend meeting transcripts in my data analysis. The first meeting occurred on March 17, 2022, prior to the commencement of the study, where we discussed the proposal and initial views on NOS. The second meeting occurred on April 6, 2022, while the study was in progress, and the third meeting occurred on April 22 after the completion of the study.

Data Analysis

The data that I analyzed in this study was my personal research journal and the transcripts from the Zoom meetings with Tina. For data analysis, I used the Eastwood, et al. (2012) VNOS Coding Scheme to assess my own views on NOS. When analyzing my post-laboratory reflections in my personal research journal and the Critical Friend transcripts I used an inductive approach, following the "Phases of Thematic Analysis" outlined by Braun and Clark (2006) to identify recurring words, phrases, or ideas that I identified as codes.

I then narrowed these codes down to a smaller set of categories, where I identified the emergence of patterns. The overarching patterns were then identified as themes. The quality measures used in this study included collaboration with a Critical Friend and the use of Tracy's (2010) criteria for quality qualitative research, which includes: transparency about my data collection process and a reflexivity statement examining my own epistemology and myself in relation to the study site.

Results

The results of this study are split into two sections: 1) Personal Understandings of NOS and 2) Teaching Strategies. The results of Personal Understandings of NOS relied on data found in my personal research journal entries and the Critical Friend meeting transcripts relating specifically to my own understandings of NOS. The results for Teaching Strategies also relied on data found in my personal research journal entries and Critical Friend meeting transcripts but were focused on my teaching of the concepts and my reflections on how students were responding.

Personal Understandings of NOS

My initial understandings of NOS and my final understandings of NOS did not change during the study, but I did come away with a more nuanced understanding of my student's conceptions of NOS and their gaps in understanding. I also recognized that there were gaps in my ability to explain my own conceptions of NOS to students and that by introducing the NOS discussions in class I was able to grapple with and refine my own conceptions. By comparing my answers to the VNOS coding scheme (Eastwood et al., 2012) I established that my views on the nature of science for the following themes: Empirical (C1), Creative (C8), and Social/Cultural (C10) all fell under the "Informed" category. When Tina reviewed my responses, she coded them is C1 - "Transitional,"C8 - "Informed," and C10 - "Informed." The possible coding categories were Informed, Transitional, and Naïve.

Initially when answering VNOS-C1, I described science as:

> Trying to find 'truth,' trying to organize and categorize the world so that it makes more sense, trying to solve problems to make life easier/more enjoyable (personal research journal).

I acknowledged that there was an overlap between these characteristics in other disciplines, such theology, philosophy, and history. Therefore, I clarified my definition of science as:

> The way that science differs, in my understanding, is that it is focused primarily on understanding the natural world and is only capable of studying the natural world…it starts with an observation and then evidence is gathered that will either support or fail to support a claim (personal research journal).

Because I teach at a Catholic institution, I went on to discuss the differences between religion and science – being that science is limited to the realm of studying natural phenomena, while religion and perhaps other disciplines can study what some people perceive to be supernatural phenomena. This is a topic I explored more with Tina. Tina teaches college level science at a Christian institution, so she was experiencing a similar tension as me with students who felt science was in opposition to their religious beliefs. We both agreed that:

> Perhaps, reflecting on our own conceptions of NOS and defensiveness about teaching science would improve our interactions with students who struggle with this perceived conflict in beliefs (3/17/22 Critical Friend notes).

When answering VNOS-C8, I reflected that "it takes an incredibly creative mind to even think of research questions and then design experiments to test their questions" and I remarked that "this is something that I would like my students to better understand and appreciate" (personal research journal). I anticipated that my students may not have an appreciation of the creativity and imagination that is essential within all aspects of the scientific process and was eager discuss the creative nature of science, and specifically related to the creative work they were currently engaged in with their own Independent Research Projects.

VNOS – C10 addresses the social/cultural embeddedness of science. When attempting to articulate my answer to VNOS – C10, I wrote in my personal research journal:

> I believe ideally science would be universal, but the reality is that the field of science was created by humans to study the natural world, and therefore is fraught with the imperfections of human endeavors. So, yes, I believe that science reflects social and cultural values. We, as humans of our own time and cultures, see the world through a certain paradigm. Then, we ask questions and study things that already fit within that paradigm. That is why diversity of thought (through different genders, cultures, backgrounds) of scientists is so important.

Teaching Strategies

I used the VNOS-C questions (1, 8, 10) as discussion prompts at the beginning of laboratory classes over the course of two different weeks with two different classes. After the laboratory period I journaled my reflections and impressions of the students' views on NOS and my own teaching practices. Using the "Phases of Thematic Analysis" outlined by Braun and Clark (2006) I analyzed the post-laboratory entries in my personal research journal and the transcripts from my Critical Friend meetings, I was able to identify codes, categories, and themes (see Table 1). The three dominate themes that I identified were: 1) Generally, students hold naïve or transitional views of NOS; 2) My personal changes and improvements in teaching NOS; and 3) NOS needs to be taught explicitly in college-level science courses.

Table 1. Codes, Categories, and Themes

Initial Codes	Categories	Themes
• Scientific Method • Linear • Concrete • Stepwise • Content • Doing science backwards • Bunch of facts • Hostility towards academia • Outside the realm of science • Opposition to religious beliefs • Creative thinking • Imagination • Troubleshooting • Novel ideas • Cultural Beliefs	• Impressions of student views of NOS • Science and religious views • Empirical NOS • Creative NOS • Social/Cultural NOS • Students' comfort level with NOS discussion • My impressions of teaching NOS	• Generally, students hold naïve or transitional views of NOS. • My personal changes and improvements in teaching NOS • NOS needs to be explicitly taught in college-level science courses.

Initial Codes	Categories	Themes
• Science as Authority • New information • New concepts • Fun for me • Planting a seed (idea) • Scientific literacy • Enjoyed (students) • Interesting • Explicitly discussed • Discussion groups • Ongoing conversation		

The first theme, *Generally, students hold naïve or transitional views of NOS*, was supported multiple times in my personal research journal entries and Critical Friend conversations with Tina. After the laboratory where I asked students to discuss VNOS-C1, I wrote:

> In general, they seem to think [science] is more concrete and stepwise. I'm trying to challenge them to think more deeply, as I think the more middle school-esque perception of the scientific method is still embedded in their idea of what science is. I gave an example of the age of the earth. That a young earth creation theorist believes that the earth is 10,000 (?) years old and looks for evidence to support that age. Whereas, in my conception of science, a scientist wouldn't have an age in mind to begin with but would gather evidence and make inferences of the age of the earth based on that data. With this method, the researcher shouldn't be invested in a certain age of the earth at the beginning of the study. Of course, everyone has their preconceived ideas that may bias their interpretation of the data/ evidence.

In my Critical Friend meeting with Tina, I also explained to her that my impression of the students was that they held an understanding of the scientific method that was "very concrete" and "very linear."

Prior to the discussion of VNOS-C8 I had recognized in my journal that creativity in science could be a new idea for students:

> I don't think I have very explicitly stated that science is full of creating thinking and scientists have to be creative and use their imagination to try to predict outcomes, devise experiments, and (most challenging for me) come up with questions to test.

Because of this, I planned time into the lesson to challenge students to think more critically about the creative nature of science and use their imagination and creativity to collaborate with their lab groups and share feedback on their independent research projects. When we discussed VNOS-C8 the feedback that students initially gave was that science was not a creative process. I wrote in my journal:

> At first, students didn't seem to think that scientists use their creativity, but I pushed a little more and most agreed that they all had to be creative and use their imagination to think of a research topic and design and experiment to test their hypothesis. I think I could do a better job of talking about science as being creative and imaginative throughout the year.

The following week, after a class discussion focused on VNOS-C10, I stated in my journal that students held a "less sophisticated" understanding of the cultural/social aspects of science than I anticipated and a "science as authority view of scientific work." The gap between my understanding of NOS concepts and my first-year college students' concepts were larger than I had anticipated. I discussed this discovery with Tina, stating, "it doesn't seem like [NOS] is a concept that's really threaded throughout their education, K12."

The second theme, *My personal changes, and improvements in teaching NOS,* was established because it directly addressed one of the initial research questions (Will exploring my current understandings and beliefs about NOS improve my teaching of NOS to first-year biology students?), so it became a theme that I circled back to several times in my journaling and Critical Friend conversations with Tina. During a Critical Friend meeting I stated regarding teaching NOS at the college-level, "I'm wondering, would it be worthwhile to kind of do a NOS topic? Just like for 15 minutes… [as] a discussion question at the beginning of every lab?" In my journal I stated:

> I have never spent this much time delving specifically into NOS with a class because I am always so focused on the content that they need to learn, and it has made me think more critically about my own practice and the purpose of higher-level science courses/labs.

One of the topics that I realized I needed to be more transparent about when teaching science content, which relates directly to NOS, is how scientific knowledge changes over time. While reflecting on my teaching of phylogenies and how to better incorporate NOS themes I wrote:

> I will often say, "some scientists still categorize animals by the more traditional classification scheme, but others rely more on the genetic evidence" (i.e. nematoda being in different clades depending on what textbook you are using). I think this would be a good opportunity to think more about how to bring those conversations into the class and use it as an example of NOS. When we first started talking about invertebrates, we did watch a short video about whether sponges or comb-jellies were the ancestors of all other animals. Students then did a group discussion and decided whether they were "team sponge" or "team comb-jelly" and had to give an explanation to support their position. I think this helped them to see that not everything in biology has been worked out and neatly answered. There is a lot of room for more questions and research and there can be debate among scientists even when they are looking at the same data.

The acknowledgement that NOS concepts were new for my students, paired with my desire to embed more NOS into my curriculum brought me to the third theme: *NOS needs to be explicitly taught in college-level science courses*. This was evident in both my journal and my conversations with Tina. At the end of my data collection period, I wrote in my journal:

> Reflecting back on the past two weeks, my biggest revelation is how many assumptions I've made as a science teacher about my students' understanding of NOS. After intentionally embedding some of the VNOS ideas into my labs and allowing the students to discuss and share their ideas it became very apparent that these were new concepts for them - it did not seem as though these were concepts they had grappled with or had been explicitly taught before. Some seemed eager to participate in the thinking and discussions, others seemed uncomfortable going outside the bounds of "these are the facts you need to know, and this is the lab you need to complete today"

mentality… I want to be intentional about incorporating these ideas in my lectures in the future.

During a Critical Friend meeting with Tina I lamented, "I think that we just assume that students are picking up these ideas, but they're not." Tina agreed, sharing that she had had similar experiences with her college-level students. We agreed that in addition NOS being explicitly incorporated into the curriculum, it had to be "an ongoing conversation" with students throughout their academic careers.

Discussion and Implications

This study began as a doctoral class project focused on the NOS. In a literature review on the topic of improving teachers' conceptions of NOS Abd-El-Khalick and Lederman (2000) found that research efforts should pursue the relationship between teacher and student conceptions of NOS. I used that finding as a launching point to conduct a self-study where I examined my conceptions of a selection of VNOS, explicitly introduced those topics within my college-level biology laboratory sections and reflected on both my evolving understandings of NOS and my teaching strategies. I was also able to generally gauge my students' conceptions of NOS.

NOS has been a topic that I have been interested in ever since I took History and Philosophy of Science as an undergraduate student, reading *The Mismeasure of Man* by Stephen Jay Gould. It was there that I began to develop my own conceptions of science being a human endeavor and influenced by social and cultural norms. Throughout my teaching career, my continuing education, and again with this self-study I have had several opportunities throughout different stages of my life to further examine my conceptions of NOS. Taking the time to grapple with NOS concepts is an essential step for an educator to take before integrating NOS topics within college science course curricula. While my overall conceptions did not change through this study, my understandings were deepened.

Additionally, my ability to teach and confidence in teaching NOS explicitly was enhanced. It also helped me develop some pre-planned examples and ways to better communicate and illustrate the VNOS concepts that I focused on this this study. For example, regarding the social/cultural dimension of NOS I discussed with the students how for much of medical history women's bodies were not studied, explaining, "women's bodies were just seen as a defective male body because women's physiology and anatomy wasn't even being studied." I went on to discuss how this relates to the importance of a diversity of viewpoints and backgrounds of scientists. This was an example that I came up with on the spot in class when students couldn't think of examples for the discussion. In the future, I would like to have several of these types of examples ready and more polished.

Furthermore, there was one VNOS-C question that Tina and I differed on when coding my responses, which was C1, related to the empirical NOS. When I went back to my journal entry, I could see that although I felt my answer and ideas most aligned with the "Informed" category, it was not clear to Tina that I was explaining my conceptions of science in an "informed" manner. Having the outside perspective from Tina made me reflect more critically on how I am communicating "What is science?" to my students. Even as someone who has an undergraduate and graduate degree in scientific fields and 15 years of experience working in science education, I still had trouble succinctly answering this question on the VNOS-C questionnaire.

As I began incorporating the VNOS discussion prompts into my laboratory sections I realized that I was enjoying these discussions with the class and hearing their thoughts. It was fun! I was pushing the students to think outside of the content and think about what science really is and how knowledge is created. One challenge that I recognized was that I had sprung this on them in the middle of the semester. It was outside the flow of our normal laboratory routine, and I noticed that some students were uncomfortable, or maybe even annoyed, that I was asking them to form discussion groups to tackle these VNOS questions. I would advise other teachers that discussion groups and sharing as a class takes practice and to build it into the classroom routine from day one.

In the future, I will start this at the beginning of the semester with some less philosophical questions and build towards the tougher concepts. Tina and I had a whole conversation about the need to build trust in a learning community before tackling some of these VNOS topics, particularly when it comes to more controversial topics such as evolution. Tina's advice from her classroom experience for building trust was to start with questions and topics that were non-threatening, then slowly work towards the more controversial topics.

I was able to tie NOS directly to the work that students were doing on their independent research projects, which was an authentic connection that I believe benefitted their final projects and reports. For example, after talking about the creativity/imagination aspect of NOS we discussed the creativity it takes to develop an experiment – from the development of a research question all the way through the interpretation of the data. I was able to draw on this language of creative-thinking, troubleshooting, imagination when students were asked to provide feedback on their peer's projects and experimental designs. I also felt a surge of pride when at the end of the semester my students attended a research symposium for the upper-classmen and wrote reflections of the projects they learned about. I exclaimed to Tina:

> I noticed in their reflections that a bunch of them used the word "creative" when describing the research projects that they either saw the poster of or listened to the presentation. So, I thought, that was like, oh, it did something. It triggered something because we just had that conversation!

Overall, I felt that conducting a self-study by examining my own conceptions of NOS and explicitly teaching NOS in the classroom was beneficial to both myself and my students. The reflective nature of the self-study pushed me to identify my own views of the nature of science, incorporate them into my lesson planning, and then reflect on how my conceptions were changed or broadened, my students' conceptions, and the effectiveness of my teaching strategy. This form of "active reflection" was also found to be successful in deepening understanding of NOS in the Schwartz et al. (2004) study. While this self-study was conducted in a college-level classroom, I believe that it could be effective at all levels of science education and with science educators with various levels of teaching experience.

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Commentary: Self-Studies on Becoming a Teacher of Nature of Science

Our definition of self-study aligns with that of Loughran (2010) where at one level, the personal nature of self-study is important to teacher educators as a way of gathering evidence about the nature of their practice and how it influences the learning of their students of teaching. At another level, self-study must also speak beyond the individual and offer ideas, opportunities, innovation and critique if it is to lead to the creation of new knowledge – a defining feature of scholarship in the academy. All authors in this section acknowledge the importance of teaching NOS as part of science teaching and teaching it explicitly. This theme was with the elementary group, high school group, and both college science groups. The idea of "positionality" came up in three of the studies, and these were the studies with in-person teaching. It is less likely to focus on positionality in an online class due to the asynchronous nature of the course. All teachers felt a disconnect with their teaching, online teacher as well. Each instructor improved their NOS instruction and could make suggestions for future NOS instruction. All instructors noted the importance of the critical friend in helping them make changes and also confront dissonance in their teaching.

From the rural setting we found that positionality is a key to instruction as in rural areas there tend to be generations of populations living locally, and outsiders can be seen as not part of the group, and less likely to be believed. From Mary's high school chemistry classroom we learned that just knowing about NOS was not sufficient to teach about NOS, one also needs to know how to translate that knowledge to students. Mary also felt positionality being important as she sought to change her instruction to include NOS. She was concurrently conducting an action research study on what her students would learn from her instruction, and so did not want students' participation or lack thereof to become influential on her self-study. She felt initial tensions between researcher and teacher identity, but that settled in a few weeks. Stephanie included NOS within her existing curricula and acknowledged that she had not previously learned about NOS despite having two degrees in science fields, and ten years of teaching experience at the college level.

In all cases, teachers perceived a disconnect in their teaching, which then prompted improved teaching. In the case of the rural fourth grade setting, K.D. was surprised at the cooperating teacher's suggestion to "reach the students at their levels" when she believed she was doing so. Though K.D. had ample life experiences and background in science, she struggled with "imposter syndrome" where she lacked confidence in the fourth-grade classroom and felt she did not know what to do. The critical friend played a role in helping her overcome the inner voices of doubt. While Mary was a veteran teacher of chemistry, this was her first foray into incorporating NOS into her lessons. Mary struggled with the social and cultural aspect of NOS, as she wanted to avoid highlighting science as political, and also held an identity of impartial and objective scientist. Stephanie found that reflective practice was particularly important in teaching about NOS, and thought about the correlation with trusting science, and understanding NOS, which could lessen the politicization of science. Nicole experienced a more nuanced understanding of her students' conceptions of NOS, and recognized gaps in her ability to explain NOS conceptions to students.

In all cases, the teachers improved their teaching. K.D. learned to slow down the pace of her lesson, and to include more reflection for learning about NOS. Mary identified importance of teaching NOS, and made suggestions for teaching observation and inference despite it not being explicit in Appendix H of the Next Generation Science Standards. Stephanie created a new NOS lesson video for her online courses, to emphasize the importance of NOS to her students. Nicole thought about including a NOS discussion with every lesson to reinforce the ideas about NOS within her science teaching.

In all cases the role of critical friend was important, as K.D. mentioned it caused her to think more deeply, and also to consider her ideas from another perspective. Mary found that the critical friend mentioned that the critical friend asked questions to engage her thinking about social and cultural NOS, as well as the "buy in" of teaching NOS—that through the study itself it became clearer that NOS was important, and students were learning. Stephanie's critical friend provided feedback to improve a particular lecture video to embrace NOS, rather than portray science as more of a linear explanation of the scientific method. Nicole discussed how her critical friend helped her make clearer to her students differences between science and religion. It is obvious that self-study methodology can be an important tool to help instructors incorporate NOS into their science lessons.

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Conclusion

The set of chapters in this volume highlight how self-study and action research methodologies can be used to improve teaching, as well as improve learning, of NOS. The self-study methodology aided the teachers in systematic exploration of their own NOS instruction in ways to improve their own practice. The action research methodology highlighted ways that improved students' understandings of NOS across grade levels and contexts. Students' understandings about NOS improved so they were closer in line with recommendations in NGSS (NGSS Lead States, 2013) as well as the NSTA NOS position statement (NSTA, 2020).

While all teachers who conducted action research studies used the Views of Nature of Science instrument that was appropriate for their grade level. In addition, due to their prior experience in teaching they were able to design and use their own assessment tools to help them determine what their students learned about NOS from their instruction. While some teachers focused on all NOS aspects, several focused on a subset of NOS aspects. While it may be viewed that NOS should be taught wholistically, in reality many experienced teachers begin with a focus on certain aspects of NOS and add to those while continuing to emphasize previously taught ideas about NOS. This practice has been shown as a way for teachers to begin teaching about NOS and for students to learn about NOS (Akerson, Carter, Pongsanon, & Nargund-Joshi, 2019).

While most of the authors of the chapters in this book are new researchers, all are also experienced teachers. It is apparent that the action research and self-study methodology proved to be good starting points for teachers to conduct research, and to develop identities not only as teachers, but also as researchers (e.g. Akerson, Pongsanon, Nargund, & Weiland, 2014). The teachers who wrote these chapters are committed to improving their practice, and a focus on their own classrooms and their own instruction in ways that they were systematically exploring their practices and influences on student learning. Therefore, the focus on their teaching and their students' learning also primed them to develop their researcher identities, and strategies for conducting classroom focused research. The authors in this volume are certainly teacher-researchers, and also teaching NOS explicitly in their science courses, as was found to be effective practice in previous NOS research (e.g. Bugingo, 2022).

From the research in these chapters, it is clear that self-study and action research are powerful methodologies for improving teaching of NOS from Kindergarten through college, and in various modalities such as in-person and online. The explicit reflective instruction used by the teachers improved student learning of NOS, and we can see that students as young as kindergarten can develop improved understandings about NOS given appropriate instruction. Several authors suggested that NOS be embedded across grade levels and science courses, and to be embedded into labs that are attached to the courses, to further emphasize NOS as being part of all science and the development of scientific knowledge.

Future research should continue to use self-study and action research methodology to explore how teachers can improve their NOS teaching and their students' learning, no matter the context or setting in which teachers find themselves. If science is being taught, NOS should be included. Self-study and action research can be used to explore various ways to use explicit reflective instruction to improve student NOS learning across grade level and contexts.

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We have structured the book into two sections: Action Research and Self-Studies. Within the Action Research section there are two subsections: In person and Online teaching. In the action research section, teachers describe how they embedded NOS into their instruction and examine students' conceptions of NOS as a result of that instruction. The Action Research Studies on In-Person Nature of Science Teaching and Learning section contains four chapters. The first chapter is a study of integrating NOS (in particular, observation and inference) into kindergarten curriculum by using fairy tales and a mock crime scene. The second chapter in this section describes a study that explores high school chemistry students' conceptions of NOS embedded in a unit on The Gas Laws and Kinetic Molecular Theory that is grounded in the NGSS. The third chapter examines how NOS can be highlighted in a unit about evolution, focusing on Darwin's life and work. The fourth and final chapter in this section examined the NOS views of students at a Christian high school. The second section in this book, which contains three chapters, focuses on Action Research Studies on Online Nature of Science Teaching and Learning The first chapter explored the results of embedded NOS into a unit of fingerprinting within a fully asynchronous online college-level forensic science course. The second and third chapters both examined NOS within fully asynchronous online college-level life science courses. The self-study section contains four chapters, with the first being in a fourth-grade classroom as a former high school science teacher strives to remind herself how to teach elementary science as well as embed NOS into her teaching. In the second chapter a high school chemistry teacher shares how she used Appendix H from NGSS as exemplars to teach her chemistry students about NOS. The third chapter highlights how an online college biology instructor incorporated NOS into her courses, and the struggles and resolutions she encountered. In the fourth chapter, an in-person college biology instructor shared her endeavors in incorporating NOS into her instruction, and how she made changes and improved her teaching about NOS. We hope you enjoy this book as much as we have enjoyed conducting the research and putting it together. We hope it adds to the field, and we hope it will prompt others to explore teaching NOS in various contexts and sharing their outcomes as well.

Enjoy the book!

TEACHING NATURE OF SCIENCE

ACROSS CONTEXTS AND GRADE LEVELS: EXPLORATIONS THROUGH ACTION RESEARCH AND SELF STUDY

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