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INTRODUCTION

Exploring Social and Cultural Contexts of the Nature of Science through Action Research

Ingrid S. Carter , **Valarie L. Akerson** , **Gayle A. Buck** 

This book elucidates explorations of the Nature of Science (NOS) within classroom contexts through action research. The *Framework for K-12 Science Education* defines NOS as

...knowledge of the constructs and values that are intrinsic to science. Students need to understand what is meant, for example, by an observation, a hypothesis, an inference, a model, a theory, or a claim, and be able to distinguish among them (NRC, 2012, p. 79).

In the United States, this framework provided the theory and context to develop the Next Generation Science Standards (NGSS). Many states have either adopted the NGSS outright or developed state standards based on them. Akerson (2022) notes that NOS comprises key tenets that can be taught explicitly through science content.

The seminal works of Norman Lederman, most notably Lederman (1992), have defined these tenets. The NGSS includes these tenets using language that slightly differs from Lederman's original work. However, Akerson (2022) notes that these tenets are most prominently featured in two of the three dimensions of the national standards: the Science and Engineering Practices (SEPs) and the Crosscutting Concepts (CCCs).

Simply put, the SEPs describe scientists' behaviors as they explore phenomena. The tenets of NOS also describe these behaviors, emphasizing that the development of scientific knowledge is robust and dynamic. As Akerson (2022) outlines, the following tenets of NOS

correlate with the SEPs: a) science uses a variety of methods; b) scientific knowledge is developed by collecting empirical data, scientific data leads to the development of theories and laws; c) scientific knowledge is robust and can be revised based on new knowledge; and d) collecting scientific data includes making observations and inferences. The CCCs within the NGSS also correlate to NOS (Akerson, 2022). These include a) science is a way of knowing; b) science as a way of knowing includes a set of procedures and norms that differ from other ways of knowing (such as art, religion, and philosophy); c) scientists search for patterns in the natural world; and d) science is a human endeavor that is influenced by context and prior knowledge.

This book focuses on one of the tenets of NOS that needs further exploration in current teaching practice: the social and cultural aspects of NOS. This tenet recognizes that science is a human endeavor and is thus inevitably influenced by social and cultural contexts. While scientists employ procedures to validate the applicability of their work to others and engage in robust investigations, they cannot fully remove their context from their work. This correlates to the CCCs, as “a careful analysis of the crosscutting concepts included in the *Framework* shows that they are more than organizational schemas that interrelate knowledge from different scientific fields. They also encapsulate overarching ways of thinking that we should help our students to develop” (Talanquer, 2019, p.18). The CCCs capture the complexity of the nature of scientific knowledge and recognize the rich contextual factors that impact the science practices. This book includes exploration of some of these contexts through educators’ action research in their career setting.

Action Research

Action research is defined as “a disciplined process of inquiry conducted by and for those taking the action. The primary reason for engaging in action research is to assist the ‘actor’ in improving and/or refining his or her actions” (Sagor, 2000, p. 3). Action research is a powerful methodology that is often employed in educational research as it includes “building the reflective practitioner, making progress on schoolwide priorities, and building professional cultures” (Sagor, 2000, p. 7). Action research is centered on an educational issue and is intended to open possibilities or find solutions to problems of practice.

Indeed, action research can be conducted by classroom teachers on their teaching practice wherein the researcher can be an active participant in seeking solutions to problems of practice (Clark et al., 2020). Clark et al. (2020) note that action research is a constructivist process that allows educators to develop first-hand knowledge of an issue in their classroom. Designing an action research project includes planning, observing, reflecting, and acting. This interactive cycle continues with observing, reflecting, and acting, involving informed decision-making and change.

Exploring the Social and Cultural Aspects of NOS through Action Research

The authors in this book are educators who have explored embedding NOS into their teaching practice. They engaged in action research to address the need for more focus on science as a way of knowing within their science teaching context. The authors explicitly or implicitly focused on NOS's social and cultural aspects to engage in deep exploration of this critical tenet of NOS. The contexts in which they engaged varied, and lessons can be learned from each. True to the essence of action research, each author focused on making changes to their practice. The chapters of this book are organized into three sections: Social and Cultural Aspects of NOS, Social and Cultural Aspects as One of Several Targeted Aspects of NOS, and Social and Cultural Aspects as Part of General NOS Instruction. An overview of each section is provided below.

Section 1: Social and Cultural Aspects of NOS

The first section features studies from teacher-researchers teaching NOS's social and cultural aspects. These investigators sought to better understand teaching various topics such as biomedical research, optometry, climate engineering, and endangered species. In addition, one teacher-researcher investigated the inherent complexities of preparing other teachers to teach about this aspect of NOS.

In the first chapter of this section, Gayle Buck and colleagues point out that teaching science topics heavily influenced by social and cultural aspects can be inherently complicated. One complication they encountered was the emotional aspects of learning about diseases. Their study explores efforts to prepare in-service teachers to address student emotions within biomedical science, specifically cancer. These educators teamed up with one of the teachers

leaving their workshop to utilize the strategies with her sixth-grade students. Their efforts focused on understanding the impact of their workshop. Similarly, Arya Karumanthra worked with in-service teachers to improve her professional development workshop. However, her team's work focused on the workshop's initial design, which was initiated before conducting the full workshop. Their efforts focused on using socio-scientific models in the engineering design process to teach the contentious topic impacting their state. That topic was geoenvironment, specifically Carbon Capture and Storage. Georgia Watson also studied actions associated with teacher professional development. However, instead of focusing on efforts to teach about the social and cultural aspects of a specific science topic, she explored using culturally relevant pedagogy to help in-service teachers themselves understand the social and cultural aspects of NOS.

Teaching about NOS's social and cultural aspects is also essential at the university level. In Chapter 4, Nitya Murthy and Valarie Akerson note that the social and cultural aspects of NOS are seen throughout the field of optometry. Their action research study contributes to a professional gap in understanding how NOS aspects can be integrated into the optometric clinical curriculum in a manner that improves the students' motivation and understanding of how clinical concepts relate to one another. Also working with university students, Nivedha Sundar and her colleagues explored their teaching efforts to promote undergraduate students' understanding of the social and cultural embeddedness inherent in understanding endangered species. Unlike the previous studies, however, these authors engaged in a type of action research that focuses on themselves as instructors of these students instead of the action itself. These authors understood the importance of teaching NOS's social and cultural aspects. However, their academic background did not include learning opportunities in this way. With their study, they sought to better understand their preparedness to teach this aspect and use that knowledge to improve their practice.

Section 2: Social and Cultural Aspects as One of Several Targeted Aspects of NOS

The chapters in the second section show that social and cultural NOS instruction can be incorporated across content levels and other NOS aspects. Other strategies can be used, such as AI, and consideration of scientific literacy. These efforts can be successful for students through college, and for practicing teachers.

In Chapter 6, Dan McCarthy explores teaching the cultural and social aspects of the nature of scientific knowledge along with the distinction between theories and laws. He chose this focus as this is part of what he would need to teach as part of a genetics unit. He combined instruction on Mendel's life history, along with a focus on the science content and NOS concepts to improve his students' understanding. In Chapter 7, Deborah Nowakowski used the physical science content of atomic bonding to help students conceptualize the social and cultural nature of NOS, along with the distinction between observation and inference, the importance of empirical evidence, and how scientific claims can be tentative but reliable. She also engaged her students in focusing on the importance of data analysis as part of making scientific data meaningful.

Caitlynn Richardson explored AI to facilitate explicit-reflective NOS instruction to connect to real-world science applications. In addition to the social and cultural nature of scientific knowledge, she emphasized the tentative yet reliable nature of science, as well as the creative nature of science. Victoria Tabibi incorporated the nature of scientific knowledge not only to emphasize to her students that knowledge but to help them improve their physics content knowledge. She incorporated culturally relevant instruction to aid in students gaining an understanding of all target objectives. In a setting that worked with practicing science teachers, Le Dolino and colleagues focused on multiple components of NOS as part of scientific literacy. The study took place in a science - technology- society course and showed that language use can be very important in teaching, and context does contribute to learning.

Section 3: Social and Cultural Aspects as One Part of General NOS Instruction

The third and final section includes action research studies that explore social and cultural aspects of NOS as a part of general NOS instruction. The researchers focused on all tenets of NOS within their instruction, of which social and cultural aspects were just one area of various emphases. Brooke Stewart examined the use of a maker project to embed NOS instruction into her teaching of a biology lab. Furthermore, she explored how a maker education project could include more accessible teaching practices for differently-abled students. Using multiple data sources, she found that maker projects provide opportunities for students to adapt their instruction for more inclusive practices, but that NOS could be emphasized more deeply.

In another creative approach, Corey Zickel examined the use of puzzles, riddles, and brain teasers to support his ninth graders' understanding of NOS tenets in a physical science course. He used the VNOS D+ to measure the effects of explicit and reflective NOS instruction through puzzles to increase engagement and interest. Taking a unique perspective, Ricardo Guimarães examined social and cultural aspects of business, namely, foreign exchange rate forecasting within international trading patterns. Using the NOS framework, he administered and analyzed exam questions before and after the intervention, the VNOS-C, and his own teaching notes to explore students' conceptions.

In a more common approach, Daniel Evans explored explicit and reflective NOS instruction within his high school chemistry course. Evans examined students' confidence and understanding of both chemistry content and NOS through inquiry-based learning. He did so through analysis of unit assessments and the V-NOS. David Gardner explored historically underserved (which he terms "at-risk") high school students' perceptions of NOS. He administered the VNOS-B before and after his instruction. He noted that results may improve if NOS instruction was more explicit and if students had multiple opportunities to grapple with NOS within the instructional context. In this section, the authors grappled with the level at which they emphasized NOS within their science instruction and whether more explicit, reflective instruction is needed.

A Path Forward

The chapters in this book explore various ways to embed the social and cultural context of NOS into science instruction. They build on other works that explore NOS instruction across contexts through action research (Akerson & Carter, 2022; Namakula & Akerson, 2024). We hope that works within this book offer ideas to shape your practice. Some tenets of NOS are more concrete, such as that scientific knowledge is developed by collecting empirical data.

Focusing on the empirical nature of science may be conducive to a variety of contexts and concepts within science because of the concrete nature of collecting data. Other NOS tenets connecting to the CCCs are more complex and abstract, presumably because they cross disciplines and focus on a dimension of science with which educators may be less familiar. The science content, or what the NGSS call Disciplinary Core Ideas, and inquiry/process skills, or Science and Engineering Practices, have had a place in science education discourse

for many years. The CCCs offer a level of depth to science teaching and learning, offering a new dimension to the work of scientists. Researchers have found that CCCs can be challenging for teachers (e.g., see Arias, 2024), thus action research is logical approach to systematic investigation of classroom approaches to this work.

Collectively, the chapters demonstrate the complexity of teaching the social and cultural aspects of NOS and they suggest that powerful contexts, such as environmental issues and biomedical research, provide rich settings in which to explicitly and reflectively teach this tenet. Furthermore, they recognize the multifaceted essence of the social and cultural context of NOS and the importance of teaching those facets, such as the emotional spaces of science content, to support students' full understanding of and engagement in complex issues. The chapters in this book explored various creative contexts to NOS to allow students to explore NOS in different ways (puzzles, makers spaces, etc.). While these contexts can be interesting and engaging, explicit instruction is a critical aspect of developing deep NOS understanding. Social and cultural aspects of NOS are rich and complex, and while creative contexts can allow for unique ways of developing understanding, the robust research base indicating best practices for teaching NOS (Akerson et al., 2014) must still be applied and emphasized.

While the chapters in this book demonstrate a multiple of ways to approach the social and cultural context of NOS, further questions arise. For example, should NOS tenets be taught individually rather than collectively, especially in the social and cultural context of NOS? What characteristics of the context most support rich exploration and understanding of the social and cultural aspects of NOS?

Further research can explore action research approaches to teaching social and cultural aspects of NOS through general NOS instruction, as the chapters in this section noted that deeper focus was needed. These approaches could emphasize explicit instruction and continue to offer students opportunities to reflect and explore NOS in multiple ways. We wonder if embedding NOS into science teaching, and perhaps focusing on the more complex dimensions of science more explicitly, reflectively, and individually, would allow for deeper understanding and more realistic planning and instruction., or, as the studies in section 1 indicated a rich context and clear focus on social and cultural aspects of NOS are necessary for meaningful engagement.

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SECTION I

Chapter 1 - Preparing Teachers to Address Student Emotions within the Social and Cultural Aspects of Biomedical Science

Gayle A. Buck , Tajinder Saroya , Adam Scribner , Kelley Wright

Chapter Highlights

- The connection between science's social and cultural aspects and student emotions is explored.
- A call is made to understand how to support teachers in addressing such emotions in the science classroom.
- Strategies for preparing teachers to address student emotions while teaching about cancer are discussed.
- Some nuances of addressing student emotions while teaching about cancer are discussed.
- An empirically based professional development program is provided to prepare teachers to teach about cancer at the upper elementary and middle levels.

Introduction

Cancer cases are increasing at a significant rate (Katella, 2024), and a steady increase in the need for cancer services puts further pressure on a shrinking workforce. In 2007 and 2016, the ASCO's Board of Directors warned about a shortage in the oncology workforce shortage. This trend continues and is expected to worsen, as illustrated by the 2022 ASCO Snapshot: State of the Oncology Workforce in America (2022). That snapshot revealed 13,365 oncologists engaged in active patient care in 1602 oncology practices. Of those oncologists, 22% are nearing retirement (age 64+), whereas only 13.9% are early-career oncologists (age <40); the overall median age was 53 years. The expected shortages of oncologists from underrepresented populations are even more severe. Female oncologists represent 35.8%, Hispanic or Latino oncologists represent 4.7%, and Black oncologists represent only 3% of the population. Only 10.5% of oncologists practice in areas defined as rural. Given the dire situation, efforts have been put into lessening the shortage. The strategies implemented include internships, scholarships, and increasing attention to getting students into the oncology pathways. The National Institute of Health's National Cancer Institute has aimed to increase the number of people from all populations in cancer pathways (Talesnik, 2024). This includes efforts to start career education in late elementary and early middle schools.

For pathways initiatives to succeed, teachers need more access to quality biomedical education and early exposures to the research enterprise, which significantly impacts students' motivation to pursue careers in biomedical research. Thus, more attention is needed on teacher professional development (PD), ultimately increasing the quality and quantity of professionals in the biomedical workforce. This is necessary at all levels of P-12 education, with particular emphasis on upper-elementary and middle-level teaching (NSTA, 2016). At these levels, teachers provide their students with the prerequisite knowledge and dispositions inherent in career pathways. With this in mind, we developed a PD program to help teach cancer research and careers in cancer research and are finding many successful aspects of our program. We are also encountering new questions regarding how to successfully prepare teachers to guide their students into the beginning stages of the medical research pathway. One such question is how, or if, teachers can address the emotional aspects of learning about cancer and cancer research. Very shortly into the program, the participating teachers noted a concern about teaching about cancer in their classrooms because many of their students have been impacted by cancer in some way. Similarly, while working with and learning about

cancer researchers and the reasons why they got into the field, we noticed that many of them noted that they or someone close to them had cancer.

This collaborative action research project aimed to increase our understanding of preparing upper elementary and middle-level teachers to incorporate social-emotional learning (SEL) strategies into a unit on cancer and cancer pathways, enabling them to address students' emotional reactions to this topic. This process cannot occur without teaching upper-elementary and middle-level school students. We must deeply understand teachers' classroom experiences with such units to create a PD program. Thus, together with a science teacher who participated in one of our workshops and subsequently joined our research team, we developed and sought to answer the following questions: (1) Does our PD program prepare teachers to incorporate SEL strategies into their cancer units? (2) What aspects of our PD approach foster or hinder participating teachers' ability to use SEL strategies to address upper elementary and middle-level students' emotions with biomedical science's social and cultural aspects, specifically oncology?

Guiding Literature

Emotions and Science Learning

Science is often portrayed to students as a rational, systematic, and solitary endeavor, where only observations and data influence the findings and conclusions. This notion of science as a dispassionate and emotionless pursuit is misleading. As a human endeavor, science is imbued with the full range of human emotions—joy, wonder, amazement, surprise, anxiety, anger, fear, and hopelessness. These emotions are also prevalent in science education. Research has shown that emotions in the classroom impact learning outcomes (Pekrun & Stephens, 2012).

Without social and emotional competence, students lack the skills to effectively manage tasks such as working cooperatively, solving everyday problems, and controlling impulsive behavior (Elias et al., 1997). Moreover, without the ability to identify and manage their emotions effectively, students are vulnerable to emotional hijackings, wherein they cannot think clearly due to being emotionally overwhelmed (Goleman, 1995). Students are more likely to be motivated to attend schools prioritizing emotional competence, fostering healthy relationships, interpersonal problem-solving, and resolving peer conflict. Emotional intelligence is a pivotal framework for addressing these interconnected skills and knowledge

domains (Elias et al., 1997). Effective social problem-solving and decision-making skills are paramount, necessitating the ability to recognize and understanding emotions, setting goals, generating solutions, making informed choices, and reflecting on the decision-making process (Elias & Tobias, 1996). Deficiencies in these areas are commonly observed among young people facing academic, social, and health-related challenges (Elias & Tobias, 1996).

Emotions in educational contexts are discipline-specific (Goetz et al., 2006), indicating the importance of examining their role in each academic domain, including science. Emotions significantly influence cognitive processes and shape how individuals interpret events (Lazarus, 1984). When science education involves sensitive topics like cancer, the role of emotions becomes notably more profound and nuanced. Emotions influence how students perceive and engage with the material and shape their understanding and retention of complex information. The middle-level years are when students can benefit most from learning how to deal with emotional topics (ACTE, n.d.). This process can include building self-awareness, learning about the things that impact our lives, and developing a plan for reaching future career goals. In addition, the process is one of many in these years that tends to shape a student's identity (e.g., someone good at STEM). The National Science Teachers Association (2016) notes that the school experiences before high school are pivotal in developing a person's understanding of and enthusiasm for science. It is also a pivotal time to bring up crucial emotional topics and, unfortunately, aligns with a time when students begin a well-documented decline in interest, motivation, and attitude toward science and scientific careers (Potvin & Hasni, 2014).

Given the evidence that science topics that include an emotional component can impact student learning and emotional well-being, we deliberately sought to address student emotions when starting a biomedical research career pathway learning program. Doing so in the upper-elementary and middle-level years assures this is addressed at a critical time in their career pathway.

SEL and the Social and Cultural Aspects of Science Learning

Incorporating SEL into educational settings offers a promising avenue to contribute meaningfully to students' holistic development and well-being. SEL activities support students' social and emotional intelligence by developing the necessary skills, attitudes, and

values (Elias et al., 1997). Through SEL activities, teachers engage students' interpersonal and intrapersonal intelligence, providing opportunities for problem-solving, stress management, civic engagement, and conflict resolution and negotiation strategies. Additionally, the learning process serves a crucial role in dismantling affective barriers, such as frustration, low self-esteem, anxiety, and depression, which can distract students, disrupt cognitive functioning (Goleman, 1995), and hinder academic achievement (Maag & Forness, 1991). SEL activities influence attendance and motivation (Glasser, 1997), as it helps create a safe and nurturing environment that encourages children to participate.

Examples of research-backed SEL strategies include problem-based instruction, real-world issues, meditation, and storytelling. Vestad and Tharaldsen's (2022) research study showed that mindfulness activities and addressing social-emotional competencies, such as relationship skills and effective planning, significantly enhanced their motivation and fostered a growth mindset (Vestad & Tharaldsen, 2022). By learning to work through authentic and vital societal problems, students gain confidence and feel more receptive to new skills, and their attitudes toward learning changes. Studies have also shown that SEL reduces stress and anxiety, which improves focus, attention, self-awareness, and well-being. For example, research demonstrated that mindful meditation supported student well-being and academic success (Fuertes & Wayland, 2015). As a result, students can engage more actively in discussions and learning activities while effectively absorbing course materials.

Science-based stories or story mapping in science classrooms is pivotal in enhancing students' understanding and fostering their connection to the subject matter. Research has demonstrated that a story-based approach impacts students' motivations for pursuing science. For example, in a study by Korkmaz (2011), students' interest in science was driven by curiosity, excitement, or the desire for personal gain, such as wealth, popularity, or fame. However, students' perceptions had shifted significantly after an intervention that included a story-based approach. Most began to desire to pursue science for altruistic reasons, such as helping others, protecting animals, and contributing to society and humanity. Furthermore, feedback from student surveys highlighted how problem-based learning, when paired with narratives or fictional stories, helped clarify abstract or complex topics. Observational data further revealed that this approach allowed students to connect more easily with real-world problems while making the classroom environment more engaging and intellectually stimulating (Fischer, 2019).

Given the well-documented connection between SEL and student motivation, learning, and the ability to manage stress and anxiety, our program used an SEL approach to address student emotions within biomedical science's social and cultural aspects. This was done by incorporating an overview of SEL and explicitly focusing on problem-based instruction, mindfulness, real-world applications, and storytelling.

Teacher Professional Development

Although there are many different models and approaches to teacher PD, six common characteristics exist (Roehrig, 2023). These include 1) content-focused, 2) coherence, 3) active learning, 4) PD grounded in effective models of instruction, 5) participant collaboration, and 6) PD of adequate duration (Roehrig, 2023, p. 1199). First, effective PD is content-focused, including subject-matter content and knowledge of how students learn the content. Teacher content knowledge is arguably the key driver for student outcomes (van Driel et al., 2023). The PD process is incomplete until the teachers possess the necessary content knowledge and understanding of how students learn that content (Lynch et al., 2019). Second, effective PD assures the content is aligned with a teacher's knowledge and beliefs and with the school, district, and state requirements that impact the teaching and learning process. This seems straightforward, but research has shown that there are nuances that, if missed, could significantly impact achieving the goals of a program. PD should include an opportunity to understand the content within the realities of curriculum standards, parent expectations, school expectations, and a specific student population. Third, effective PD actively engages teachers in the practices they are learning. The teachers should experience the process before returning to the classroom. This engagement should involve collaboration, reflection, and inquiry (Russell & Martin, 2023). Practice-oriented conversations have been shown to support teachers during this engagement (Boschman et al., 2014). Fourth, and connected to the previous characteristic, the PD instructors should model the instruction emphasized in the program. Fifth, effective PD creates spaces for teachers to share ideas and collaborate in learning. Ideally, teachers from a specific grade in the same school would work through the process. However, this could be teachers from different schools or different grades at the same school that support each other through the process. Sixth, the PD program should provide teachers adequate time to learn the emphasized practices and ideally involve mentors or classroom coaches. Several of the abovementioned characteristics require significant amounts of time. These are substantially supported by the facilitators or coaches

(McFadden & Roehrig, 2020) and provide the opportunity to redesign and design future instructional activities.

Our PD model was developed with these common characteristics. Our program included contemporary and accurate content associated with cancer and cancer research. To ensure this, medical researchers, educational researchers, and classroom teachers informed and co-facilitated the PD planning and implementation to ensure this. The participating teachers engaged in inquiry-based lessons and activities to elucidate and deepen their understanding of medical research. The lessons and activities we introduced during the PD aligned with relevant state science standards and Next Generation Science Standards (NGSS), including disciplinary core ideas from life and physical science and science and engineering practices (NRC, 2012). Also, a particular emphasis was placed on the participating teachers generating lessons to address standards and topics often overlooked in life science, such as science communication, scientific argumentation, and integrating SEL standards. Our cohort was supported with 30+ hours of summer PD, followed by six hours of PD in the fall and classroom site visits during teacher implementations in the winter and spring. The site visits were intended to aid teachers' adoption and application of the project's lessons in their classrooms (Reinke et al., 2014) and aid project assessment and evaluation. Using a cohort structure, our program emphasized collective participation among the teachers (Hundal et al., 2014). The PD sessions provided opportunities for in-person, video conferencing, and online collaborations in which the participating teachers shared their challenges and successes.

Method

Action Research Approach

With this study, we sought to better understand our PD program's impact on preparing teachers to address student emotions within biomedical science's social and cultural aspects. We selected an action research approach that would allow us to engage in an authentic teaching experience at the level we were preparing teachers for. By becoming involved in the teaching experience of a teacher leaving our PD program (action plan) to implement the suggested strategies, we could feel the same emotions and constraints of the participating teacher leaving our program, and the participating teacher could feel our constraints as teacher educators. Collaborative action research, a process where researchers and educators closely collaborate to address practical challenges encountered in teaching, offered a valuable

approach to navigating the emotional dynamics inherent in teaching socially and culturally embedded science topics. Defined as a collaborative effort between researchers and teachers, collaborative action research aims to solve practical issues encountered when seeking social change (Greenwood & Levin, 2007). In collaborative action research, rather than generating or confirming new theories about teaching, the primary goal is to develop nuanced understandings of practice within specific contexts and enact educational changes accordingly (Feldman & Weiss, 2010). This approach aims to bring together a group of collaborators, including higher education researchers and community partners, to create shared understandings through the action research process (Bennett & Brunner, 2020).

Participants and Context

The procedures of collaborative action research involved a research team comprising one sixth-grade science teacher, two science education professors leading the PD program noted above, and an educational researcher with expertise in developing and implementing SEL programs. The participating teacher was selected due to her involvement in the PD program, current assignment as an upper-elementary teacher with an assignment involving science teaching, and interest in serving as a collaborative partner in this inquiry.

Due to the participatory nature of the investigation, another critical criterion used in the selection process was our favorable assessment of this teacher's ability to see herself as a full member of the research team. To allow the reader to follow the interactions of the various team members, we refer to this member as "the teacher," but she was also a researcher on the team. Her teaching assignment involved teaching science to children in kindergarten through sixth grade. At the sixth-grade level, she taught four classes of 25-30 sixth-graders for two-week intervals, with only one class being taught during each two-week interval. Thus, she had the first class of sixth graders for two weeks, after which she taught the unit for the second class for two weeks, etc. This unit was a part of a series of themed lessons around the question, What problems do scientists solve? The lesson was designed to be conducted in ten 45-minute class periods.

The collaborative team met throughout the project and worked through virtual means in between. The unit was carried out in the context of the teachers' teaching assignment. This was her actual assignment and not designed for the study. The school site was in a

Midwestern rural school district. The school population was approximately 500 students. The curriculum covered during our study was based on district objectives.

Action Plan

Given the focus of our study, the action plan is the PD model. The PD program was structured as a two-year program run for three cycles. Each two-year cycle focused on one cohort of approximately 10-15 teachers. Year one is learning and designing, and year two is implementing and revising. This study focused on year one/cohort one. That learning and designing year included four 2-hour virtual sessions and a one-week workshop in the summer. Participating teachers were provided with pedagogical content in cancer and cancer research-related practices. Teacher educators and cancer researchers also supported them as they developed curricular units for their classrooms. At the end of Year One, teachers were notified that they would receive ongoing support from the program facilitators as they implemented their newly developed units in their schools (year two).

By immersing ourselves in the implementation process with a teacher who completed Year One, we sought to experience what it is like to be a teacher tasked with teaching cancer research and use that experience to help revise aspects of the PD for future iterations. Thus, we met with the teacher three times to plan the unit she started in the workshop, once as the unit was being taught and once after the unit's completion. Although we immersed ourselves in the teaching process, we focused on improving and refining our PD program. In brief, year one/cohort one included:

Table 1. Action Plan

Topic(s)	Brief Description
Pedagogy	
Scientific and Engineering Practices, Inquiry-Based Learning Problem-Based Learning	Facilitators covered the pedagogical practices that support the goals of the PD model. Each approach was reviewed, discussed, and experienced through one or more sample activities.
Cancer	

<p>Game: Cancer and the Cell Cycle (SEPUP, 2019).</p> <p>Review of Cells</p>	<p>Teachers are put into groups of four and play a hat that simulates the cell cycle. The game highlights specific types of cells and introduces the cancer cell. Summarized learning and how to use in the classroom.</p> <p>Facilitators covered the content addressed in the NGSS.</p> <p>This included cells</p>
<p>Cancer Data and Statistics (Centers for Disease Control and Prevention, 2024)</p> <p>Cancer and Environmental Justice: EJ Screen Tool (EPA, n.d.)</p>	<p>Teachers were introduced to the current cancer statistics. Simultaneously they explored the statistics along with using the U.S. Cancer Statistics Data Visualization Tool and EJ Screen Tool. Made observations of rates and concentrations of cases. Discussed environment, cancer and environmental justice.</p>
<p>Medical Research</p>	
<p>Clinical Trials: Clinical Trial Activity (NWABR, 2024)</p> <p>The Immortal Life of Henrietta Lacks (Skloot, 2011).</p>	<p>Facilitators took teachers through this activity. They learned about the purpose and structure of clinical trials. Facilitators lead a discussion of using this in the middle level classroom. Provided an overview of the story of Henrietta Lacks. Discussed how her cells became an important aspect of cancer research. This was done without her permission.</p>
<p>Cancer Researchers</p>	<p>During the academic year, three different cancer researchers met with teachers to discuss their research. During the summer workshop, teachers toured their labs.</p>
<p>SEL and Science</p>	
<p>5-Minute Meditation (Goodful, 2019)</p> <p>Emotional Check-Ins</p>	<p>All teachers together did this mindfulness activity for first 5 minutes and try to experience their present state of mind. Facilitators discussed using this in classrooms.</p> <p>Teachers learned about emotional check-ins and how to conduct them in a classroom</p>
<p>SEL Competencies (CASEL, 2020)</p>	<p>Facilitators introduced to the five different SEL skills of self-awareness, self-management, social awareness, relationship skills and responsible decision making. Each skill was reviewed, discussed, and experienced through one or more</p>

	sample activities.
Stories of Cancer and Cancer Researchers: Dr. James Lupski genome activity (Brackett et al., 2019) Webquest: Dr. David Fajgenbaum	These stories highlighted the importance of resilience, perseverance, vision, emotions, and attitudes. With this activity, teachers learned about the genetics keyterms, genome sequencing, gene database with the help of website given in the provided working sheet. Teachers completed a webquest on this doctor. They learned how David Fajgenbaum discovered a cure for his own disease.

Research Methodology

The qualitative data sources we utilized included (a) recorded and transcribed collaborative meetings, (b) a teacher development workshop plan (action plan), (c) a classroom unit plan with progressive changes/discussions noted, (d) all classroom documents, and (e) team members' individual written reflections completed following the planning meetings.

Our collaborative meetings of the project provided opportunities to identify approaches to improve education outcomes for the science classroom and how we prepare teachers to navigate this improvement. During the planning stage, three meetings focused on designing a unit for a school and its demands (e.g., students, structure, standards). During the implementation of the unit, two meetings were held to discuss emergent themes, the similarities and differences in interpretations, future directions for classroom practice, and future directions for our teacher development action plan. The meetings allowed us to take advantage of information as it evolved and adjustments a teacher must make daily. This continuous analysis became part of the recorded meetings and, as such, became additional data to be analyzed after our project.

Each team member wrote three semi-structured reflections throughout the study. The first reflection occurred after the planning was complete. The second reflection occurred after the lesson was taught. The third happened three weeks after the entire research was deemed complete. Example reflection questions included: (1) Did the implementation process change your thoughts about the most important things to consider when planning to integrate SEL

into cancer and cancer research lessons? (2) At this point, what are the essential understandings and skills you think a teacher needs when teaching lessons that integrate SEL into cancer and cancer research lessons?

All classroom planning documents were developed, progressively edited, and commented on in an electronic file. The complete action plan was also shared and commented on as the study progressed. All worksheets and emotional check-in sheets were also included.

The cumulative data set was analyzed in a series of steps. We read the data multiple times, identified categories, coded the data, and made statements about the categories utilizing references to the actual data as support. The final results were developed as a team, and all members contributed to reporting the findings.

Results

The Planning Phase

The data showed that, in general, the team members felt that the planning stage went smoothly, with few uncertainties or mistakes. For example, the teacher noted, “The teacher development program ... was instrumental in preparing us for the challenge of integrating SEL into lessons on cancer research”. However, in light of the few uncertainties or mistakes noted, the group identified areas of preparation for planning that needed further exploration. These included 1) clarifying the purpose of incorporating SEL strategies, 2) knowing how to plan to handle student emotions once identified, 3) understanding students’ ability to deal with emotions, and 4) gathering resources that would appeal to adolescents.

The first area that needed further exploration was addressing the appropriate role of SEL in the sixth-grade science classroom. This was evident across all the data from the planning period. The group members quickly wondered if everyone was thinking about this incorporation similarly. It was not long into the process when one member reflected:

“... we need to clarify the ‘why’ we are integrating SEL into the lessons – and keep returning to it. As integrating SEL into the science classroom is a rare practice, it too quickly became about SEL and not about science learning. I believe this is mainly because SEL is usually taught separately, mostly about schooling – and not in learning about science.” (Written Reflection)

This reflection came after the first planning meeting, during which a significant amount of time was spent with the members navigating the project's purpose. For example, one member noted: “They (students) can understand the (science) topic but must also understand their ... emotional connection to it...We need to foster their self-awareness of their emotions related to the topic” (Recorded Meeting). At the same time, another went deeper into the need for SEL overall. That member noted:

“I feel like, socially, not just socially emotionally, we have disconnected...it (SEL) will bring them together. When it comes down to it, they will find community... I don't want them to be too emotional that it takes over this class. .. but I want them to have more empathy and community... And, empowerment.” (Recorded Meeting)

Another stated similar understandings, such as:

“... I think we need to continue to focus on what characteristics we want to instill in the project's participating students. Characteristics may include empathy, emotional resilience, and social responsibility.” (Recorded Meeting)

However, as the planning moved forward, members expressed concern that SEL was becoming the primary focus. They felt that student emotions do hinder learning about some topics, whether we acknowledge them or not. Thus, they must be addressed if learning is to occur. However, regarding the discussion of the role of SEL in this unit, one member noted that the primary focus must remain the opportunity to *learn science*. She said that some social and cultural topics in science bring about student emotions, and we need to explore “how do science teachers deal with topics that are emotional such as climate change, cancer,... but we are definitely interested in how to teach science” (Recorded Meeting). Another member later commented on this when he noted a need to keep focused on the content:

“The biggest challenge is keeping the lessons focused on cancer research and not necessarily focused on those who are affected by cancer. The challenge can be overcome, in part, by having students read about - and critically think about – real cancer researchers and using mindfulness and emotional check-ins about the people in the readings.” (Written Reflection).

In sum, the group members came to the planning process with subtle differences in their beliefs about the role SEL should have in this unit. Some gave SEL the primary role as cancer and cancer research is explored, while others felt it was merely as a support for learning

about cancer. The differences were subtle, but they did come about as they impacted the planning process, elevating them to something that needs addressing.

The second area the data shows needs further exploration was preparing to deal with student emotions once uncovered. One of the research team members asked to what extent the teacher was comfortable going into student emotions. She felt prepared for the most part but knew there could be a point where she would not be the most appropriate person for the students, mainly if she came across too many emotions in the classroom. She told the story of a local child who lost the battle with cancer. What if that came up? Should it be addressed before it could come up? (Recorded Meeting). The team felt they were ready to incorporate mindfulness and discussion of emotions about cancer but decided to steer away from stories of the local child who lost a battle with cancer or students' family members. Instead, they would seek out and use stories one step removed, focusing on using emotions to guide and develop research. Another member noted, "It does make me nervous because we are not trained for emotions...we need to use stories of others" (Recorded Meeting). Another member noted several stories of others that could be used.:

"We need to go beyond what SEL is. We need to learn about SEL strategies and ask, 'What here do you think offers us a way to address student emotions inherent in learning about cancer and cancer research? ... I believe teachers need a 'toolbox' of SEL strategies they may use if they encounter an emotional problem, but they should not be prepared to teach SEL to the point of understanding it.'" (Written Reflection).

Another noted:

"Teachers need a thorough understanding of the specific SEL framework adopted by their school or district. A common framework provides consistent vocabulary and strategies for addressing the emotional and social aspects of learning, which is especially important when dealing with sensitive and potentially distressing subjects like cancer. A teacher equipped with SEL knowledge can create a safe and supportive learning environment where students feel comfortable engaging with difficult topics. In cases where a school or district does not have a dedicated SEL framework, it becomes even more important for educators to advocate for adopting one. This would ensure a cohesive approach to integrating SEL, particularly when addressing emotionally charged subject matter like cancer." (Written Reflection).

Ideas presented in the workshop were used to develop emotional exit tickets that could be used in the classroom. The students would have three emojis to select from to represent varying emotions. But a question came up about what to do with the emotions. This was not addressed in the workshop. The group developed three ways to address emotions, which were checked. These included (1) ‘Big Emotions’ which means the classroom teacher would send a recommendation to the school counselor; (2) ‘Something My Teacher Can Address’ which means the teacher will address it within the lessons or offer to talk to the student; or (3) ‘No Concerns Let’s Keep Going’ (Program Documents). The teacher noted that she would let the school counselor know this was being discussed and seek advice on handling situations where students admitted they needed to discuss their feelings. She would also present these approaches to the students before the first emotional exit tickets (Recorded Meeting).

In sum, the group members went into the planning process confident that they were ready to address emotions in the science classroom. However, very quickly, it became evident that they were prepared to uncover emotions but not deal with them. Together, they developed a strategy for addressing emotions in the science lesson.

A third and related area that needed further exploration in preparing for the planning process was the level of ability upper elementary students possessed to understand and deal with their cancer-related emotions. One member questioned at what level sixth-grade students were ready to discuss emotions. The teacher assured the member that the students were capable of doing so. She noted that self-awareness is hard, but it is expected in the class. She assured the group that the SEL strategies were age-appropriate. But, she did note that she was worried about getting the kids too emotionally charged. Ultimately, the team proceeded with the selected SEL strategies for these sixth-grade students, given the teacher’s understanding and familiarity with her students. However, this was noted as a gap in the PD developers’ knowledge of emotional maturity and the age-appropriateness of SEL strategies, which would need further exploration.

Finally, the research team felt that planning resources offered by the existing PD model were well utilized. The content, activities, and stories provided in the workshop were beneficial in designing and implementing the instruction in the classroom. However, the group realized that a fourth area that needed to be addressed was the appropriate resources for youth. This was especially true for the stories of cancer and cancer researchers. This realization started

when the teacher noted, “I wish I could add a younger person...to the conversation...if I can find an example of a young person that overcame cancer... (Recorded Meeting). In this case, another group member found an example of a young student who invented a soap for persons with skin cancer (Recorded Meeting, Program Documents). This started a level of overall scrutiny of the resources. At the end of the planning phase of the study, the teacher noted:

“One of the more significant challenges was identifying age-appropriate activities for students while still maintaining the seriousness of the topic. Cancer is a deeply emotional and complex subject, and designing informative and sensitive lessons to students' developmental stages requires careful thought.” (Recorded Meeting).

These final two areas, identified as needing further exploration, understanding levels of emotional maturity, and age-appropriate resources, were addressed relatively quickly in the planning process. However, we identified them as impacting the planning process and that they should be addressed before that point.

The Teaching Phase

In general, the implementation also went very well. However, the team noted that the implementation stage also revealed two additional areas beyond those identified in the planning phase, in which our PD program needed adjustments to prepare teachers adequately. There were only two, but they were significant issues. The members felt they were easily handled within this collaborative action research group structure, but they worried that teachers leaving our program would have a different level of support structure to navigate these issues. Members questioned whether teachers would persist in light of these issues. The concerns centered on time constraints and an emotional classroom atmosphere.

First, although the planning process included time and effort to acknowledge and explore emotions, the degree to which these came out was more significant than anticipated. Over half of the students knew someone with cancer, and the emotional connections were strong from the start. The planning stage ensured that the teacher was prepared to deal with them, but given the strength of the emotions, it took more time to deal with than anticipated. This was further exasperated as the students were more involved due to these emotions. For example, several students gathered around one student who had recently had a family member die of cancer. As this occurred, the feelings grew and spread. There was also some

minor misbehavior by other students that surprised the teacher. It was later discovered that there was cancer within some of their families, and the group wondered if this may have led to the behavior. Uncovering these emotions and their consequential actions led to addressing how to deal with this. The classroom teacher was prepared to work with her students, but this demanded more attention than anticipated. Arguably, the time led to greater student engagement and learning, but handling the added time commitment was done as the teacher taught.

“The lessons sparked a level of engagement and curiosity that I hadn’t anticipated, which led to great conversations and a deeper dive into research, but this also created time management issues. We found ourselves spending more time on these discussions than originally planned, which disrupted the pacing of the lessons. Unfortunately, I had to make adjustments and adaptations as we progressed through the unit, cutting out some of the content. In future iterations, I will reconsider the time being allocated to different parts of the unit, allowing for more flexibility to engage in these discussions without sacrificing the structure and content of the lessons, possibly planning for additional days in order to complete the unit in its entirety (Recorded Meeting).”

In sum, student engagement with the lesson was extraordinary, but the impact on the necessary amount of time to teach the unit was more significant than expected. The group members knew this was good overall, but it constrained an already packed timeline. Arguably, the time should be given, but this impacts other areas and topics that need to be taught. In this case, it was negotiated within the group. However, this would be put on one teacher to address without the collaborative group structure.

The second issue that the group felt needed to be addressed in the PD model was dealing with a depressing and sorrowful classroom environment on the second day of the unit. Although everyone expected some student emotions to be negative, the group was surprised by the depressing classroom atmosphere that some of the discussions caused. As noted by the teacher:

“The second lesson was tough... they did such a great job, and we all brought ourselves down and really quiet (with the mindfulness activity)...but, it was almost like they were too low, and then the story (book on cancer) really brought them down... they were brought down so low that it was almost too much to read that book

and come back... then we started talking about cancer and ...there were big feeling ...We made it through, but there were lots of tears”. (Recorded Meeting).

Another member responded:

“There is more to consider when preparing teachers to address the emotions inherent in Cancer and Cancer Research. There was bringing the emotions out and addressing them, but there is also how this will change your classroom and overall practice. In this case, the emotions led to a subtle depressing atmosphere – which changed more than just learning. They may have been still learning – but who wants to be in an atmosphere like that? But then it changed to a very positive one. This all isn’t necessarily bad, but it needs to be considered. What do we want in terms of a classroom atmosphere? Should it always be positive? Is there room for negative emotions? Is it better to be middle of the road? These are not addressed in teacher education programs” (Written Reflection).

The negative atmosphere was mainly in the parts of the lesson that were focused on the content of cancer, and the emotions in the classroom turned halfway through the planned unit when the stories and research came into focus. The change in emotional energy in the classroom was dramatic once the lesson switched to the stories and focused on overcoming personal challenges. The teacher noted, “You could tell there was an emotional switch for many of the kids. The story activities were excellent because we could discuss how others felt” (Recorded Meeting).

This collaborative group was surprised by the impact on the classroom environment. They felt this needed to be addressed in the PD program so that an individual teacher would not be surprised.

Conclusion and Discussion

Overall, the PD program encouraged a thoughtful approach to planning and implementation, and the action research approach offered the opportunity to work collaboratively with other educators. All group members noted that they learned a lot through the collaborative process. We took our new understandings and returned to our research questions to consider these changes and determine if and how to adjust.

Does our PD program prepare teachers to incorporate SEL strategies into their cancer units?

Overall, the results show that the answer is ‘yes.’ The PD model prepares teachers to incorporate SEL strategies into the cancer units. In this classroom, cancer and cancer research were successfully explored with SEL strategies. However, there is a caveat to this answer. There was strong evidence that this action research group was a part of that success. So, we will proceed with our PD model, but there will be adjustments in light of the areas the action research group found themselves working through. These are elaborated with research question 2.

What aspects of our PD approach foster or hinder participating teachers’ ability to use SEL strategies to address students’ emotions with biomedical science’s social and cultural aspects, specifically oncology?

First, the PD model did foster teachers’ abilities by addressing the ‘what’ and ‘how’ of SEL. All members understood SEL throughout the planning process. However, there was much discussion on the role SEL should take in the overall unit. The group successfully negotiated the role in the planning process. The action research group, including the classroom teacher, the PD developers, and an SEL expert, aided this. However, the fact that this took a significant portion of time and diverse perspectives to address suggests that the lack of attention to the role of SEL could significantly hinder teachers’ ability to use SEL strategies to address the program’s overall goals. Second, our PD model provided many resources for classroom teachers, including several stories of people that illustrate resilience. These resources were effectively utilized in the classroom and fostered the learning as anticipated. However, the lack of some resources that would appeal to adolescents hindered the process. This study’s planning and implementation phase demonstrated that the existing resources, particularly the stories, were of people the program developers could relate to.

Third, the SEL activities in the PD program fostered increased emotional engagement with the topic found within the classroom. However, this also hindered the overall process, significantly impacting an already constrained time allotment. The group negotiated the time constraints, which could significantly deter such units’ utilization. The PD program fostered the teachers’ abilities to bring out student emotions inherent in engaging with cancer and

cancer research. But, there was a level of surprise at how these emotions could affect the classroom environment. This could be overwhelming and hinder learning during the teaching process. This should be addressed in PD. Similarly, the PD program structure did foster the teacher's ability to uncover emotions. However, the lack of preparation regarding addressing the students' emotions when uncovered was a hindrance. The program did address how to explore them, but it was not until this group was in the planning phase that the members questioned what to do with the emotions. This did not impede the planning and implementation of this particular unit. However, that was due to the teachers' connection with the school counselor and the fact that her school had an SEL program facilitated in the homerooms. However, the teacher educators of the group acknowledged that they did not prepare the teachers for this, and things may have gone very differently if she had not come with the skills and knowledge.

Recommendations

This study aimed to increase our understanding of incorporating SEL strategies into a PD program to enable teachers to address students' emotions when teaching about cancer and cancer research. With a science teacher who participated in one of our workshops and subsequently joined our research team, we immersed ourselves in the teaching and learning process. We uncovered aspects of our PD model that fostered and hindered our ability to achieve our goals. As this was action research, the focus was narrowly on our actions. Thus, our recommendations are focused on our action plan – our PD model.

We will continue with the portion of our program that explains SEL and why it is essential. However, we will add several components. First, we will address existing SEL programs in schools and invite guidance counselors to speak to the teachers. This will connect this instruction with the larger contexts. Furthermore, when we introduce the SEL strategies, we will foster a discussion among the participants and various experts about the role SEL should have in the overall school and the science classroom.

Regarding the classroom environment, we will share this action research study about teaching cancer and cancer research in the sixth grade and how it impacted the classroom environment. Then, we will discuss with the teachers how they would handle such an emotional environment. In doing so, we will explore resources for dealing with emotions in

the classroom. We will share the one we developed and include others so the teacher has choices. We will also explore various stories of cancer researchers and patients. These will allow teachers to address emotions in a manner that positively impacts the classroom.

We will prepare the teachers for the time requirements of teaching such an emotional topic. We will add more resources of varying durations to allow for flexibility in timelines. This will also be considered when adding to our teacher resources. We found the resources we provided in our PD model valuable and appropriate, but the set needs to be expanded in terms of time and appeal. The one used in this process is one example that could be utilized, but more should be added.

We began this journey to improve our PD program, and the findings were instrumental in improving it. Furthermore, we will use this experience and subsequent understanding to further our efforts to prepare teachers to address student emotions within the social and cultural aspects of biomedical science.

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Chapter 2 - Enhancing Teachers' Understanding of Socio-scientific Models in Climate Engineering: A Participatory Action Research

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Chapter Highlights

- The role of climate engineering in contemporary science classrooms is explored.
- Strategies for preparing teachers to teach climate engineering in the high school classroom are explored.
- A professional workshop for preparing teachers to teach about climate engineering is provided.
- The effects of incorporating the Socio-Scientific Model while teaching climate engineering topics are explored.
- Ways to incorporate social dimensions in science lessons are provided.

Introduction

Integrating the engineering design process (EDP) into K-12 instruction has gained momentum in the past decade due to its inclusion in K-12 educational frameworks like Next Generation Science Standards (NGSS; Lead States, 2013). Given the intersection of engineering and societal issues, this inclusion has led to a need to develop a socially relevant engineering education (Mcalister & Lilly, 2023). Rather than just focusing on the technical aspects of engineering design, K-12 educators need to integrate socio-scientific issues into STEM lessons to promote social thinking necessary in engineering design (Roehrig et al., 2021). This becomes even more crucial when teaching controversial and complex topics like climate engineering.

Climate engineering, also called geoengineering, is the large-scale intentional modification of the earth's climate system to mitigate climate change. Geoengineering offers promising solutions to mitigate climate change (Kravitz et al., 2013) but raises concerns about the unintended environmental consequences (Robock, 2008). Moreover, ethical and moral concerns exist about where to pursue this strategic investment (Mintz-Woo & Lane, 2021). Carbon Capture and Storage (CCS) is one of the geoengineering projects aimed at reducing the carbon dioxide level in the atmosphere by capturing carbon dioxide from industries and injecting it underground permanently. The public is highly concerned about the safety of such projects, fearing the potential of environmental calamities associated with them. Many regions worldwide are beginning to struggle with concerns regarding climate engineering projects. Given the lack of complete certainty of its implications, choices about if and how to implement it in the future will need to be made.

With the increase in social issues correlated with the engineering domain, especially in topics like climate engineering, it becomes essential to teach students about the socio-scientific dimensions of engineering design (Goddard et al., 2024). This becomes particularly relevant given the significant public outcry, differing opinions between scientists and the public, potential benefits, and associated risks. To help future citizens understand the complexities of societal acceptance of advancing technical solutions to mitigate climate change, our K-12 teachers must explicitly engage them in this process. But often, teachers do not understand how to navigate this process independently. Professional development is necessary for teachers if schools are to educate students about climate engineering.

We seek to design a workshop for secondary school science teachers intending to utilize socio-scientific models (SSM) in the EDP to teach contentious topics like climate engineering. SSM considers social factors while understanding and predicting complex socio-scientific issues (Ke et al., 2023). Through this participatory action research, we brought teacher expertise into the design process of this workshop to understand how it fosters or hinders teachers' understanding of integrating SSM into EDP. The findings will refine the workshop and our knowledge of effective professional development in this area. The research questions that guided this study were

1. How did the workshop impact the teachers' understanding of implementing SSM in the EDP while teaching climate engineering?
2. What aspects of the workshop fostered or hindered their understanding of integrating SSM into the EDP?

Guiding Literature

Socio-scientific Models

Model-based learning has been used to support both students' and teachers' understanding of science. Models are a simplified representation of real-world phenomena that help in visualizing and explaining complex systems (Hmelo et al., 2000). Systems thinking is the fundamental concept underlying modeling, as it encourages students to think about the interrelated components of a system (Yoon, 2008). This practice is a key component in NGSS, where it emphasizes using models as a tool to engage students with cross-cutting concepts of science (Lead States, 2013). While scientific modeling is used to explain natural phenomena, the growing research on socio-scientific issues has led to the use of scientific modeling in the context of socio-scientific issues to explain complex societal challenges (Zangori et al., 2017).

Ke and co-workers (2021) classify models into two major categories: scientific models and SSM. While scientific models focus on representing natural processes and rely on empirical data, SSM consider the social dimensions that influence these processes and let the learners evaluate evidence from different methodological traditions (Ke et al., 2023). This requires understanding not just scientific facts but also the societal implications, policy decisions, and ethical concerns. This is represented using arrows to show the interaction between scientific and social elements. This approach allows learners to construct and represent scientific

knowledge in relation to other disciplines like policy, economics, sociology, etc, and have a more integrated understanding of the issue. SSM also possesses a multilevel structure covering personal, community, and societal levels, increasing their complexity.

The primary epistemic goal of utilizing SSM is to help learners understand complex issues from a systems perspective (Ke et al., 2023). Climate engineering is one such contemporary global issue that is complex in nature and necessitates a systems perspective to understand its implications. Understanding climate engineering cannot be done by learning isolated scientific facts; rather, it requires an interdisciplinary approach to utilizing scientific knowledge in relation to other social factors. SSM could be considered the most appropriate tool to develop learners' understanding of climate engineering and apply their unique cultural lens to the issue (Lesnefsky et al., 2023). Therefore, in this workshop, we aim to equip in-service teachers to utilize SSM to teach the climate engineering topic of carbon capture and storage.

Professional Development for Pre-college Engineering Education

The NGSS has incorporated engineering practices to K-12 standards, showcasing a commitment to engage students in real-world problem-solving by applying scientific knowledge. A successful translation of the standards to classroom practices requires teachers to be adequately prepared with the necessary skills and knowledge. Since then, numerous professional development programs have aimed at teaching teachers how to integrate engineering into K-12 classrooms most efficiently (Billiar et al., 2014; Maeng et al., 2017; Nesmith & Cooper, 2019). These PDs have increased the enhancement of teachers' knowledge of engineering design, their familiarity with engineering concepts, and their confidence in implementing engineering lessons in K-12 classrooms.

Utilizing EDP was the key theme in most professional development as it is considered an effective way to integrate engineering practices into classroom instruction (Bowen, 2014; Porter et al., 2019; Yoon et al., 2013). A study conducted by Crotty et al. (2017) found that introducing engineering early in STEM units and revisiting it throughout led to greater student achievement on engineering assessments compared to only incorporating it at the end as a design challenge. This reinforces Guzey and coworkers' (2014) findings on the significance of using a realistic context to place an engineering problem, thus helping

students realize the need for a solution. Situating engineering problems in a realistic context has also improved student motivation to participate in the activity.

The explicit inclusion of EDP components in teacher professional development (TPD) has influenced teachers to adopt these practices, showing that how teachers implement engineering lessons is closely tied to the structure of the TPD they receive (Guzey et al., 2014; Nesmith & Cooper, 2019). This is the reason why TPD facilitators must be mindful of how they design their sessions, as teachers may tend to gravitate toward the literal steps of the EDP and not fully address or encourage students' engineering thinking (Pleasants et al., 2020; Watkins et al., 2018).

In our workshop, we were mindful of these concerns and drew on the lessons learned from previous research studies of TPD for integrating EDP into classroom instruction. The EDP in our workshop was tied to a real-world context, in fact, the most pressing concern humanity faces today. We wanted teachers to brainstorm engineering design solutions for the increased carbon dioxide emissions and engage in a process similar to what their students will experience in the classroom. Said that by utilizing an EDP approach, we were not expecting teachers to make working models. Instead, we wanted them to think through the process of engineering solutions for a growing environmental challenge. The primary aim of this workshop was not to educate teachers about the utilization of EDP in the classroom but to educate teachers on the use of SSM in EDP in order to expose students to the social factors concerning the acceptance of climate engineering projects. Through this, ultimately, we wanted to advance socially relevant pre-college engineering education that would equip our future engineers to address socio-technical issues.

Methodology

We used participatory action research to answer our research questions because of its collective and self-reflective nature (Kemmis & McTaggart, 2000). Through this PAR, we sought to transform our practice as teacher educators by understanding secondary school teachers' experiences participating in our professional development efforts. In this process, we share the ownership of this research project with the participating teachers, considering their contributions to the refinement of this workshop.

Context and Participants

Our PAR team included two teacher educators and two classroom teachers. Among the teacher educators, one was a new teacher educator (TE1), and the other had over 25 years of experience conducting professional development (TE2). The two classroom teachers were secondary school science teachers. One is a male high school physics teacher with 17 years of teaching experience (T1), and another is a female 7th-grade science teacher with 28 years of teaching experience (T2). They both teach in two different public schools in the same state where the university is located.

Action Plan

TPDs are carried out to improve teachers' knowledge and classroom practices and significantly change students' learning outcomes. The student learning outcome we sought was to equip these future citizens with an understanding of the socio-scientific aspects of engineering solutions, especially while addressing problems like climate engineering. To achieve that goal, our workshop focused on developing and delivering instruction to secondary school teachers. To ensure the quality of the workshop, we followed the characteristics of effective teacher professional development enlisted by Roehrig (2023) based on Desimone's (2009) and Darling Hammond et al.'s (2017) research work. The six defining characteristics of effective TPD are content focus, coherence, active learning, grounded in effective models of instruction, collaboration and collective participation, and duration.

The content focus in a TPD relates to the knowledge the teacher acquires during the TPD, including the subject matter knowledge and how students learn that content. In this workshop, we provided teachers with essential subject matter knowledge on climate engineering and carbon capture, hoping to deepen their understanding. This was delivered through a brief introduction and a video of how carbon capture works in a real-world setting. To improve teachers' knowledge of how students learn this content, we encouraged teachers to reflect on the socio-scientific implications of CCS through role play where they take roles like scientists, environmentalists, government officials, etc., and by creating an SSM concept map. The role play simulated how students might interact with science concepts, integrate societal and environmental perspectives, and create SSM alone. It also helps teachers to

understand the process their students would undergo. By involving in these activities, teachers realize how students can connect scientific knowledge to societal issues, and it would improve their understanding of guiding students to make meaningful connections between science and society.

Coherence in a TPD refers to how the content is aligned with broader educational standards, and it ensures that TPD supports what teachers are already working on and fits into the larger academic context they operate. The TPD was aligned with NGSS, which emphasizes climate engineering as an essential learning outcome. Our workshop targeted this standard as one of the ultimate student learning outcomes we envision as a product of this TPD.

Active learning in a TPD suggests the need for teachers to be directly involved in the learning practices throughout the workshop. Collaboration and collective participation are extensions of this, suggesting that professional development must create opportunities for teachers to collaborate and share their ideas. In this workshop, we provided teachers with the opportunities to engage in all the activities and also a space to collaborate. The activities included the initial engineering design challenge, hands-on carbon capture and storage, creating SSM, and role-playing. In all these activities, teachers collaborate and work together. As was observed from the previous studies, the structure of TPD highly influences how teachers implement the lesson in the classroom (Guzey et al., 2014; Nesmith & Cooper, 2019). Therefore, we put extra care into designing the learning activities and let the teachers actively participate in them as their students would.

An effective TPD would be grounded in effective models of instruction. This emphasizes the need to provide teachers with effective models of instruction that would guide them in selecting appropriate strategies to meet diverse student needs in their classroom. Our workshop provided teachers with instructional models that illustrate the intersection of scientific concepts and socio-scientific issues. Teachers can visualize effective pedagogical strategies that engage students in complex real-world problems by modeling instruction through hands-on activities and role-play scenarios. This helps teachers create a practice that includes content knowledge and encourages students to be involved in critical thinking and ethical decision-making.

Considering all the six characteristics of effective TPD, we sequenced an action plan for this

workshop. The action plan is divided into the following four sections.

Engineer Solution for Rising Carbon Dioxide Emissions

The first part of the workshop emphasized the content by providing a brief introduction to climate change and climate engineering. Similar to what their students experience in their class, teachers were provided with a real-life scenario and asked to design a model (prototype) that would remove carbon dioxide from the atmosphere and store it safely to prevent further climate impact. This highlights the significance of using a real-life context for engineering design (Guzey et al., 2014). Teachers were asked to follow the EDP based on the Massachusetts Curriculum Framework (2006). Craft materials were provided to build the prototype. Through this, teachers enter into active learning, where they are asked to collaborate with their peers and be involved in hands-on activities. The instructional strategies teachers can utilize while implementing this part of the lesson in their classroom were emphasized.

Carbon Capture and Storage

In this section, the particular example of CCS was emphasized by conducting a hands-on CCS activity. The hands-on activity involves the reaction of baking soda and vinegar to release carbon dioxide, which is then captured in a balloon. The captured carbon dioxide is released into a conical flask with the bromothymol blue solution, resulting in a color change from blue to yellow. This hands-on activity is introduced to the teachers in the same way it will be introduced to their students. Teachers get a chance to actively participate in this activity, reading through the instructions and doing the activity by themselves. This provides them with a taste of what their students would go through in their class. After the activity, teachers are shown a video of a real-life CCS project. This is done to improve teachers' content knowledge on the topic and enhance the discussion of how this content could be delivered in the class.

Socio-scientific Model

After the hands-on activity, we introduce the teachers to social factors concerning climate engineering using an SSM and involve them in a role-playing game. Teachers are introduced

to existing SSM and how to create them based on Ke and co-workers' study (2021). This time we familiarized teachers with the topic and how to create an SSM using existing examples before they went ahead to create their own. We also emphasized the need for such a model in secondary classrooms. Once we realized teachers were familiar with the topic, they were asked to create an SSM using an online tool by considering three questions – who benefits from CCS? Who might face challenges? How do stakeholders view it? Teachers were provided with similar instruction that their students would receive. This gives them a chance to critically analyze the instructional strategy utilized and modify it based on the needs of their classroom.

Teachers were then presented with the SSM created by the teacher educators. Through this, we wanted teachers to see an already created SSM model, which is based on evidence from news articles and research papers. This way, teachers will be provided with more content knowledge and an alternative way of creating SSM.

Teachers were then introduced to the role-play activity called Village Verdict. In this activity, each participant gets a role – local community leader, government official, environmentalist, geologist, and industrial investor. The task is to engage in a structured discussion where each of them presents their perspectives, debates the merits and drawbacks of the CCS projects, and proposes solutions. After the discussion, the group will vote on whether to proceed with the project, taking into account the scientific, economic, environmental, and social dimensions. The village verdict game is designed based on other existing role-playing activities (Goddard et al., 2024; Matzner & Herrenbrück, 2017). Teachers in our workshop didn't perform this activity due to the limited number of teachers. Rather, we had a thorough discussion on the ways in which this activity could be delivered in TPD with more participants as well as in middle school classrooms. This way, we discussed the pedagogical practices teachers can utilize while delivering this activity.

Revisiting and Revising

After the activities, teachers revisited their SSM and were asked to make any additional changes. They were also asked to revisit their initial prototype and revise it after considering societal factors impacting their prototypes. This leads to the integration of SSM into the EDP. Revisiting and redesigning their prototype is one of the most efficient ways to involve

participants in the engineering process (Crotty et al., 2017). Teachers were asked to be involved in this process to get a taste of what their students would experience. This is to make them realize how revisiting their designs would change their understanding of the topic.

Data Sources and Analysis

The primary data for this study was the focus group discussions carried out by teacher educators and teachers throughout the workshop. Other data sources included a pre- and post-questionnaire, teacher artifacts including their CCS model, and online SSM. After the workshop, teacher educators discussed the findings and developed themes, which were sent to the teachers for their review and responses. These responses were an additional data source for this study.

The pre-questionnaires were designed to capture teachers' initial understanding of SSM, EDP, and how to utilize this to teach a climate engineering topic. This provided us with a baseline for comparison. The post-questionnaires provided after the workshop aimed to assess the changes in teachers' understanding. The data sources also included teacher artifacts from the workshop, which consisted of initial SSM teachers created using an online tool and their revised version, which they created towards the end of the workshop. Teachers also created a CCS model initially and were asked to revise it after they had created their SSM. The comparison of the initial and revised models helped us assess how using an SSM model helped teachers consider societal factors while making a geo-engineering model through EDP. Together, these responses acted as the data source for evaluating the impact of this intervention on teachers' understanding.

This study's most significant data source is the focus group discussion about the workshop elements carried out by the teachers and teacher educators, which was video recorded. The video was recorded to capture the feedback and interactions throughout the session. Two video cameras were used in which one of them was focused on the teachers, and the other one focused on the teacher educators. This approach allowed us to capture all the team members' interactions throughout the intervention as well as to document facilitation strategies and instructional choices. The focus group discussions were carried out at four key points during the workshop. The prompts that guided each of these sessions are given below.

Focus Group Discussion 1

The following questions were used to guide the discussion after the first part of the action plan.

How are you feeling about the scenario we just discussed? What do you think about the approach of using EDP to tackle this issue? Are there any areas where you feel more explanations or clarifications are needed? What suggestions do you have for improving this part of the workshop?

Focus Group Discussion 2

The following questions were used to guide the discussion after the second part of the action plan.

How did you find the hands-on activity? Was it clear and easy to follow? Do you think this activity could help your students understand the concept of carbon capture? Why or why not? Were there any challenges or areas where the instructions or process could be improved? What suggestions do you have for making this activity more engaging for students?

Focus Group Discussion 3

The following questions were used to guide the discussion after the third part of the action plan.

How did creating the SSM help you think through the complexities of carbon capture and storage? Did the village verdict game enhance your understanding of the social, economic, and environmental dimensions of CCS? Why or why not? How do you feel about using role-play activities like the village verdict game in your classroom? Do you think it could engage your students in critical thinking? What improvements or changes would you suggest to either the model-making or the role-play activity to make them more effective?

Focus Group Discussion 4

The following questions were used to guide the discussion towards the end of the workshop.

How did integrating the SSM into your EDP influence your thinking about your prototype? What changes or improvements did you make to your initial prototype after considering the SSM? Do you feel that updating the concept map helped deepen your understanding of the connections between scientific, societal, and engineering concepts? Why or why not? What are your overall thoughts on the workshop? What aspects were most helpful, and what suggestions do you have for future improvements?

The observation notes of the workshop were taken by one of the teacher educators (TE2), providing an additional data source for this study. These notes captured key moments, participant interaction, and the overall flow of the workshop. This complemented other data sources.

This study used a constructivist grounded theory approach to analyze the data (Charmaz, 2000). Unlike the objectivist grounded theory that leans towards a positivist outlook, a constructivist grounded theory lies between a post-modernist and post-positivist outlook on qualitative research. Here, rather than providing a single viewpoint, we aim to incorporate multiple viewpoints. In addition to the teacher educators' viewpoint, we include the meanings interpreted by the teachers'. Through the data analysis, we aim to disclose the experiences teacher had during the workshop and how it impacted their understanding of utilizing SSM for teaching climate engineering. The data which was gathered from multiple sources were coded and categorized into broader themes. Rather than coding it very objectively, we used a subjective interpretation of the codes.

Results

The findings of this study are organized based on the two research questions.

How did the workshop impact the teachers' understanding of implementing SSM in the EDP while teaching climate engineering?

The workshop positively influenced teachers' understanding of SSM and their utilization in teaching complex topics like climate engineering. Before the workshop, teachers were unfamiliar with the concept of SSM and had no knowledge of their use in teaching. However,

after the workshops, teachers understood the components of SSM and suggested that incorporating

“SSM makes the issue more immediate and personal to kids. It stops just being something in a science class and starts having cultural importance.” (T1, post-questionnaire)

They also suggested that after implementing SSM in classrooms, students are more likely to think more deeply about the issue and have a better understanding of EDP.

This is also evident in teacher’s responses when they revisited their CCS model after creating an SSM. Teachers noted,

“Obviously, the science is great. But we need to consider where we are putting this in to, are the local people in favor of it, who is gonna make money, lose money, lose jobs, or have jobs, how big is it, how much carbon we actually sequester”. (T2, focus group discussion)

This highlights a shift in teachers' focus from merely constructing prototypes to considering the broader social impacts of their projects. Initially, their attention was primarily on the technical aspects, but after the introduction of SSM, they engaged in discussions about the community impacts of their designs.

When asked about how they would introduce climate engineering topics in their class, in the pre-questionnaire, teachers’ responses focused on exploring inequities and open-ended discussions, but in the post, they integrated the creation of SSM, indicating a clearer strategy to facilitate student engagement and structured processing. There is a transition from a discussion-focused approach to a more inquiry-focused approach. Also, both teachers plan to use SSM beyond climate engineering topics, showing interest in using it while teaching other scientific lessons. Teachers also reported higher confidence in applying SSM in their classrooms with guidance but suggested they are not yet very confident. The post-workshop response highlights the use of SSM, which is directly related to the workshop’s goals of incorporating SSM within climate engineering lessons.

In response to the question regarding their plan to incorporate societal issues in their future lessons, teachers said they would incorporate village verdict lessons and SSM when

applicable and have students consider this when building prototypes. But they also said it would take some time to plan for and fit the SSM into their existing curriculum. Overall, after analyzing teachers' pre and post-questionnaires, focus group discussions, concept maps, and prototypes, it shows that attending the workshop has a positive effect on teachers' understanding of SSM and its use in teaching climate engineering.

What aspects of the workshop fostered or hindered their understanding of integrating SSM into the EDP?

Throughout the focus group discussion, teachers explored how this entire unit might look in their classroom, along with discussing how we could refine this TPD for other teachers. Our conversations focused on refining this TPD to meet the needs of teachers and better fit mainstream classroom settings. The findings of this section are grouped into the following five themes.

Hands-on Learning and Practical Application

The aspects of the workshop that fostered teachers' understanding were related to hands-on activities and ready-to-go examples. Teachers valued the opportunity to engage with the initial CCS activity and thought it helped to understand the abstract concept of carbon capture. They were able to experience the same excitement that their students would if they used the activity in their classroom. They suggested that the activity would help students understand what we mean by capturing carbon, aiding teachers in translating abstract concepts into teachable content. Teachers valued the opportunity to create SSM and the role-playing exercise that followed as an effective way to integrate complex ideas into classroom practice. T1 highlighted it by saying,

“Using SSM will allow us to see that science is not removed from everything else and there are connections.” (T1)

T2 suggested the usefulness of SSM and the role-playing activity by noting that this could be scaled to various grade levels. Teachers also said they would consider adopting the model to other science topics they are teaching. TE1, in her reflection after the workshop, expressed her satisfaction when seeing the teacher's enthusiasm during the carbon capture activity. It unfolded in the way she hoped, with teachers visibly engaged and excited by the project.

Contemporary Relevance

T2 shared an incident from their community where two farmers strongly opposed the installation of wind farms, leading to heated community meetings. T2 was also concerned about how the discussions on climate change can often get entangled with local politics. The group felt using SSM offers a nuanced understanding, allowing for an informed perspective that addresses diverse stakeholder viewpoints. The introduction of SSM in the workshop was taken very positively by both teachers, as hoped by the teacher educators. Teachers' interest in using the SSM and the village verdict game is expressed in the following quotes:

“I really like the idea. You know exactly who the stakeholders are. Exactly what you are doing. You get a clear idea of your stance. Here's your stance, here's their stance and then more of a debate type.” (T2)

“I like that SSM. I think I am gonna use something like that in some sections of my course. I don't know if CO₂ capture is really gonna be something I do in a math class or a physics class. The idea of the SSM, I think it is great” (T1)

Challenges with Background Knowledge

A challenge that hindered teachers' understanding was the lack of initial background knowledge when introducing concepts like CCS and EDP. Building a carbon capture model through EDP without much background knowledge was not effective, and instead, teachers suggested that it would be better to introduce the problem and lead a discussion before going to EDP. The discussions can include what they don't know and what they need to know to brainstorm solutions for this problem. Teachers emphasized the need to discuss what students need to learn before jumping into solutions. They saw the value in brainstorming and gradually moving to EDP rather than rushing into building solutions. T1 suggested that, due to his limited background knowledge on the topic, he would have preferred a group activity where participants first draw their ideas and then pass them to others to add their input rather than simply being given materials and asked to build something independently. Even though teachers found the approach to using EDP to tackle this issue helpful, the lack of background knowledge was a limitation.

Teachers felt that having a foundational understanding was crucial for them to feel confident in teaching the topic. According to T2, having a teacher handout with background knowledge

is very helpful, as she mentioned that sometimes she struggles to answer specific student questions due to a significant time gap between the professional development program and classroom lessons. To address this, T2 suggested the need for a teacher handout with all necessary background information along with the student handouts. T2 also said she prefers to use the activities from the workshop, which have ready-to-go student handouts, making her day more manageable. Her concern is shared in the following quote.

“Like a teacher blurb somewhere. Like I would feel better if I went to the workshop on Saturday, then I taught it in a month or six months later. Here is the teacher handout so when the kids ask questions I feel confident..... That's the other thing, like separating here's the student clean. I could just go to the copy machine and I'm ready to go and here are the directions for teacher background.... I appreciate when we go to the workshops and there are sort of, you know that parts kind of already, the thought of the scaffolding's already been put in there.” (T2)

Structured Guidance and Clear Instructions

Teachers suggested a need for more structured guidance and clear instructions for the workshop activities. For the initial construction of a CCS model using EDP activity, the teacher suggested using a planning sheet to help them organize their thoughts. This includes breaking down tasks, starting with listing five possible solutions and selecting one to develop further. The teacher also emphasized the need to communicate to the participants that we are looking for creative models rather than realistic models; this would further be communicated to the students, making them less stressed, as some might be stressed about making realistic models. After the activity, T1 suggested implementing a group discussion where participants can explore various CCS models and engage in debates about which solution is most effective.

“Like the models are all setup someplace and have them go around and match the different ones with theirs. Look back at their SSM and see which one (CCS model) is better” (T1)

This should be structured using a checklist to guide their discussions. And this could be transferred to the classroom easily by teachers. Once they have chosen the best model (solution) out of the lot, teachers could ask their students to write a paper explaining why their chosen model is the most suitable one.

For the hands-on CCS activity, teachers suggested providing two separate handouts for capture and storage steps and specifying the quantities of the materials used. They also recommended providing discussion checkpoints where participants can review how the carbon was captured, what will be done with it, and analyze the results. TE1, in her reflection, noted that she had overlooked the necessity of a detailed explanation for chemical reactions. With her background in chemistry, TE1 assumed the directions would be straightforward, but it led to confusion among teachers. This signifies the importance of considering varying levels of subject familiarity when designing instructional materials.

For the online SSM activity, rather than introducing all the different dimensions at once, T2 suggested using the “red hat, black hat, green hat” method, where students take a specific perspective/dimension one at a time. This structured approach will allow for a more focused discussion. This would help them stay more engaged on a topic, as everyone was focused on the same perspective at the same time, leading to deeper and more organized conversation. TE2 supported T2’s suggestion, and the following quote highlights this.

“This makes something because they wouldn't necessarily think economics and like they wouldn't think these areas, but then after you do this, then they could think across all of those perspectives.” (TE2, focus group discussion)

Teachers also suggested the need for a more scaffolded version, where teachers could provide students with a few initial perspectives and let them build from there. Teachers recommended conducting a follow-up discussion after the role-play activity that prompts students to reflect on their experiences, asking questions like “How do I feel about my role now? Do I still agree with my position, and if not, why? Did anyone else’s perspective influence me?” T2 suggested a need for such a reflective process as students can be easily swayed in their opinions.

Challenges with Technology

During the workshop, teachers faced difficulty accessing the online Tool. This needs to be considered in future professional development programs. Alternative suggestions for this include providing a pre-set computer for website access and incorporating hands-on activity instead of an online task. Rather than using an online platform, teachers suggested students might perform better using a whiteboard and post-it notes to create their SSM. In future

professional developments, incorporating this diverse option to conduct the same activity would benefit the teachers. After the workshop, T2 had more time to practice with the online tool, and she reached back and said she found it very useful. So, the concern was the limited amount of time provided for teachers to get familiarized with the new tool.

Conclusion and Recommendation

The workshop was successful in its primary purpose of improving teacher's understanding of SSM and how they could use it while teaching complex concepts like climate engineering. The workshop familiarized teachers with integrating scientific knowledge with societal factors by using SSM in the EDP. Both teachers and teacher educators were engaged in meaningful discussions about the factors that fostered and hindered teacher's understanding of integrating SSM in to EDP. The findings suggests several key recommendations for refining the workshop. The conclusion and associated recommendation are summarized and presented in bullet points below:

1. The teachers highly value the hands-on approach to teaching such a complex topic. They felt this benefited the lesson on climate engineering but could also be added in other curriculum areas. A recommendation is to keep the hands-on activity that was used and to add others that had the potential to make connections elsewhere in the curriculum.
2. The teachers noted the connection to a local challenge but were unsure of all the details. It was pointed out that this would be important to know when teaching it. A recommendation is for the PD developers to be more knowledgeable of their participants and come prepared for some local challenges. Although they can't know them all, they can share some and discuss how to identify if any issues exist in the area.
3. Similarly, the teachers felt they needed more content knowledge themselves. Although they understood the 'science' behind it and approached some of it as a review, it was fine; this is a new topic, and it was not around when they were in college. They would need a more up-to-date understanding of what is going on themselves. A recommendation is to allow more time for content background and provide more resources.
4. The teachers felt that more guidance was needed in going through the lesson. They felt uncertain at some points in the activity and felt certain their students would as

well. There needs to be more structure throughout the hands-on activities.

5. The teacher provided several specific recommendations for changes in the activity. These will be added.

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Chapter 3 - Guiding Teachers in Using Culturally Relevant Pedagogy to Address the Social and Cultural Aspects of the Nature of Science

Georgia Watson 

Chapter Highlights

- Using culturally relevant pedagogy can improve student achievement.
- Understanding the nature of science impacts student learning and influences future science class choices.
- Professional development and collaborative conversations effectively educate high school science teachers on the social and cultural aspects of the nature of science and culturally relevant pedagogy.
- Professional Development and collaborative conversations can provide teachers with the skills necessary to effectively incorporate the nature of science and culturally relevant pedagogy into a lesson plan.
- Further research on incorporating the nature of science and culturally relevant pedagogy in high school science classrooms is needed to help close the achievement gaps between black and white students in STEM.

Introduction

The Nature of Science (NOS) is an essential component of science education and critical to scientific literacy (Lederman, 2007). The National Science Teaching Association (NSTA) reiterates the crucial role of the NOS in its position statement declaring that “it is necessary knowledge for students to make informed decisions with respect to the ever-increasing scientifically-based personal and societal issues” (www.nsta.org). In 1991, the NSTA also recognized the importance of multicultural science education and recommended incorporating Culturally Relevant Pedagogy (CRP). Unfortunately, despite the emphasis on both the NOS and CRP, little research has been conducted that connects the two concepts, particularly the social and cultural aspects of the NOS.

The problems I sought to address with this research were two-fold. One is the lack of sufficient knowledge regarding the social and cultural aspects of the NOS by teachers, as demonstrated by the research done by Akerson et al. (2000). The other is the achievement gap of underrepresented and marginalized science students, perpetuated by a lack of CRP (Ladson-Billings, 1995a). Ultimately, specific ways to incorporate CRP when viewing issues in science from a social and cultural context were sought. The purpose of my study was to find ways to successfully educate teachers on the social and cultural aspects of the NOS and CRP, as well as find ways to guide science educators to use CRP to address the social and cultural aspects of the NOS. My work was guided by the following research questions:

How can I effectively teach educators about CRP?

How can I effectively teach educators about the social and cultural aspects of science?

How can I effectively guide educators in using CRP to address the social and cultural aspects of science's nature?

The Achievement Gap

The National Center for Education Statistics produced a report in 2020 titled “Conditions of Education” (www.nces.ed.gov). This report shows the achievement gap between black and white students has not been closed, black students have higher dropout rates than their peers, and thus lower high school graduation and college enrollment rates. The United States Department of Education Office of Civil Rights 2014 reports show while black students make up about 16% of the population, they represent just 9% of the students taking higher-level

college prep classes (www.civilrightsdata.ed.gov). In fact, “students belonging to certain ethnic and racial groups—including Latinx, Indigenous, and Black/African American students—still earn a disproportionately low percentage of bachelor’s degrees in STEM fields in comparison to their representation in the general population of the United States” (Palid et al., 2023, p.1). However, according to Palid et al., disparities in gender and race in STEM fields have been studied for over four decades, and they persist. The National Science Teacher Association (NSTA) recognized the importance of multicultural science education on student achievement and developed a six tenets position statement in 1991 that was revised in 2000. These tenets speak of the importance of the curriculum including all cultures to contribute to our knowledge of science and teachers using culturally responsive ways to teach (Cooper and Matthews, 2005). Research studies by Ladson-Billings, Gay, and others show that student achievement can be improved through cultural connections or by using CRP (Samuels, 2018).

The Correlation between NOS, Culture, and Education

Irvin et al view education as a socio-cultural process in which “it seems logical to examine how culture affects teachers and their ability to interact with minority students to improve achievement” (Irvin and Darling, 2005, p. 46). Nieto held similar views on the importance of culture in education believing that “when cultural needs are not met or valued, ...the academic and social progress of the child may be sacrificed” (Irvin and Darling, 2005, p. 47). Gay insists that culture is the base of all learning (Gay, 2010).

Ladson-Billing also studied culture in education and defines CRP as “a student-centered approach to teaching that includes cultural references and recognizes the importance of students’ cultural backgrounds and experiences in all aspects of learning” (Samuels, 2018, p.23). She believed that CRP could be used to close the achievement gap by increasing the academic outcomes of black students and other marginalized populations, which could create empowering and inclusive learning environments (Ladson-Billing, 1995b). In fact, In Ladson-Billings’ article “But That’s Just Good Teaching! The Case for CRP”, she notes examples of teachers incorporating CRP into their classrooms, leading to increased student engagement (1995a). These examples ranged from teachers inviting members of the community into their classroom to share their expertise on a particular topic to simply getting to know the students on a personal level. Byrd also speaks of culturally relevant teaching as

an effective method for increasing student engagement, and achievement, and reducing achievement gaps (Byrd, 2016). Mensah’s research found that group collaboration was the most effective practice for learning to teach in culturally relevant ways (2011). Horowitz et al did a research study with college students that showed “teaching science in more culturally responsive ways..have demonstrated themselves to be effective at improving the science achievement of underrepresented students” (Horowitz et al, 2018, p.8). They determined “culturally responsive science teaching as the integration of content, pedagogy, and knowledge of students into one cohesive framework...” (Horowitz et al, 2018, p.8). Even though research has shown the benefits of using culturally responsive pedagogy, specific applications of it being used in high school science courses are missing from literature (Mensah, 2011).

The objective of fostering students’ understanding of the NOS has been widely accepted by science educators, scientists, and science organizations over the past 85 years (Akerson et al., 2000, p.295). Several researchers including Faber, Bianchini, Lederman and Abd-El-Khalick, have emphasized the importance of understanding NOS. Misunderstanding of the NOS can influence students’ attitudes toward science and science classes, ultimately impacting student learning and influencing future science class choices, according to Faber (Faber, 2003). Bianchini et al believe that any efforts to achieve scientific literacy for all must address the issues of power and privilege, gender and race, and positionality and context (Bianchini et al., 2003). Lederman et al. say that science is culturally and socially embedded, and it “affects and is affected by the various elements and contexts of the culture in which it is practiced” (Lederman and Abd-El-Khalick, 1998, p.36). Some of Lederman’s and Akerson’s work has focused on the most effective ways for teachers and students to learn the NOS. They agree that the NOS is best learned in context by being integrated into the lesson (Lederman and Lederman, 2004). In fact, “an explicit, reflective approach to NOS instruction embedded in the context of learning science content would not only facilitate developing science teachers’ NOS views but might go a long way in helping teachers translate their NOS understandings into actual classroom practices” (Akerson et al., 2000, p.295).

Method

I used two current high school science teachers as my participants for this research study. One participant has over 20 years of teaching experience and will be referred to as the veteran

teacher. The other participant has less than five years of teaching experience and will be referred to as the novice teacher. The teachers participated in two professional development sessions that I designed and implemented. Before the first professional development session, the participants completed a View of the NOS (VNOS) pre-survey adapted from Lederman et al. (2002) and a CPR pre-survey adapted from the Due East Educational Equity Collaborative (dueeast.org). These surveys were used to measure the participant's current level of knowledge regarding these topics. During the first session, participants engaged in activities that addressed the social and cultural aspects of NOS explicitly and used activities outlined in Lederman et al. book "Avoiding de-natured Science: Activities that Promote Understanding of the NOS" (1998). Specifically, the participants completed two activities, one titled That's Part of Life! and the other Young? Old? After each activity, the participants and I discussed the implications of the activities and how they could be used in their classrooms to help students understand the social and cultural aspects of the NOS. The That's Part of Life activity, required the participants to read the following passage without any context:

The procedure is actually quite simple. First arrange things into different groups. Of course, one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities, that is the next step, otherwise you are pretty well set...It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important, but complications can easily arise. A mistake can be expensive as well. At first, the whole procedure will seem complicated. Soon, however, it will become just another facet of life. It is difficult to foresee any end to the necessity of this task in the immediate future, but then one never can tell. After the procedure is completed, one arranges the material into different groups again. Then they can be put into their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. However, that is part of life (Lederman & Khalick, p.54).

After the participants finished reading the passage, they were asked if they had any understanding of its content. Even though the passage contained comprehensible words and sentences neither the veteran nor novice teacher could make sense of the passage. I then tell the participants that the passage was about doing the laundry, thus providing context for them to keep in mind as they read. After the participants finished reading the passage again, they were asked if it made more sense to them. Both the veteran and novice teacher were able to comprehend the passage with ease the second time. I asked the participants if they thought a

person who only had experience washing clothes by hand versus using a washing machine, would have the same understanding of the passage. The veteran and novice teacher both doubted that a person who had only washed clothes by hand would be able to comprehend the entire passage, especially the part relating to lack of facilities and the importance of not overdoing it. The participants and I then had a conversation about the importance of context and personal experience and how it related to their eventual understanding of the passage. I then related this experience to that of a scientist. I stated that “Scientists need to bring in their prior knowledge, experiences, and expectations in order to put the data into context. Only then can scientists make any sense of or interpret the available data” according to Lederman & Khalick (1998, p.24).

During the second activity, Young? Old?, the participants were given an image. This image had a picture of a young lady transposed on an image of an old lady. The participants were asked to view the image and tell me what they saw. The novice teacher said that she saw a young woman. The veteran teacher had seen the image before and thus was able to recognize the young lady transposed on the image of the old lady. The veteran teacher guided the novice teacher trying to point out the features of the young lady so that the novice teacher could see it. This led to a discussion between the participants and I on how they can look at the same image but see different things. I specifically ask the participants if it is possible for scientists to look at the same piece of evidence or set of data and see different things or come to different conclusions? They both agreed to this possibility and based it on the views of the scientists. I expanded on this thought by telling the participants that “scientist’s training, previous knowledge, and experiences dispose him/her to see a certain set of evidence from a certain perspective.... Scientist sometimes tend to infer different things from the same set of data.” (Lederman & Khalick, p.25). We concluded our discussion by talking about specific examples of the social and cultural context of science. We discussed the extinction of the dinosaurs, female birdsong research, and the role of women in hunter-gather societies and how competing theories exist for these topics. These competing theories can exist even when the same evidence is presented because scientists can approach an issue from their own perspective thus possibly reaching a different conclusion.

The participants were asked to bring a lesson plan, covering a topic of their choice, to the first professional development session. After the participants had completed the NOS activities and discussed their implications in their classrooms, we evaluated their lesson plans to

determine ways in which the social and cultural aspects of NOS could be incorporated and explicitly discussed with the students. Upon conclusion of the first professional development session, the participants filled out a journal indicating what they had learned and noting any questions they had.

In the second professional development session, participants engaged in activities that addressed the CRP explicitly and used activities outlined on The National Association for Multicultural Education website (nameorg.org/learn) and on USF Culturally Responsive Coaching Questions (usf.edu). After the participants had completed the CRP activities and discussed their implications in their classrooms, we evaluated their lesson plans to determine ways the CRP could be incorporated and explicitly discussed with the students. Upon conclusion of the second professional development session, the participants filled out a journal indicating what they had learned and noting any questions they had. The participants also completed the post-VNOS and CRP surveys.

Results

Pre and Post VNOS and CRP surveys

Before starting my research, both participants were asked to describe the similarities and differences between art and science as part of the pre-VNOS survey. The veteran teacher stated that “both art and sciences require practice and are built on art and science of the past.” In contrast, the novice teacher stated that “science and art being similar due to the freedom of the individual to explore different areas within each discipline”. When referring to the differences between art and science, the veteran teacher stated, “Art is often seen as more emotional and subjective, science is more analytical and calculated” while the novice teacher’s opinion was that “art is seen as more of a ‘soft skill’ area, whereas many people see science as the opposite”.

Upon conclusion of my research, the veteran teacher indicated in the post-VNOS survey that art and science are similar because “both can be perceived differently by different observers”. This is a change from the veteran teacher's initial response in which there was no mention of people’s ability to evaluate the same data and end with different conclusions, which is an important component of understanding the social and cultural aspects of the NOS. Specifically, the veteran teacher noted in the pre-VNOS survey that if different conclusions

were reached from the same experiment, it was due to the researcher's perspective only in terms of “what components are being measured and studied”. The novice teacher also acknowledged people’s ability to evaluate the same data and end with a different conclusion in the post-VNOS survey stating that “the object or scenario being studied is not different, but the life experiences and/or values of the observer have an impact on what is perceived” and that researchers “likely have different fundamental beliefs, values, or experiences in the field that sway their own conclusions to be different than another individual's”. This view by the novice teacher is a change from the initial beliefs that “many of the differences people perceive are due to the differences in the ‘audiences’ each discipline attracts”.

The CRP pre- and post-survey used was adapted from Due East Educational Equity Collaborative and focused on specific components of the CRP Self-assessment and Reflective Conversations (dueeast.org). The components evaluated in this research study were Recognizing the Educational Impact of Cultural Diversity, Building Relationships across Cultural Differences, and Adapting Curriculum to Reflect Cultural Diversity. The survey featured a rubric for participants to assess their effectiveness, encompassing categories such as beginning, developing, proficient, and exemplary. The results of this survey for two out of three components are listed below in Table 1 for the veteran teacher and Table 2 for the novice teacher.

Table 1. Recognizing the Educational Impact of Cultural Diversity and Building Relationships across Cultural Differences (Veteran Teacher)

	Beginning	Developing	Proficient	Exemplary
Pre-CRP Survey	0	4	7	3
Post-CRP Survey	0	5	8	1
Changes	0	1	1	2

The veteran teacher had three notable changes in their pre- and post-CRP survey. Two responses went from exemplary to developing, two responses went from proficient to developing, and two responses went from developing to proficient. The majority of the changes were seen under the sub-category of Pattern of Cultural Interaction in Recognizing

the Educational Impact of Cultural Diversity.

Table 2. Recognizing the Educational Impact of Cultural Diversity and Building Relationships across Cultural Differences (Novice Teacher)

	Beginning	Developing	Proficient	Exemplary
Pre-CRP Survey	0	9	5	0
Post-CRP Survey	0	0	10	4
Changes	0	9	5	4

The novice teacher's pre- and post-CRP survey showed three notable changes. Two responses went from developing to exemplary, two went from proficient to exemplary, and six went from developing to proficient. The majority of the changes were seen in the category of Building Relationships across Cultural Differences. The veteran teacher and novice teacher had the same response for five questions on the pre-CRP survey (see Figures 1-5 below). They both rated themselves as proficient on two questions and developing on three questions. Both teachers rated themselves proficient in the areas of Building Relationships across Cultural Differences under the sub-category of Effective Communication with Diverse Groups of Parents and Recognizing the Educational Impact of Cultural Diversity under the sub-category of Awareness of Own Culture.

I regularly seek to engage and communicate effectively with families through a variety of means and methods.
2 responses

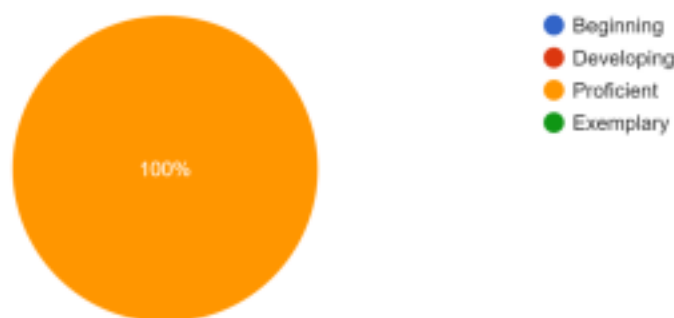


Figure 1. Effective Use of Communication Support Resources (Pre-CRP survey)

I continuously seek professional development opportunities to explore my own and others' cultures.

2 responses

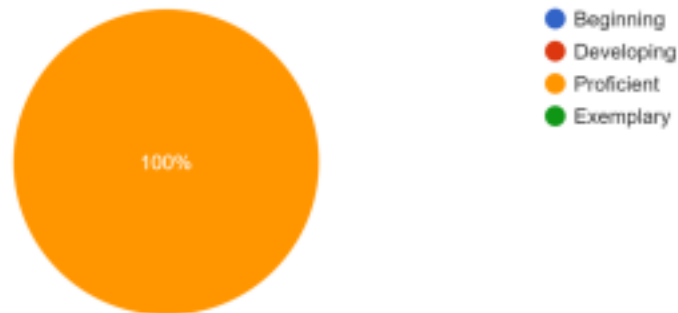


Figure 2. Awareness of Own Culture (Pre-CRP survey)

I create a welcoming learning environment that reflects the cultural backgrounds of my students.

2 responses



Figure 3. Knowledge of Students' Cultures (Pre-CRP survey)

I consistently and effectively use instructional strategies that build on students' cultural strengths and promote success.

2 responses



Figure 4. Patterns of Cultural Interaction (Pre-CRP survey)

I seek to learn about the family culture and values of my students in order to build relationships that support learning
2 responses



Figure 5. Effective Communications with Diverse Groups of Parents (Pre-CRP survey)

Post-CRP survey, the veteran teacher and novice teacher responded the same to four questions (see Figures 6-9 below), in which they rated themselves proficient in Recognizing the Educational Impact of Cultural Diversity under the sub-category Patterns of Cultural Interaction. For two of the questions listed below, both teachers went from rating themselves as developing in the pre-CRP survey to proficient in the post-CRP survey. When asked questions regarding Adapting Curriculum to Reflect Cultural Diversity in the pre-CRP survey, the veteran teacher cites the use of different approaches for student learning, student choice on how they divide projects into specific tasks, and student choice in the use of resources.

I consistently and effectively use instructional strategies that build on students' cultural strengths and promote success.
2 responses



Figure 6. Patterns of Cultural Interaction (Post-CRP survey)

I regularly communicate to every student, in various ways, my belief in their ability to achieve.
2 responses

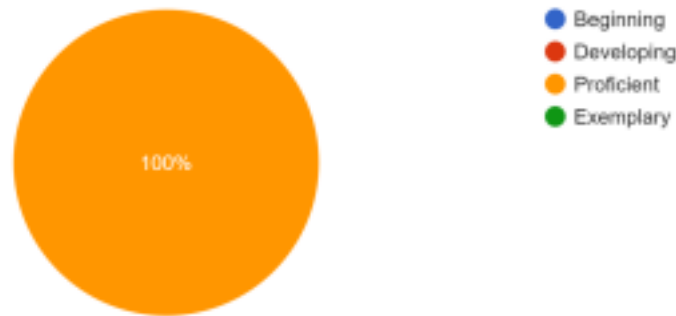


Figure 7. Culturally Responsive Learning Spaces, Relationships & Expectations (Post-CRP survey)

I design and adapt my classroom management approach to meet the needs of students and to support relationships with and among students.
2 responses

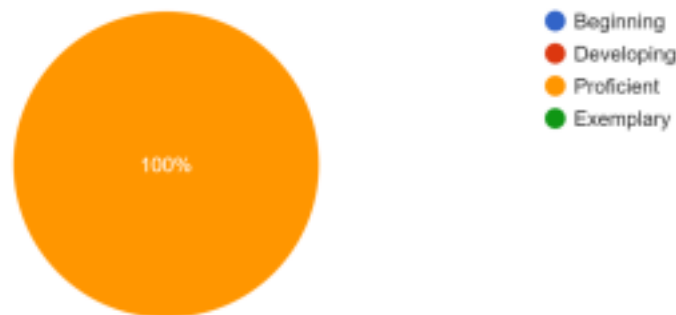


Figure 8. Culturally Responsive Learning Spaces, Relationships & Expectations #2 (Post-CRP survey)

I seek to learn about the family culture and values of my students in order to build relationships that support learning
2 responses



Figure 9. Effective Communications with Diverse Groups of Parents (Post-CRP survey)

The veteran teacher expands the approach of student choice to include presentations and assessments in the post-CRP survey. This expansion of student choice is an important component of Adapting Curriculum to Reflect Cultural Diversity in the sub-category of Multicultural Content Integration and multiple perspectives. The novice teacher cites using student choice and voice, displaying student work, getting to know student culture, and flexible seating in the pre-CRP survey. The concept of student choice and voice is expanded in the post-CRP survey to include the encouragement of student discussion and sharing of cultural experiences. This expansion of student choice and voice is an important component of Recognizing the Educational Impact of Cultural Diversity in the sub-category of Patterns of Cultural Interaction. The concept of getting to know student culture is expanded to include using that knowledge to guide student understanding of topics taught in class. This falls under the sub-category of Knowledge of Students' Cultures. The flexible seating approach has also been expanded to include the development of a welcoming classroom. This approach is part of Adapting Curriculum to Reflect Cultural Diversity in the sub-category of Physical classroom environment.

Pre & Post Lesson Plans

The veteran teacher's original lesson plan brought to the first professional development session was titled NOS Checks Activity. The objective of this activity was as follows: "The students will use checks written by a fictional family for different purchases and make inferences about the family's life. They will then analyze how this is like science". The observation and inferences aspect of the NOS was embedded into this lesson plan by directly asking students to observe a set of checks and infer information about a family based on the observations. The empirical basis aspect of the NOS was also embedded into this lesson plan by directly asking the students to think about how the activity is "like science". Aspects of CRP were not found in the original lesson plan. After the last professional development sessions, adjustments were made to the original lesson plan by the veteran teacher to include social and cultural aspects of the NOS and CRP. The social and cultural aspects of the NOS were embedded into the lesson plan by adding an activity in which two different groups of students receive the same set of checks, make observations and inferences about the family, and then compare their results. The students are prompted to discuss why differences exist in their results given they have the same set of data. Through collaborative conversation, the participants and I determined that this prompted discussion was a means of getting students to

understand that the interpretation of data is influenced by social and cultural factors. Recognizing the educational impact of cultural diversity and Adapting curriculum to reflect cultural diversity are the aspects of CRP that were added to the lesson plan. This was accomplished by asking students to list their five most recent transactions on a Google document, displaying that data, and having students guess the identity of the person whose data is being displayed. These added activities fall under the sub-categories of Patterns of Cultural Interaction and Multicultural Content Integration and Multiple Perspectives on the CRP survey. After adjustments were made to the lesson at the end of the professional development sessions, the veteran teacher's response to “What takeaways do you have from this lesson?” was that “there are easy and multiple ways to make lessons more culturally relevant for students”.

The novice teacher's original lesson plan, which was brought to the first professional development session, was titled Dimensional Analysis. The objective of this activity was as follows: “Use mathematical representations to support a claim regarding relationships”. Observations and inferences and empirical basis are embedded aspects of the NOS in this original lesson plan. These aspects are embedded by having the students measure a portion of an object in their school and then make inferences regarding the object’s total size. Building relationships across cultural differences was the aspect of CRP embedded into this original lesson plan by having a section that used “differentiation strategies to meet diverse learner needs” which falls under the sub-category of Culturally Responsive Learning Spaces, Relationships & Expectations on the CRP survey. After the last professional development sessions, adjustments were made to the original lesson plan by the novice teacher to include social and cultural aspects of the NOS and CRP. The social and cultural aspects of the NOS were embedded into the lesson plan by explicitly asking students reflection questions about “why we use the empirical system versus the metric system”, “would they prefer to switch to the metric system”, and “who would be impacted by this shift?”. Through collaborative conversation, the participants and I determined that this prompted discussion was a means of getting students to understand that the interpretation of data is influenced by social and cultural factors. Adapting the curriculum to reflect cultural diversity was the aspect of CRP added to this lesson by incorporating student experiences as part of the learning process. Based on interest, students are asked to determine the size of various objects or locations in the school using dimensional analysis. This activity falls under the sub-category of Multicultural Content Integration and Multiple Perspectives on the CRP survey. After

adjustments were made to the lesson at the end of the professional development sessions, the novice teacher's response to "What takeaways do you have from this lesson?" was that "The inclusion of cultural relevance in lesson plans are multi-fold. When we reviewed the lesson plans we adapted in the previous sessions, there was a long checklist of items that could be used to promote cultural relevance like student choice, peer interactions, and other opportunities for students to share experiences".

Discussion

My research purpose was to educate teachers on the social and cultural aspects of the NOS and CRP and find ways to guide science educators to use CRP to address the social and cultural aspects of the NOS. Previous studies by Lederman and Lederman indicated the most effective way for teachers and students to learn the NOS is in context by being integrated into the lesson (2004). Akerson et al study on effective ways to teach the NOS indicated that in addition to integrating NOS instruction into the "...context of learning science content..", using "an explicit, reflective approach to NOS instruction...would not only facilitate developing science teachers' NOS views but might go a long way in helping teachers translate their NOS understandings into actual classroom practices" (Akerson et al, 2000, p.295). My research results aligned with these studies as I also used an explicit reflective approach, through professional development and collaborative conversations, to teach the social and cultural aspects of NOS resulting in teachers embedding this concept into the context of their lesson plan. My results showed positive changes in the participants' perceptions and awareness of the social and cultural aspects of the NOS as indicated by the comparison of the pre & post-NOS survey responses. My results also showed the participants' ability to embed these concepts into a lesson plan, as indicated by the changes in pre- and post-lesson plans.

Research done by Mensah cited group collaboration as the most effective practice for learning to teach in culturally relevant ways (2011). Ladson-Billings' research included examples of teachers incorporating CRP into their classrooms ranging from teachers inviting members of the community into their classroom to share their expertise on a particular topic to simply getting to know the students on a personal level (1995a). My research results aligned with these studies as I also used collaborative conversations in conjunction with professional development to educate teachers about CRP resulting in the teachers finding

ways to incorporate CRP into their lesson plans. My results showed some positive changes in the participants' perceptions and awareness of CRP as indicated by the comparison of the pre & post-CRP survey responses. My results also showed the participants' ability to embed these concepts into a lesson plan, as indicated by the changes in pre- and post-lesson plans.

An unexpected result of my research came from the pre- and post-CRP survey of the veteran teacher. The veteran teacher's self-assessment of CRP awareness decreased on four out of fourteen questions from the pre- to post-survey. My expected result was that through professional development and collaborative conversation, each participant would only increase their awareness of CRP and that their self-assessment responses would increase up the scale that ranges from developing to proficient. However, I believe the decrease in scores represents increased knowledge or awareness of CRP and how it shows up in the classroom. I can make this assumption because, during the professional development sessions participants were given definitions of CRP and various ways it could be incorporated into the classroom. We then engaged in collaborative conversations about ways each teacher could incorporate CRP into each of their classrooms in general and, especially related to the lesson plan they used for this research.

Implications

My research results implicate that using professional development and collaborative conversations are effective ways to educate the high school science teachers in this study about the social and cultural aspects of the NOS and CRP and guide them towards implementing these concepts into their lesson plans. The research methodology I used was similar to those deemed effective for teaching NOS and CRP in other settings. However, the academic research field currently lacks an abundance of studies that combine the use of CRP to address the social and cultural aspects of the NOS in high school science classrooms. This study paves the way for further research on effective methods for educating other high school science teachers about the NOS and CRP, as well as how to integrate these concepts into their classrooms.

Future research could include an extended study of the impact on student outcomes if more high school science teachers continue to learn about aspects of NOS and CRP and consistently incorporate them into their classrooms. Since previous research has shown that

using CRP results in increased student engagement and achievement, and other scholars in this field believe it could be used to close the achievement gap, it would be interesting to see if this holds true if applied specifically in high school science classes (Byrd, 2016) (Ladson-Billing, 1995b).

Conclusion

Professional development and collaborative conversations were effective ways for participants to increase their perceptions and awareness of the NOS and CRP and be able to embed these concepts into a lesson plan. This is evident from the analysis of the pre- and post-VNOS and CRP surveys and the pre- and post-lesson plans. Research by experts in the fields of teaching the NOS and CRP aligns with my research results. Using a reflective, explicit approach that embeds these concepts in context is an effective way to educate the teachers that participated in this study. My research focused specifically on teaching these concepts to two high school science teachers. The academic field needs more research on these concepts in this particular setting. Research has shown that using CRP increases student achievement and understanding of the NOS concepts, can impact student learning, and influence future science class choices (Faber, 2003) (Byrd, 2016). The National Center for Education Statistics report shows that there has been a persistent achievement gap between black and white students (www.nces.ed.gov). There is also a gap between black and white students obtaining a bachelor's degree in STEM fields (Palid et al, 2023). Considering these dire statistics and the knowledge of a means to effectively address these inequalities through teaching the NOS and CRP, action must be taken in the form of research and implementation in high school science classes and beyond.

Recommendations

I have a few recommendations for ways to improve this study. First, I would have incorporated parts of the VNOS(C) questionnaire into my pre- and post-VNOS survey. My survey only focused on the VNOS(B) questionnaire. Using part C and part B could have led to more insight into the participants' perspectives and responses regarding the social and cultural aspects of the NOS. Secondly, I would have liked to follow up with the teachers to see how the adjusted lesson went and take notes on how it compared to when they taught it without incorporating NOS and CRP. Finally, I would like to have teachers adjust more than

one lesson plan, preparing at least one per month to consistently incorporate NOS and CRP into the classroom possibly leading to a greater impact on student outcomes.

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Chapter 4 - The Social and Cultural Aspects of NOS in Optometric Clinical Education

Nitya Murthy, , Valarie L. Akerson 

Chapter Highlights

- Nature of Science (NOS) education has been shown to enhance learning and retention of science knowledge even in higher education curriculums.
- Optometry clinical education features a high volume of information with limited NOS-specific instruction, though NOS aspects are covered.
- The social and cultural embeddedness of science is particularly relevant in optometry as the field is in dynamic growth and evolution due to political, economic, and social factors.

Introduction

The Nature of Science (NOS) is the epistemological study of scientific knowledge and the aspects of science that distinguish it from other fields. One such aspect is that science is socially and culturally embedded, and the social context of the time affects the content, timing, relevance, and use of scientific knowledge (Abd-El-Khalick et al., 1998). NOS is a set of guidelines which aim to distinguish the practice of scientific inquiry. It is not clearly defined, as the very nature of science lends itself to preventing rigid characterization of its own self. The generally agreed upon aspects of NOS are: scientific knowledge is based on empirical data, scientific models, laws, and theories are intended to describe and explain natural phenomena, scientific knowledge is tentative, scientific inquiry is a distinguishable way of knowing in ways that other practices are not, there is no universal recipe-like method for conducting science, observations are theory-laden, science is creative, and scientific knowledge is socially and culturally embedded (Abell and Lederman, 2007). It is this last aspect that we take special interest in throughout this text, as the impact of the social and cultural context on the development of knowledge has yet to be studied as it relates to optometry.

The importance of teaching NOS in science curriculums has been established. Understanding the fundamental practice of how scientific thinking is conducted and how it is different from other fields helps students understand the sources and limitations of scientific knowledge and it helps them make informed decisions about how to solve problems which are scientifically based (Akerson & Hanuscin, 2006). In medicine and optometry, this understanding is vitally important as an infinite combinations of clinical case presentations, disease manifestations, patient demographics, and clinical contexts exist, and it is not possible to teach students to memorize appropriate diagnosis and treatment plans for every such case. Students must be proficient in scientific critical thinking and be capable of refining their own knowledge and practice throughout their careers in order to sufficiently bear the responsibility of managing patients' health.

Optometry students are taught to hone their critical thinking skills and develop a sense of medical decision making based on clinical gold standards. This is a crucial part of their medical education, as being able to think about each individual patient and apply case-specific logic quickly and accurately is vital to their medical practice (Maudsley & Strivens,

2000). Research has shown that when medical students have a greater foundation in understanding the nature of science (NOS) and how knowledge is developed, the metacognitive skills required to understand the nature of science translate into an increased ability to ask descriptive questions and think creatively (Lederman et al., 2002). These qualities are valuable in developing holistic clinicians who can sort through different things that they have learned and apply the appropriate principles to specific contexts. Though some work has indicated that generally medical students have a good understanding of some aspects of NOS, specifically that science is tentative, their understanding of other aspects of NOS is not well understood (Kandell, 2019). There is even less information regarding optometry students' understandings of various aspects of NOS, but for the purpose of this study, we will reasonably assume that medical and optometry students may have similar background knowledge with regards to NOS.

There is also insufficient investigation as to the precise methodology that optometrists follow for making clinical decisions as it pertains to social and cultural factors. It has been studied that clinical reasoning is subjective and individualized to the practitioner to some degree; that though there are gold standards and established treatment protocols for specific situations, the highly individualistic nature of patient care provokes an equally individualistic approach to treatment. Thus, there is a lack of understanding of how optometrists make clinical decisions and specifically, what in their knowledge bank contributes to the decisions they ultimately arrive at (Faucher et al., 2012). The scientific knowledge that comprises the clinical curriculum has been attained over many decades of research and testing from various doctors, scientists, and research groups. Oftentimes students lack the long-range perspective of understanding how the facts they learn in classes came to be and in what framework the science was constructed within.

In the optometric curriculum, the history of optometry is not taught in a standardized manner. Some schools choose to address it early on in the program or invited guest speakers occasionally make a nod towards the advancements of the profession, but it is rarely taught within the framework of NOS. We posit that it is useful to teach NOS within the optometric curriculum because NOS education has been shown to improve students' understandings of science knowledge. It can also be argued that the scientific practices of thinking and inquiry encourage students to be better critical thinkers when faced with unfamiliar situations.

Background

Historical Background

Optometry is uniquely positioned within the healthcare field. Current day optometrists conduct medical examinations of the eye and the ocular structures, and yet some vestiges of the previous practice of optometry remain. In its original iteration, optometry was the practice of producing the optical measurements associated with correcting refractive error and so optometry was primarily concerned with fitting glasses and contact lenses. However, as the field has evolved, it has largely moved away from refractions and dispensing glasses and contact lenses as its primary focus. Instead, a new field has emerged to fill that gap, and modern-day opticians are highly skilled experts in cutting lenses, determining measurements, and fitting glasses. Contact lenses, specialty lenses, and more complex binocular vision disorders remain under the jurisdiction of optometric practice, leading to a unique milieu in the optometry field in which some practitioners conduct medical exams of the eye and adnexa whereas others specialize in the fitting of glasses and contact lenses.

When we examine the reason for this shift in optometry, several key factors can be identified. First, as technology progressed, more in-depth evaluations of the eye could be conducted and with it came the opportunity to do much more on the clinician's side to prevent vision loss and blindness. Indeed, between 1990 and 2020, the global prevalence of blindness decreased by an impressive 28.5% when standardized for age (Burton, 2022). As knowledge of disease and transmission has progressed, so too has the capacity for preventing vision loss. The World Health Organization (WHO) estimates that at least 2.2 billion people globally suffer from a vision impairment, but encouragingly, in at least 1 billion of these cases, the cause of vision impairment is easily treatable or preventable (World Health Organization, 2019). This further underscores the crucial role of scientific research and advancement in shaping the field of eyecare.

The major advancement seen in vision care over the last 100 years is due to the development of new knowledge and technology which allowed for several key diseases to become curable and preventable. One important example is the prevalence of diabetic retinopathy in the 1950s-1970s. Over the course of the 20th century, a significant increase in the prevalence of type 1 and type 2 diabetes was observed. This was partially due to underdiagnosis prior to this time, and so the true incidence of diabetes, particularly Type 1 diabetes, may have been

closer to the values determined in the population the twentieth century, but it is undoubtedly true that changes in longevity, an aging population, and a rapid increase in the availability of sugar within our diets led to an increase in diabetes throughout the world. With the rise of imperialism and modern industrial societies, sugar was the cheap source of calories for urban workers and industrialization allowed for the mass production of refined sugar. Sugar plantations spread across the Americas and the popularity and demand for sugar grew. During the rise of industrialization in the 1900s, urban workers were undernourished and could not maintain the necessary energy required for the work hours. At the time, scientific knowledge indicated that all caloric intake was the same and achieving a certain amount of caloric intake a day was sufficient to address nutritional needs. Sugar was the cheapest and quickest way to ensure this, and so the U.S. government subsidized the production of sugar leading to cheap prices and an overconsumption arc that continued for decades, even until today (Bosma, 2023).

As the population's diet changed and people started living longer, the incidence of diabetes and with it, diabetic retinopathy, increased greatly. Losing vision due to diabetes was poorly understood until the National Eye Institute conducted the landmark clinical trial called the Early Treatment Diabetic Retinopathy Study (ETDRS), which is still referenced as the gold standard today. This study sought to understand diabetic retinopathy, which is a disease characterized by the growth of new, leaky blood vessels in the retina, fluid buildup in the macula, and retinal hemorrhages. The study examined the efficacy of laser photocoagulation, which was a relatively new treatment developed at the time, at stopping the leakage of proliferative blood vessels in the retina. The results were complex but positive and yielded immensely useful knowledge that has now become the foundation of diabetic retinopathy detection and management (National Eye Institute, 2019). Newer technology, specifically optical coherence tomography, has helped clinicians further refine the treatment protocols put forth by the results of the ETDRS study, but nevertheless it was these early works that established our modern characterization of this disease process.

We review this case to illustrate the importance of understanding social and cultural contexts in the development of new knowledge. The clinical guidelines for managing diabetic retinopathy were not produced by a recipe-like formula and straightforward experiments, but rather by several clinical trials which were modified and whose aims changed as new information was discovered. Furthermore, as time passed, the scientific knowledge harnessed

from the early clinical trials has not been proven wrong, rather it has been expanded upon and enhanced, illustrating the tentative nature of science. The necessity of this research has socioeconomic causes as well. Vision loss due to diabetes was an extreme burden on the afflicted patients and on the healthcare system at large, and so the initiative to conduct this research was rooted in the complex relationships between industrialization, economic policy shifts, changes in the aging population, and corporate influence on changing the diets of Americans.

There are several other key examples of the influence of societal factors on the topics that were expanded upon in optometry. For instance, retinopathy of prematurity (ROP) was a common and devastating cause of irreversible blindness in babies in the 1950s. The disease was occurring due to the best practices at the time that dictated the use of high levels of supplemental oxygen in premature infants in order to help them breathe (National Eye Institute, 2019). Over time scientific knowledge evolved and showed that the oxygen levels being used to treat premature infants were unnecessarily high and were contributing to the overgrowth of abnormal blood vessels in the retina, which was causing blindness in infants. Because scientific knowledge is tentative, new information allowed us to change what we once believed to be true.

In the 1980s, the AIDS epidemic dominated the forefront of healthcare problems and research. Ocular involvement was regularly a part of the illnesses that afflicted patients with AIDS because opportunistic infections such as cytomegalovirus retinitis led to blinding inflammation of the retina. Some level of blindness was present in up to forty percent of AIDS patients (National Eye Institute, 2019). This prompted the need for vision-specific scientific research. One such study that undertook this endeavor was the Longitudinal Study of Ocular Complications of AIDS in 1998 to study the effects of ocular retroviral agents in preventing and treating ocular complications of AIDS. The knowledge gained from this, and subsequent studies, allowed for the prevalence of ocular AIDS to be greatly minimized (National Eye Institute, 2019). Other landmark studies include the Framingham Eye Study conducted between 1971 and 1974 which looked at how social factors such as smoking and alcohol consumption affected a person's risk of developing macular degeneration and other age-related eye conditions (National Eye Institute, 2019). In another example, the Baltimore Eye Survey established the link between African American patients and their significantly higher association with visual impairment due to open-angle glaucoma (National

Eye Institute, 2019). These and other studies were conducted as a response to social and political movements at the time. Ocular research has often echoed the calls of social, political, and economic needs in society. Healthcare funding frequently stems from a political or social need, and so vision science advancements can easily be tracked by the societal progress of the time.

The clinical knowledge database that has been developed over time reflects the society and environment in which these treatment protocols were developed and tested. To the best of our knowledge, the impact of social and cultural context on the expansion of optometric knowledge has not been studied, yet the real-life examples of this aspect of NOS in optometry exist. Anecdotally we have observed recurring instances of disparity in clinical education. For example, many of the textbook models used for teaching purposes are based on Caucasian eye and skin types, and a lack of access to eyecare in minority communities leads to most optometry students having diminished cross-cultural experience during their clinical rotations. This leads to optometry students being less familiar with the disease manifestations in morphologically different posterior and anterior segments. A study conducted on optometry students' perceptions of cultural competency found that a significant number of students reported that they felt unprepared to manage patients from cross-cultural backgrounds (Lewandowski et al., 2021). As optometric knowledge is almost entirely developed from medical practice and clinical experience, there may certainly be a lesser understanding of ocular conditions that present in minority populations, including patients from lower socioeconomic backgrounds and those with disabilities. Teaching students this aspect of clinical education through a NOS lens helps them get a more holistic understanding of the limitations of their own practice.

Another example of the relevance of social context in optometry is that in the past, pseudoscientific viewpoints argued for the existence of biological and genetic distinctions between races. Although this belief has been debunked, a lingering emphasis on racial groupings continues to persist, though it is now without pejorative intent (Geiger, 2003). Furthermore, literature has shown that practitioners continue to hold implicit biases, both consciously and subconsciously, with regards to treatment protocols, responsiveness to pain indications, and overall treatment of minorities within the healthcare system (Geiger, 2003). Previous work has shown that the cultural background of both the doctor and patient affects the patient-practitioner encounter (Truong & Fuscaldo, 2012). In general, within the scope of

medicine, culture is usually associated with ethnicity, nationality, and language (Kleinman & Benson, 2006). There is a paucity of work focused on the intersection between optometry and cultural factors, but one study conducted in Australia showed that there is a potential negative effect on cross-cultural communication between doctors and patients with potentially worse treatment outcomes (Truong & Fuscaldo, 2012). This further highlights the need to identify where the possible deficiencies in cross-cultural patient examinations stem from, and most importantly, if there are aspects of the clinician's training which contributes to a disparity in communication between patients and doctors of different social and cultural backgrounds.

Currently, cultural competency training is limited within the optometric curriculum, and when present it is grounded in specific facts related to the prevalence of eye health conditions in different patient demographics. Continuing education for practicing optometrists occasionally broaches the topic of applying social and cultural backgrounds of patients to medical decision making—indeed in some views, it is frowned upon so as to not practice patient discrimination. However, research has shown that a lack of sufficient acknowledgement and communication between patients and doctors regarding cultural aspects of clinical care leads to worse patient outcomes (Truong & Fuscaldo, 2012). Furthermore, this same study showed that students and practitioners alike place value in learning actual and practical knowledge that is relevant to health care issues (Kai et al., 2001). Though cultural competency training of this nature has proven to be effective at improving doctor-patient relationships, invoking optometry students' understanding of NOS as it relates to social and cultural contexts may be more effective long-term at teaching students how to dynamically tune their practice to different case encounters depending on the contexts of each situation.

NOS in Optometry

NOS research has been the focus of education reform policies for the last several decades, with some accounts pinpointing the rise of modern NOS development in the 1970s and 1980s. NOS is identified as a key component of scientific literacy by the National Science Teachers Association and has become incorporated into science education in many nations around the world including Canada, South Africa, the United Kingdom, and Australia (Lederman et al., 2013). As there are different interpretations and applications of NOS at different educational levels, some existing research is contradictory and subject to

modification. This paradigm both represents science and distinguishes itself from it, as there is not a single set of standards to describe NOS. However, its open-ended nature allows ample work to be done in this field. Students' understanding of NOS serves as a useful measure by which we can gauge an educational system's efficacy in teaching science (Chalmers, 1982). The shift from teaching facts isolated from appropriate contexts to aiming to teach scientific literacy with emphasis on how and why we know things has been motivated by a desire to yield well-informed citizens capable of critical thinking and reflection in a busy world with ever-increasing amounts of information and media consumption.

Scientific literacy is a goal of the optometric curriculum. The OECD describes scientific literacy as being composed of three areas: content knowledge, procedural knowledge, epistemic knowledge (OECD, 2019). Understanding NOS is an important aspect of scientific literacy. The views of nature of science (VNOS) questionnaire is a useful tool to gauge subjects' understanding of different aspects of NOS (Lederman et al., 2002). In this study, we utilize the VNOS Form C to evaluate changes in understanding of NOS in an explicit-reflective curriculum. Third year optometry students were chosen for this study. Eight weeks of NOS instruction as it relates to optometric clinical education were presented. At the end of the semester, the students and researcher reflected on understanding and implementation of NOS, specifically the social and cultural aspects of NOS in optometry.

Purpose

The purpose of this action research study was to determine whether students can reflexively understand and apply nature of science principles to the critical thinking skills they develop during their clinical education. Specifically, that science does not occur in a vacuum and research conducted in different social and cultural environments shapes the nature of the knowledge we study today. Understanding these aspects of clinical education makes practitioners more enlightened and ultimately allows them to provide better clinical care to their patients.

Research Questions

1. a. How does a semester of NOS education infused in their clinical training impact

third year optometry students' views of NOS?

- b. What are third year optometry students' views of NOS at the beginning of their clinical education? In particular, what is their understanding of the social and cultural context of how science is developed, especially clinical science?
2. Is there a link between optometry students' understanding of the cultural aspect of NOS and their approach to patient care with regards to their own social and cultural contexts?

Research Intervention

For this action research study, an explicit-reflective approach was taken to teaching NOS to third year students as a part of their clinical education. For each week's meeting, a common primary care lesson topic was selected, and the group discussion at the end of clinic was developed to be focused on these specific lessons. Clinical instruction was presented regarding each topic, but importantly, *how* this knowledge was learned and what context doctors and scientists developed their early findings were also taught to students. Different pedagogical tools were used each week including videos, news articles, designing experiments, and discussion questions. After the lesson was presented and the students completed the corresponding activity, we had open-ended discussions in which we reflected upon how the lesson and activity helped their understanding of the content and of NOS in optometry.

The action for this research project was the NOS instruction infused into each week's lesson plan. I focused on teaching the social and cultural aspects of NOS within an optometric curriculum, which was previously not a part of the curriculum. The goal of this action was to determine whether students could have an improved understanding of NOS through explicit-reflective instruction in clinical education. The tool used to measure this was the VNOS-C instrument. The practical implications of this work are that the third-year clinical optometric curriculum can be modified to include NOS instruction that may enhance students' understanding of clinical information.

Methods

Four participants were enrolled from an accredited optometry school program in the United

States. Each student was in their third year of the optometry school program completing their spring semester clinical rotation. We chose this stage of their education for intervention because by the end of their third year, optometry students have completed all the didactic portion of their education and are in the process of reviewing material for national board examinations. We felt that this was an opportune time to gauge students' fundamental understanding of science concepts as they were being asked to cross-reference different subjects and topics and complete independent reviews of all the material they had learned thus far in optometry school in preparation for national boards. At the peak of the amassed efforts of their teachers, tutors, test prep courses, and their own efforts, we hoped to see how well a fundamental understanding of NOS could be integrated.

This study took place during the spring semester of 2024 between the months of January-March. It was an eight-week clinical rotation with weekly meetings. The course summary is as follows:

This course goal is to provide an integrated perspective of optometry in the paradigm of problem-based learning (PBL). The problems will be clinical cases which relate to the contents of courses taught contemporaneously in optics, biomedical, and ocular biology modules. Students will meet in small groups to discuss the problems guided by a faculty facilitator. Clinical practice in visual analysis, patient care, and optometric procedures. Case discussion and student evaluation on a regular basis.

Throughout the course of the clinical rotation, students were asked to see patients, take notes on their exam findings, and present the attending physician with a diagnosis, assessment, and plan. At the end of the clinic day, all student groups convened for “grand rounds” discussion with the instructor. It was during this time that in-depth discussions were conducted regarding the facts of the cases, but also how different aspects of optometry are integrated within the case, how each case relates to real-world practice, what trends we can observe, and how it helps build the foundational understanding of optometric practice.

Timeline

- 1) Each student completed the VNOS Form-C assessment prior to the start of the clinical rotation.

- 2) Then, each week, they received explicit instruction in NOS principles as it could relate to optometry (Table 1). Additionally, weekly teacher logs were kept.
- 3) After four weeks, two semi-structured interviews were picked with two randomly selected students to check in about their understanding of the factors that go into medical decision making, including social and cultural contexts.
- 4) At the end of the 8 weeks, they completed a VNOS Form C post-test (Akerson and Hanuscin, 2006). Two final semi-structured interviews were conducted with the same participants as before.

Data Sources

- A. VNOS-C pre- and post-test
- B. Weekly discussion summaries
- C. Teacher logs
- D. Semi-structured interview transcripts

A. VNOS-C

For data analysis purposes, the coding of the instrument is as thus: a) the instrument, b) the form, and c) the question number. For example, question 5 on the VNOS Form C will be labelled as VNOS-C-5. The VNOS-C is an expanded version of the original VNOS instrument. It was chosen for this study because it includes questions on the social and cultural context of science, which is of particular interest for the focus of this text. The VNOS instrument is graded by dividing student responses to questions as either naïve views, transitional views, or informed views. Naïve views are those that are not consistent with contemporary understandings of NOS. Transitional views are those which show some understanding of NOS principles but lack sophistication. Informed views are consistent with thorough understanding of NOS and show mastery over the aspect.

Prior to the start of the clinical rotation, each student was given the VNOS Form C questionnaire to complete in sixty minutes. They were informed of the overarching goal of the experiment and were asked to answer the items in the VNOS-C honestly.

B. Weekly Discussions

In structuring my curriculum for NOS instruction, I chose the following topics for each week (see Table 1).

Table 1. Course Topics and NOS Instructional Strategies for Spring Semester Clinical Curriculum

Course progress	Discussion topic	Explicit NOS concepts	Instruction strategies	Reflective discussion prompts
Week 1	Glaucoma and understanding changes in demographic trends	Social and historical context	Knowledge claim questions	How has our understanding of who is most susceptible to different types of glaucoma changed over time? To what extent does demographic trends affect how we treat patients with different racial backgrounds?
Week 2	Macular degeneration and anti-VEGF	Tentative and empirical nature of science	NEI Leading the Fight Against Blindness video, AREDS 1 and 2, smoking summary	Watch the NEI video on vision advancements over the last 50 years. According to the video what are the scientists most proud of uncovering? What did they learn about Factor X? How did the social prevalence of smoking change the structure of the AREDS studies?
Week 3	Geometric optics and Snell's Law, how do we know?	Science is theory-laden Law and theory are not in a	Knowledge claim activities	According to Snell's law, the ratio of sine of angle of incidence to the sine of angle of refraction is equal to the ratio of refractive index of second medium to the first medium.

		hierarchy		Each point on the wave front emits a semicircular wave that moves at the propagation speed v . We can draw these wavelets at a time t later, so that they have moved a distance $s=vt$. Huygen's principle tells us that each point on a wavefront is a source of secondary waves, which add up to later wavefronts. In this way, Snell's law can be derived from Huygen's theory, yet there is no hierarchical relationship.
Week 4	Dry eye disease	No recipe like formula for science	Create a mental map of dry eye disease, how you would modify treatment	How do we conduct experiments in optometry? What is an example of an experiment you would conduct in clinic? What competitive treatments are there on the dry eye market? What economic factors might be prompting the research in this field?
Week 5	What fields in optometry are growing? Why?	Social context	News articles reading material Scope of practice expansions	Why are some specialties growing at faster rates than others? How is the scope of practice changing the nature of optometry?
Week 6	Myopia epidemic	Social context	Review key articles that cover change	How has our body of knowledge changed from new information we've learned over

			in bifocal spectacles for treating myopia	various myopia control studies?
Week 7	Specialty contact lens design	Creativity	Humdingers	Consider the difficulties in achieving good optics, comfort, and health when designing a contact lens. Discuss the challenges in scleral lens fitting. Create your own model of a contact lens design for a cornea with keratoconus.
Week 8	Fallacy between similar cases	Science is observable and empirical	Patterns experiment	Think of three cases you saw this semester with similar presentations. Find a pattern between these 3 cases. Is this science?

C. Teacher Logs

Researcher logs were kept each week which included reflections on how students responded to the activities and discussions, what questions were raised, and my role in facilitating the conversation. Notes were taken on a paper journal during the weekly meetings and then assembled into a formal reflection.

D. Semi-structured Interviews

In this action-research study, the participants were aware of the goals and parameters of the experiment and were encouraged to offer feedback throughout the semester if the teaching strategies were ineffective or unclear. At two time points, semi-structured interviews were conducted with two randomly selected participants. The discussion prompts for these interviews were:

1. Tell me about your impressions of our weekly activities.

2. Describe your understanding of the nature of science.
3. Is it different from the beginning of the semester?
4. What place does the nature of science have in optometry?

Demographics

This cohort was specifically chosen because by the spring semester of the third year of optometry school, nearly all of didactic education is complete and students have received a comprehensive understanding of optometric practice and its many facets. In their fourth-year optometry students complete clinical rotations full-time, so we chose to intervene at this time to gauge how well students conceptualized NOS concepts at the end of their didactic education. In this study, three participants were female, and one was male. All were between 25 and 28 years of age. All participants were Caucasian.

Results

A. VNOS-C

Following the recommendation of previous research in the field, I coded my students’ responses to each VNOS question. I established validity by grossly comparing the VNOS responses to the general themes found in my other data sources (weekly discussions, semi-structured interviews) to ensure that the VNOS questionnaire was effective at eliciting responses from this cohort. Because there was a small group of participants, all students’ data was included for analysis. Their responses are summarized in Table 2.

Table 2. Individual Student VNOS Results for Pre- and Post- VNOS-C

	Student 1 Pre-test	Student 1 Post-test	Student 2 Pre-Test	Student 2 Post-test	Student 3 Pre-test	Student 3 Post-test	Student 4 Pre-test	Student 4 Post-test
VNOS-1 Empirical NOS	Transition al	Informed	Transition al	Informed	Informed	Informed	Transition al	Informed

VNOS-2 General structure and aim of experiments	Naïve	Transitional	Transitional	Informed	Transitional	Informed	Transitional	Informed
VNOS-3 Validity of observationally based theories and disciplines	Naïve	Transitional	Transitional	Informed	Transitional	Informed	Transitional	Transitional
VNOS-4 Nature of scientific theories	Naïve	Informed	Naïve	Informed	Informed	Informed	Transitional	Informed
VNOS-5 Relationship between theories and laws	Naïve	Transitional	Naïve	Informed	Informed	Informed	Transitional	Informed
VNOS-6 Inferencing and theoretical entities	Transitional	Informed	Transitional	Transitional	Naïve	Transitional	Transitional	Informed
VNOS-7 Inference and theoretical entities	Informed	Informed	Transitional	Informed	Transitional	Informed	Informed	Informed
VNOS-8 Theory-laden NOS	Naïve	Naïve	Naïve	Transitional	Naïve	Transitional	Transitional	Transitional
VNOS-9 Social and cultural embeddedness of science	Transitional	Informed	Informed	Informed	Informed	Informed	Informed	Informed
VNOS-10 Creative and imaginative NOS	Naïve	Transitional	Naïve	Transitional	Transitional	Informed	Naïve	Transitional

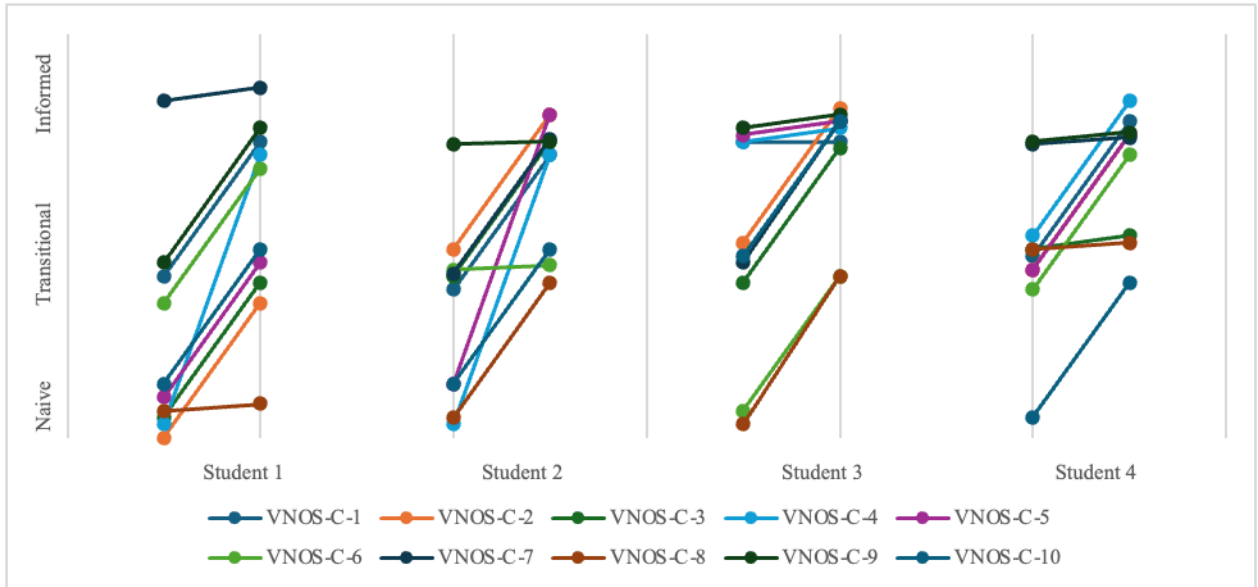


Figure 1. Changes in VNOS Results between Pre- and Post-testing, Eight Weeks Apart

B. Weekly Discussions

Notes were kept and transcribed from each weekly discussion. These transcripts were then coded, and themes were drawn from the compilation of codes for each week. Thematic analysis was chosen for this data set in order to represent a large volume of qualitative data in a concise form. The students shared similar sentiments and rarely had opposing opinions; if present, those statements are included below. Table 3 summarizes this data, with sample representative statements made by students included for each week’s discussion.

Table 3. Thematic Analysis of Weekly Discussions

	Explicit NOS Concepts	Sample Reflection Discussion Statements	Coding	Themes
Week 1	Social and cultural embeddedness of science	<i>“As we’ve learned more about glaucoma, we have learned about demographic trends where primary open angle glaucoma affects the African-American</i>	Racial disparity Socioeconomic factors affecting healthcare Access to healthcare Minorities in the	Social, political, and economic factors shape how optometry has made advances over

		<p><i>population at a higher frequency. It's like, something to keep in mind whenever you have an AA patient."</i></p> <p><i>"But is that racial profiling? For us to assume all AA patients are at risk for glaucoma?"</i></p> <p><i>"I think if the result of the so-called profiling is we give more thorough care to this population, doing so because we know they have more prevalence, then the net result is not a bad thing."</i></p>	<p>United States Economics of medicine</p>	<p>the past several decades.</p> <p>New information changes practice guidelines.</p>
Week 2	<p>Scientific knowledge is tentative</p> <p>Scientific knowledge is empirical</p>	<p><i>"I never realized how hard it must have been to treat AMD without knowing what 'factor X' was."</i></p> <p><i>"The scientists who modified the AREDS formula for AREDS-2 had to change their experiment when they realized they had been wrong to include beta-carotene"</i></p> <p><i>"It makes sense why beta-carotene was found to have a negative effect on former smokers—the study was done in the 2000s but</i></p>	<p>Tentative nature of science</p> <p>New ideas and creativity</p> <p>Teamwork in science</p> <p>Recipe-like formula for science</p>	<p>New ideas change practice guidelines.</p> <p>Scientific research has specific structure, but it can be modified according to the needs of the experiment.</p>

		<i>all the patients in the study were elderly and were young adults during the prime decades of smoking in America”</i>		
Week 3	Science is theory-laden Distinction between laws and theories	<p><i>“Because you can derive Snell’s Law from Huygen’s Principle, does that make all laws a product of principles or theories? Are those the same thing?”</i></p> <p><i>“But in a way, you can also say that Huygen’s Principle could have been made up from Snell’s Law.”</i></p> <p><i>“How do we know? Is it whatever came first chronologically?”</i></p> <p><i>“I think that laws, theories, principles are all sort of the same thing, which is the most reasonable and testable relationship between things”</i></p>	<p>Circular relationship</p> <p>Scientific definitions</p> <p>Intersection of science and other fields</p>	<p>There is not a hierarchy in scientific knowledge.</p> <p>Science shares characteristics with other fields, but it is distinct.</p>
Week 4	Scientific method	<i>“I feel like it’s not real science if we don’t like officially state a hypothesis and make graphs to present data and stuff. Isn’t research like a</i>	<p>Global influences on medicine and optometry</p> <p>Rules and expectations</p>	<p>Scientific research has specific structure, but it can be modified</p>

		<p><i>whole thing?”</i></p> <p><i>“I think that there are a lot of ways to do scientific research- because the scientific method probably wasn’t invented until sort of recently. People have been doing science for a long time.”</i></p> <p><i>“Science is a way of thinking, it is its own thing but it doesn’t have to be according to Western principles. Nothing would ever get done if everyone was always following a strict protocol. I think presenting science in an organized way just makes it easier to communicate globally.”</i></p>	<p>Recipe-like formula for science</p> <p>Historical context</p>	<p>according to the needs of the experiment.</p> <p>Social, political, and economic factors shape how optometry has made advances over the past several decades.</p>
Week 5	Social and cultural embeddedness of science	<p><i>“With optometry trying to distinguish itself as a profession, we all want to specialize in things that make us uniquely optometrists.”</i></p> <p><i>“I wonder what we would be interested in doing if politicians weren’t trying to limit optometric scope of practice.”</i></p> <p><i>“Optometrists in Kentucky</i></p>	<p>Historical context</p> <p>Global influences on medicine and optometry</p> <p>New ideas</p> <p>Economics of medicine</p> <p>Optometry changing in response to</p>	<p>Social, political, and economic factors shape how optometry has made advances over the past several decades.</p>

		<p><i>and places with more advanced scope are different than those in Florida where it's more limited. Do those patients get different care? No wonder people are confused about what it is we do."</i></p>	<p>economic and political cues</p>	
<p>Week 6</p>	<p>Social and cultural embeddedness of science</p>	<p><i>"The growing myopia epidemic is related to increased screen time and globalization."</i></p> <p><i>"It's kind of amazing to see medicine change in our own lifetime because I remember going outside and playing a lot more than kids do now."</i></p> <p><i>"Optometry growing forwards will always teach myopia management and myopia disease because we have to, so our body of knowledge has literally changed forever"</i></p>	<p>Global scientific advances</p> <p>Historical context</p> <p>Tentative nature of science</p>	<p>Social, political, and economic factors shape how optometry has made advances over the past several decades.</p>

<p>Week 7</p>	<p>Science is creative and imaginative</p>	<p><i>“I had forgotten that we can still invent things. Sometimes it feels like everything that needs to exist already does.”</i></p> <p><i>“I really enjoyed this exercise in coming up with my own design. Somebody must have had an idea and that’s how the field of specialty lenses was created.”</i></p>	<p>Tentative nature of science</p> <p>New ideas and creativity</p> <p>Teamwork in science</p> <p>Rules and expectations</p> <p>Recipe-like formula for science</p>	<p>Scientific research has specific structure, but it can be modified according to the needs of the experiment.</p>
<p>Week 8</p>	<p>Scientific knowledge is empirical</p>	<p><i>“If we didn’t intend to do the experiment but the pattern is there, like the data, do we still consider that science?”</i></p> <p><i>“Even though the same thing happened several times, I don’t think that we can call it science because science can’t be a coincidence.”</i></p> <p><i>“I think the difference is that we didn’t test any opposing variables and control other variables to make sure this wasn’t a coincidence”</i></p>	<p>New ideas and creativity</p> <p>Circular relationships</p> <p>Recipe-like formula for science</p> <p>Scientific definitions</p>	<p>Scientific research has specific structure, but it can be modified according to the needs of the experiment.</p>

C. Teacher Logs

When parsing through my teacher logs, I started to notice that many of my reflections shared

the same themes as those identified in the student discussions. This is reasonable as my reflections on our discussions were focused on what I felt the students were learning from the instruction. My teacher logs had reflections about the strengths and weaknesses of my teaching activities, though they were all mostly positive as the students seemed to respond well to each activity. Rather than represent repetitive data, I chose to present how many times the codes elicited from the students' discussions appeared in my own logs (see Figure 2).

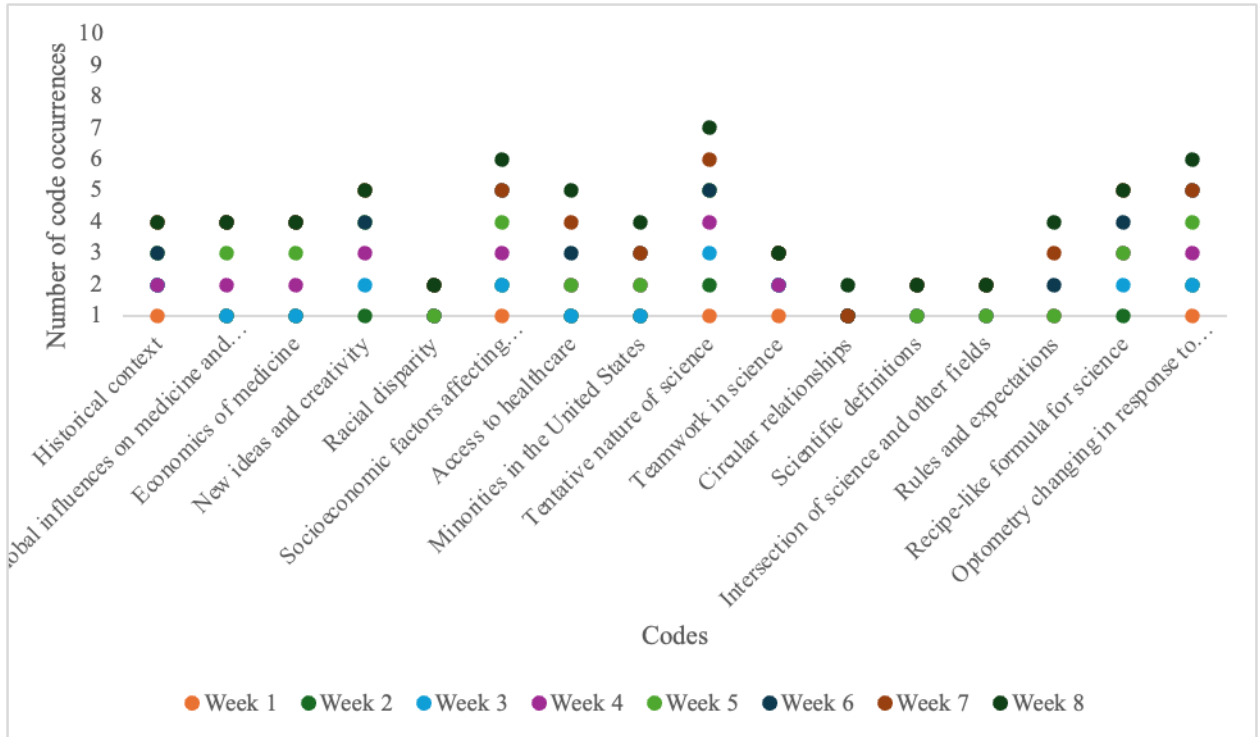


Figure 2. Total Compilation of All Codes and How often they Appeared in my Teacher Log over the 8-week Period

D. Semi-structured Interviews

The individual student interviews were transcribed and coded. The students were asked general open-ended questions regarding their learning experience and understanding of NOS concepts. As the interviewer, I allowed the discussions to evolve on their own and did not overly structure it as I intended for the students to have the freedom to share their thoughts openly. Additionally, I was open to hearing feedback on my explicit instruction activities and whether they were effective. I conducted the interviews at the 4 week and 8-week time points and intended to change my curriculum if the students were having difficulty at the 4-week check-in interview. However, both of the students who were interviewed affirmed that they

felt the curriculum was effective and did not have suggestions for change. The most common themes from these interviews are shown in Table 4, along with specific excerpts from the interview pertaining to each theme.

Table 4. Specific Excerpts from Semi-structured Interviews with Two Students at 4 Weeks and 8 Weeks

	Mid-semester interview	Final interview
Social, political, and economic factors shape how optometry has made advances over the past several decades.	<i>“I thought the social/political aspects of optometry were like, AOA advocacy for scope of practice. I didn’t realize it’s actually a part of all of optometry in some shape or form.”</i>	<i>“Optometry knowledge was a shared effort from many researchers and doctors who had different reasons and motivations for researching a particular area. Optometry as we know it is a reflection of the priorities of all the generations that came before us.”</i>
New information changes practice guidelines.	<i>“It’s okay for doctors to be wrong. All we can do is try our best with the information we’re given. That’s why we spend so much time in school, so that we learn as much as we can. We also have to keep taking continuing education classes so that we stay up to date with the latest protocols and technologies.”</i>	<i>“Science isn’t wrong, it’s tentative. It’s a part of what makes it science. I used to think science was different from the arts because we operate on absolute facts. But after this semester I understand that science is going to change and sometimes contradict previously held beliefs. What makes this science and not guesswork is testing and researching and being aware of biases and agreeing together that something is most likely true.”</i>
Scientific research has	<i>“I just remember the scientific method being taught in school as</i>	<i>“The NOS aspect of there being no recipe-like instructions for</i>

<p>specific structure, but it can be modified according to the needs of the experiment.</p>	<p><i>the way to do science. I guess it makes sense that not everything in the real world is only a product of strict adherence to the scientific method because nothing would get done. I still wonder if discovering things by accident is considered science. And in a way, the scientific method makes sense because it's basically keeping you focused on a single variable and following a logical pattern. I'm not exactly sure why people wouldn't just choose to follow the scientific method."</i></p>	<p><i>science is meant to echo the fact that science can be tentative and creative. Certainly many times you can and do follow the traditional scientific method, but the nature of science is such that if new knowledge is developed and it wasn't a result of traditional step by step methods, it can still add to the scientific body of knowledge if it's in line with all the other things that makes something scientific.</i></p>
<p>There is not a hierarchy in scientific knowledge.</p>	<p><i>"You're not working your way up to a scientific law. A principle, theory, equation are not weaker than a scientific law and a scientific law doesn't trump those things. It's just a word that helps explain the relationship between things. It's basically interchangeable with all those other words."</i></p>	<p><i>"Scientific relationships are described by various equations, laws, and principles which are so called because they can be consistently observed and like we saw with Huygen's Principle and Snell's Law, sometimes one can be derived from the other. Sometimes scientific laws change if there is compelling new information."</i></p>
<p>Science shares characteristics with other fields, but it is distinct.</p>	<p><i>"Something we've talked a lot about this semester is what makes something science. I never really thought too much about it because I felt that anything that's real and true is science, and anything that's a guess or a coincidence is not science. But lately we've had a lot</i></p>	<p><i>"This whole semester has been about the nature of science and now I feel like I get it. It's true that science can change, that it's not cut and dry. We can use our creativity, we can do science experiments in our own clinic without the formal steps of the</i></p>

	<p><i>of stuff in the news about alternative facts and science seems to be questioned more than ever. People seem to not be trusting science because like with COVID-19, scientists told us one thing about masks and then changed their minds. It seemed like there was misinformation about it. That sort of thing has cast a lot of doubt on good science versus bad science. At my undergrad lab, it seemed like the goal was just to publish papers and sometimes I wondered what the point was. Like we talked about, economic factors definitely play a role in science now. But I still think science is real and that's what makes it different from other fields."</i></p>	<p><i>scientific method necessarily. The aspects of NOS that we've covered has given me a whole new perspective on optometry and I feel like I can shape our field too. It's not just stuff in textbooks that we have to memorize and then go do. We are all going to contribute to it and now I feel like I have a much better understanding of how and why I should."</i></p>
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Discussion

This action research project was a pilot study in exploring how explicit-reflective NOS instruction could be used to assess students' learning and understanding of specific NOS concepts, in particular the social and cultural embeddedness of science, after 8 weeks of explicit-reflective instruction. The majority of NOS research to date focuses on K-12 education and there is limited research on NOS in higher level programs. This is likely because there is an expectation that effective instruction of NOS during elementary years should prepare students with sufficient understandings of NOS, and so there is perhaps less need to evaluate adult learners. However, in the case of science-based graduate school programs like optometry and medicine, students continue to attend school and engage in robust curriculums well into their adult years. Previous work has aimed to assess the use of the VNOS instrument, specifically the VNOS-C, in undergraduate and graduate students

(Lederman et al., 2002). Though there are many open-ended questionnaires that have their strengths and limitations in assessing NOS, the VNOS-C is effective in gauging optometry students' understanding of the social and cultural contexts of NOS.

We chose an explicit-reflective instruction approach for this study because studies have shown that this method can help provide students with a real-world context and a framework with which to analyze NOS aspects (Khishfe & Abd-El-Khalick, 2002). It also encourages students to reflect upon examples they see in clinic and helps tie in NOS concepts to their clinical education. Studies have also shown that NOS education is particularly effective when correlated to socioscientific issues (Sumranwanich & Yuenyong, 2013), and so for the focus of our work, we aimed to tie in various NOS aspects to an optometric clinical curriculum.

At the beginning of this study, my students were unfamiliar with the term “nature of science”, and though they showed some degree of familiarity with NOS concepts (Table 1), they did not recall receiving explicit NOS instruction during their schooling. This may likely be due to regional differences, or may be that as young students they did not recognize NOS being taught in the classroom. Furthermore, the optometry students originally did not believe there would be significant connections between theoretical NOS and real-world optometry concepts. However, as the semester progressed, they started to understand the different NOS aspects integrated in optometric education, which is indeed the overarching goal of NOS education.

In particular, the activities which the students found most engaging were weeks 4, 7, and 8 (see Table 1), which focused on the non-formulaic aspect of NOS, the creative aspect of NOS, and the empirical evidence aspect of NOS, respectively. In week 4, we discussed the current landscape of dry eye treatment. Dry eye disease is an exceedingly common condition in which many people, especially due to the rising use of computer screens and digital devices, experience eye fatigue that manifests as eyes burning, stinging, watering, or feeling uncomfortable. Because of its prevalence, pharmaceutical companies and device manufacturers have eagerly entered the field and developed a large plethora of eye drops, light pulsation devices, tear stimulators, gland massagers, and various other therapies for treating dry eye. However, the clinical cause of dry eye nearly always has a complex and mixed mechanism, and so treatment options are not usually well-tailored. Instead, there is a tendency in the field to “try it and see”, and new pharmaceuticals or therapies are prescribed

without a formal protocol. In part this is because dry eye management is still a fledgling field, but it is also because the competing economic interests of drug and device manufacturers contribute to different practitioners getting more exposure to some treatments over others.

In our activity, I presented this context to the students and asked how they would go about selecting treatment options for their patients, and what evidence they would use to support their decision. The students really enjoyed this activity because it reminded them that even in clinical medicine, we are still science-based, and should approach clinical problems with scientific reason. Each student developed their own potential clinical experiment for assessing the efficacy of different treatments and discussed how science does not need to be conducted in a rigid format in order to yield valid results.

During week 7, we discussed the creative aspect of science. In my discussion prior to the activity, I shared how one of the aspects of NOS that seems least present in clinical education is the creative aspect of NOS, and I shared examples of how it can be found all throughout optometry. For our activity, I had students design their own scleral or specialty lens to solve a problem. In optometry, corneas with ectasias present unique fitting challenges for the practitioner as there needs to be a delicate balance of enough oxygen exchange, fluid exchange, good optics, and adhere to the anatomical variations of diseased corneas.

Ideally, the lens should be easy to insert and easy to remove. Several scleral lens designs exist, but none are optimal for all patients. I had students try their hand at designing their own lens type and asked them to draw a design and think through how the surface tension and fluid dynamics of the lens could work on the eye. The students were excited to invent their own lens and enjoyed experiencing the creative aspect of NOS.

For the last week of our clinical rotation, I had students reflect upon three or more presentations of a single disease condition and asked them to list the similarities in the cases. Then, I asked them if these qualities they had noted were always going to indicate that disease and what could be said about drawing conclusions from clinical data. We compared this activity to some of the responses we had in week 4, in which some students said a part of their clinical experimentation would be to keep logs of how well certain therapies worked on each patient they prescribed them to, and to use those logs to find trends which would then help them make their medical decisions. During week 8, I had the students reflect on

everything they had learned about NOS and we discussed what makes a practice scientific.

Each of the explicit-reflective lessons and activities we did allowed for robust discussions regarding NOS in optometry. Throughout the semester, we focused specifically on the social and cultural contexts of NOS as it is this aspect which most relates to optometry. The codes and themes extracted from the total data of weekly discussions, teacher logs, and student interviews most often related to the socioeconomic factors relating to optometry (Figure 2, Table 4). The evolving nature of optometry is in large part due to changes in insurance coverages, competition in the market for new therapies, political tensions regarding scope of practice in various states, and ensuring quality access to care in rural and underserved areas. These challenges are being addressed by the field in various ways, including increasing the number of optometry schools, political advocacy for state legislation, encouraging moving optometry practices to rural areas, and working with pharmaceutical companies to develop cost-effective and accessible therapies for patients whose insurance coverage limits them from receive adequate care.

Healthcare in general is impacted by these economic, political, and social issues. The intersection of these in modern times is a continuation and reflection of the social and cultural contexts of science that have always existed. As educators, teaching students the framework within which these issues impact the development of knowledge and their clinical practice helps them become more well-rounded and empathetic practitioners.

Conclusion

The social and cultural aspects of NOS are seen throughout the evolution and current day practice of optometry. To the best of our knowledge, this is the first study that evaluates how NOS aspects can be specifically integrated into the optometric clinical curriculum. Optometry students are able and eager to learn NOS principles when tied into real world examples, and NOS education enhances their overall understanding of how clinical concepts relate to one another.

Recommendations

Explicit-reflective teaching is effective at teaching NOS concepts to optometry students and it

can be reasonably integrated into the optometric curriculum. By framing optometry coursework in NOS concepts, the intersections of clinical subjects such as epidemiology, pharmacology, ocular disease, contact lenses, glaucoma, and pediatric vision are better retained. Understanding how we know things and why we practice how we do helps burgeoning young clinicians learn how to practice medicine with their own individualistic goals and priorities. The social and cultural embeddedness of NOS directly applies to the changing nature of optometry and should be taught in the curriculum in order to emphasize to students the importance of recognizing and responding to changes in the field.

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Chapter 5 - Preparing to Teach Undergraduates About the Social and Cultural Embeddedness of Endangered Species

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Chapter Highlights

- How diverse cultural backgrounds of instructors can be leveraged as pedagogical assets when teaching about the social and cultural dimensions of endangered species conservation are discussed.
- Some of the challenges of navigating value conflicts that emerge when teaching the sociocultural aspects of environmental science are identified.
- The importance of critically engaging with non-scientific narratives to support learning in environmental science topics is explored.
- The intentional attention to emotional aspects of learning and an underlying necessity of vulnerability that has implications for teacher education are identified.

Introduction

The nature of science (NOS) is a critical construct for science education. It is one of the three bodies of knowledge necessary for scientific literacy, alongside science content and scientific practices (Lederman & Lederman, 2014). Four aspects of NOS align with Next Generation Science Standard's (NGSS) Science and Engineering standards. These aspects are that there is no universal scientific method, science is empirically based, scientific knowledge is tentative, and science uses laws, models, and theories to describe and explain phenomena (Akerson, 2022). An additional four aspects of NOS align with NGSS's crosscutting concepts. These are: science is a way of knowing; science explains the natural world; science assumes order and consistency in natural systems; and science is a human endeavor. Unfortunately, epistemic dimensions, such as the empirical nature of scientific knowledge in the first group, overshadow the non-epistemic dimensions of doing science in the second group, such as the social and contextual factors (Garcia-Carmona, 2024), resulting in a limited understanding of science. Teaching science in such a matter is complex as it requires educators to understand science's cultural embeddedness and students' learning contexts and experiences. Additionally, challenges arise in creating or adapting resources highlighting science's social and cultural aspects, particularly in undergraduate settings.

As instructors of an undergraduate science course, we understood the importance of teaching all aspects of the NOS. Our academic backgrounds, however, seldom provided us with the opportunity to learn the cross-cutting concepts, specifically the social and cultural aspects. Through this inquiry, we sought to answer the following question: What factors should we, as university instructors, consider when teaching the social and cultural aspects of science? Since this is an introductory course on scientific inquiry, we sought to design and implement a unit in environmental science to understand our preparedness to teach these aspects to non-science majors. We chose biodiversity and endangered species as the context to address social and cultural aspects of science, fostering discussions on how different groups view animals and conduct investigations into their behaviors.

Guiding Literature

Nature of Science and Cultural Embeddedness

Nature of Science (NOS) has evolved significantly from its initial conceptualization as

primarily epistemological to a more comprehensive understanding that encompasses social and cultural dimensions. While traditional NOS instruction often emphasized the empirical basis of scientific knowledge and the role of evidence in scientific reasoning (Lederman et al., 2002), contemporary scholars argue for a more nuanced approach that recognizes science as a human endeavor deeply embedded in social and cultural contexts (Dagher & Erduran, 2016; Matthews, 2012). This requires instructors to develop what Crawford (2014) terms "adaptive expertise" - the ability to flexibly navigate between traditional scientific methods and culturally responsive teaching approaches. Teachers must create learning environments that explicitly highlight how scientific knowledge is constructed within cultural contexts, using pedagogical strategies such as cultural case studies, comparative analysis of different knowledge systems, and structured reflection activities that help students examine their cultural assumptions about science (Lee & Buxton, 2013). The sociocultural dimension of our framework draws on Aikenhead's (1996) seminal work on cultural border crossing in science education. For instructors, this involves developing what Carter (2008) describes as "cultural scaffolding" - pedagogical strategies that help students navigate their cultural experiences and scientific practice. Teachers must create what Hammond (2014) calls "culturally responsive learning environments" where students can explore how their cultural backgrounds influence their understanding of scientific concepts. This requires implementing specific teaching practices such as cultural dialogue protocols, identity-affirming activities, and structured cross-cultural comparisons of scientific understanding. Recent work by Bang and Medin (2010) and Bang et al. (2010) provides practical guidance for teachers in incorporating indigenous knowledge systems and cultural practices into environmental science instruction through community storytelling, elder interviews, and place-based learning activities.

This framework provides the foundation for examining how university instructors can effectively teach the cultural dimensions of scientific practice topics on endangered species conservation. For university instructors, this involves navigating complex pedagogical terrain where content knowledge intersects with cultural awareness and responsive teaching practices. Moreover, instructors must develop what Gay (2018) describes as "cultural competency" in science teaching, which involves recognizing and validating different cultural perspectives while maintaining scientific rigor. This complex instructional landscape requires teachers to simultaneously act as content experts, cultural mediators, and facilitators of critical dialogue about the intersection of science and society.

The Social and Cultural Embeddedness of Environmental Education

Environmental education literature enriches our understanding of effective teaching practices in this context. Barnhardt and Kawagley (2005) define "two-way learning" - that discusses pedagogical strategies that bridge Western and indigenous knowledge systems. This involves implementing specific teaching practices such as comparative case studies, cultural mapping exercises, and community-based research projects. Contemporary scholarship emphasizes the importance of explicitly addressing cultural competence in science education through specific pedagogical approaches. Wallace and Brooks (2015) offer practical strategies for teaching about endangered species through cultural lenses, including techniques such as cultural value mapping, stakeholder analysis, and community conservation case studies. The intersection of these theoretical perspectives is particularly relevant for undergraduate science education, where instructors must implement what Meyer and Crawford (2011) term "culturally authentic pedagogical practices."

Research by Tanner and Allen (2007) indicates that undergraduate students often struggle to connect scientific concepts with broader social and cultural contexts, requiring teachers to develop what Costa (1995) calls "cultural congruence" in their instructional approaches. This involves implementing specific teaching strategies such as cultural dialogue journals, cross-cultural scientific investigations, and community-based research projects. Instructors must create what Greenwood (2009) terms "critical pedagogies of place" through environmental storytelling, cultural value analysis, and community-based conservation projects. These approaches help students recognize how local contexts and cultural values influence scientific practice and environmental conservation efforts. Through these theoretical lenses, we engaged in our preparation and practice in teaching science's social and cultural aspects in the context of endangered species. This framework guides our investigation of the factors university instructors should consider when teaching about the cultural embeddedness of science, particularly in the context of endangered species conservation.

Science Educator Identity Development

Many science educators, particularly at the university level, face the challenge of translating constructivist principles into practical teaching strategies. Integrity between theory and practice becomes a much more intentional task for teachers who have learned and done

science in an empiricist paradigm but have come to new aspirations to teach science in a critical constructivist manner. However, the principles do not translate to practice neatly, and an intentional reflection would help make the teacher aware of how much they can self-actualize. Buck et al. (2016) note that science educators at the university level are often left to navigate these pedagogical complexities independently, with little structured support for transitioning from their previous experiences as science practitioners to their new roles as educators. Self-study methodology holds particular significance for international PhD students who simultaneously navigate roles as science educators and emerging scholars. These educators occupy a unique position at the intersection of multiple transitions: moving between educational systems, shifting from science practitioner to educator, and adapting to new cultural contexts of teaching and learning. In the process, we also question and understand our assumptions, beliefs, and ideas for teaching students and how they bleed into our practice.

Mensah's (2016) research on positional identity in science education reveals how teachers' self-perceptions, shaped by their intersecting social markers, fundamentally influence their pedagogical approaches and professional identity development. Her work demonstrates that science teachers' understanding of their positionality - their social, cultural, and professional locations - shapes their conceptualization of science teaching and their interactions with students. This framework of positional identity provides crucial insights into how teachers' multiple identities intersect to inform their instructional decisions and their capacity to create meaningful learning experiences in science classrooms. Thus, this self-study allows us, as international science educators, to leverage our cross-cultural perspectives as a strength in our practice and understanding of the development of our complex science educator identity.

Method

Self-Study Approach Within Action Research

The methodological foundation of this study is rooted in the rich theoretical traditions of practitioner inquiry and self-study research in teacher education. Ken Zeichner (2001, p. 274) categorizes self-study as a form of action research where educators inquire into their practice as teachers and teacher educators, a growing trend in university education contexts. At its core, this approach embodies what Cochran-Smith and Lytle (2015) term an "inquiry stance" - a philosophical orientation that positions teachers as generators of knowledge rather than

mere consumers. This perspective fundamentally shapes our understanding of how teachers develop professional knowledge about teaching science's cultural dimensions, particularly in the context of endangered species conservation. The theoretical framework recognizes what Pinnegar and Hamilton (2009) describe as the "epistemology of practice," where knowledge emerges from systematically investigating teaching experiences and professional judgment rather than being simply transmitted from external sources. As theorized by Loughran (2007), Self-study methodology represents more than a collection of research procedures; it constitutes a distinct theoretical approach to understanding teacher development and professional learning. This theoretical foundation builds upon Schön's (1987) seminal work on reflective practice, which posits that practitioners develop unique forms of knowledge through systematic reflection on their actions. This involves what Russell and Martin (2023) term "professional knowledge-of-practice" - the specialized understanding that emerges when teachers deliberately investigate their approaches to teaching about science's cultural dimensions. The theoretical depth of our methodological approach is enriched by Berry's (2007) theory of professional learning through tension, which suggests that teacher development occurs through the productive navigation of pedagogical dilemmas. As Bullough and Pinnegar (2001) argue, these tensions serve as critical sites for professional learning and theory development. This perspective helps us understand how instructors develop their capacity to teach about science's cultural embeddedness through encountering and resolving various challenges in their practice. These ideas connect with what Kelchtermans and Hamilton (2004) describe as the "biographical perspective" in self-study research - understanding how teachers' personal histories and professional experiences shape their developing knowledge and practice.

The theoretical framework incorporates Bartholomew et al.'s (2004) five dimensions of effective practice as analytical tools and theoretical constructs that help us understand the complex nature of teaching about science's cultural dimensions. These dimensions represent what Craig (2009) terms "knowledge communities" - theoretical spaces where different forms of professional knowledge intersect and develop. Through these dimensions, we examine the epistemological understanding of cultural aspects of science, the theoretical basis for teacher identity development, the foundations of classroom dialogue, the nature of student learning in cultural contexts, and the theoretical underpinnings of instructional decision-making. This comprehensive theoretical foundation provides a robust basis for understanding how university instructors develop their capacity to teach about the cultural embeddedness of

science. It acknowledges what Bullough and Pinnegar (2001) term the "transformative agenda" of self-study research - its potential to generate personal and public knowledge about teaching practice.

This framework thus serves as a theoretical bridge between the epistemological foundations of self-study research and the practical challenges of teaching science's cultural dimensions. It provides a conceptual structure for understanding how teachers develop their professional knowledge and practice while navigating the complex terrain of culturally responsive science education. The framework emphasizes the dynamic interplay between theory and practice, personal and professional knowledge, and individual and collective understanding in developing effective teaching practices.

This self-study investigation was guided by the question, what factors should university instructors consider when teaching science's social and cultural aspects through the context of endangered species conservation? This was broken down into three sub questions. These included (1) How do instructors navigate the tensions between traditional scientific perspectives and diverse cultural ways of knowing? (2) What pedagogical strategies effectively support undergraduate students in understanding the social and cultural embeddedness of science? And (3) How do instructors' cultural backgrounds and assumptions influence their approach to teaching about the social dimensions of science?

Participants and Context

Our action research team comprised of three international university instructors, all teaching at least one section of the same undergraduate science education course. In addition, a fourth university instructor served as a critical friend, challenging our perceptions and assumptions throughout. Critical friends are necessary for self-study research to “mediate, provoke, and support new understandings” (Samaras, 2011, p.5). We voluntarily engaged in this collaborative inquiry to explore practical approaches for teaching science's cultural and social aspects while systematically examining our pedagogical practices. We adopted a self-study model of action research, positioning ourselves at the center of inquiry throughout the complete teaching cycle. This approach unfolded in two distinct stages: active implementation and critical reflection. Through this two-stage process, we sought to identify critical factors that influence teaching social and cultural aspects of science at the

undergraduate level.

Data Collection and Analysis

Data collection encompassed multiple sources designed to capture our developing understanding and practice of teaching science's social and cultural aspects. The primary data sources included reflective journals, planning meeting transcripts, post-teaching reflection sessions, and critical friend discussions. Each instructor maintained a teaching journal throughout the unit, documenting their personal ideas, observations, challenges, and emerging insights about integrating cultural perspectives into science teaching. These journals served as rich repositories of our individual experiences, pedagogical decisions, and evolving understanding of culturally responsive science teaching in the context of endangered species conservation.

The instructors engaged in three structured planning meetings throughout the teaching period. These meetings were audio-recorded and transcribed, providing detailed documentation of our collaborative planning process, pedagogical reasoning, and the evolution of our teaching strategies. The timing of these meetings - before the unit began, during its implementation, and after its completion - allowed us to capture the progression of our thinking and the adaptations we made in response to classroom experiences. Our reflection process was systematic and multi-layered, comprising four distinct reflection rounds. The first reflection occurred before the start of the unit, where we documented our initial assumptions, expectations, and planned approaches to teaching cultural aspects of science. Two subsequent reflections followed each teaching session, allowing us to capture immediate insights into the effectiveness of our strategies and student responses to cultural content. The final reflection emerged from a focused discussion with our critical friend, providing an external perspective on our teaching practices and assumptions.

The analysis of this dataset followed Braun and Clarke's (2006) thematic analysis approach, providing a systematic method for identifying patterns and themes in our teaching practice. We began with thorough familiarization with the data, reading and re-reading all journals, transcripts, and reflection notes. Initial coding involved identifying key moments, decisions, and insights related to teaching cultural aspects of science. We then worked collaboratively to identify emerging themes, reviewing and refining them through discussion and comparison

across data sources.

Instructional Design and Implementation

Having established our methodological framework, we designed our instructional approach to specifically address the challenges of teaching sociocultural aspects of science. Both theoretical foundations and practical considerations of undergraduate science education informed our design choices. The intersection of socioscientific issues (SSI) and critical scientific literacy provides a robust framework for examining science's social and cultural dimensions. While educators increasingly recognize SSIs like climate change and conservation as opportunities to develop critical scientific literacy (Zeidler, 2014), this development is not automatic. Students often perceive these issues primarily as technical matters, overlooking their sociocultural dimensions (Hodson, 2011). To foster genuine critical scientific literacy, educators must enable students to recognize the sociopolitical embeddedness of science and technology. The Critical Thinking and NOS (CT-NOS) framework (Yacoubian, 2015) further enriches this approach by emphasizing two crucial goals: developing informed judgments about NOS views and applying NOS knowledge in decision-making processes (Almeida et al., 2023). Our undergraduate science course mainly focused on the latter goal, using endangered species conservation as a context for exploring science's social and cultural dimensions. Scientific practices like argumentation and explanation were built into the unit since learning to do scientific inquiry is the larger goal of the course.

We approached endangered species conservation from an SSI perspective, creating opportunities for students to examine and practice decision-making focusing on:

- The influence of social, cultural, and personal values on understanding the natural world
- The relationship between science and society
- Multiple perspectives on SSI (Sadler et al., 2007)

Our instructional design incorporated case studies featuring varied narratives of endangered species from different regions. The culminating assessment took the form of a debate, requiring students to engage critically with multiple perspectives while developing and justifying their positions on conservation efforts. We wanted the students to observe the cultural embeddedness and the resulting variation in science in two layers. These included

how different cultures viewed and interacted with the natural world differently within their social realities and how science is presented/produced in various forms by different groups.

Table 1. Case Studies Used in Instruction

Species	Location	Whose voices and narratives were strong?	Style of the scientific communication	Who are the authors?
Fiddler Crab	Chennai, India	Local community and environmental activists/scientists	Visual and narrative with supporting scientific evidence	Community members with scientists
African Elephant	Parts of Africa	Scientists	Objective-factual, technical	Scientists
Sucker Fish	California	Native American communities and Scientists	Analytical, qualitative, and interdisciplinary	Interdisciplinary STS scholar
Water Lizard	Indonesia	Local community and Scientists	Interdisciplinary, qualitative	Scientists
Whale	Poland	Local community and Scientists	Interdisciplinary	Interdisciplinary STS scholar
Leopard	South Africa	Scientists	Objective-factual, technical	Scientists
Sea Turtles	Tortuguero, Costa Rica	Local community, Tourism stakeholders and Scientists	Formal, academic	Scientists

Findings

This section presents the emergent themes that arose from this collaborative action research incorporating sociocultural embeddedness (SCE) in our undergraduate classrooms. We faced several significant challenges. These challenges can be categorized into four major themes: (1) Confronting tensions created by values and emotions, (2) Fostering student relationships

with the natural world, 3) Understanding the role of the instructor, and (4) Addressing non-science narratives.

Confronting Tensions Created by Values and Emotions

Our experience teaching science's social and cultural embeddedness through endangered species conservation revealed complex emotional and value-based tensions that significantly influenced classroom dynamics. These tensions manifested in multiple ways, challenging us to develop responsive and nuanced teaching strategies that could support meaningful student engagement with sociocultural aspects of science. The most immediate tension we encountered was the students' profound hesitation to discuss socio-scientific issues. This reluctance stemmed from what we identified as deeply ingrained expectations about science education. As Nivedha observed, *"They're having so many thoughts. I can observe that, but they're still not sharing it... because they are used to giving perfect, definitive answers in a science class"*. The challenge was further complicated by students' apparent need for continuous encouragement, with Tajinder noting that *"students demand a lot of push from us when we're repeating the things and we are saying you have to answer."* Beyond this initial hesitation, we discovered a deeper emotional burden associated with discussing conservation issues. Students appeared fearful of expressing opinions on significant environmental matters, as Nivedha articulated: *"Asking them to share opinions about these big social scientific issues... kind of scares them. It's also emotionally a bit taxing right? Because you're going to say a big opinion, and then that they were like holding them back"*. This fear was rooted in concerns about judgment and error, particularly when *"these are big things, right? So, what if they are wrong, or what if their view is considered as a bad one, or understood negatively?"*. Cultural value differences created another layer of tension, particularly evident in students' disconnect from broader conservation values. Emmanuel found that *"most of them are naïve about the values that, why will somebody want to save species,"* while Tajinder noticed how this affected their ability to engage with conservation issues: *"So how, if they don't know, if they don't know the importance of that particular species, like for the whole community... how they can feel connection with that"*.

A recurrent theme involves the tension between scientific perspectives learned in mainstream science and traditional knowledge systems. Instructors in multicultural classrooms, where students bring diverse cultural backgrounds and assumptions, face the challenge of helping

students recognize the validity of multiple ways of knowing without positioning one approach as inherently superior. We also notice that all three of us, being international instructors, have an advantage in seeing things from outside the U.S. culture and providing better representation and guidance in navigating conservation efforts in other countries. However, there is also a disadvantage since we are not remarkably familiar with American life and hence limited in our ability to steer controversial debates. This awareness was evident with all instructors as we did not get deep into specific discussions that would have brought certain cultural practices under scrutiny.

The other challenging area was helping students understand that conservation policies are rarely based solely on scientific data; they are also shaped by the values and priorities of diverse stakeholders. In this way, we had to go beyond imparting scientific knowledge to encourage critical examination of the sociopolitical factors that influence conservation decisions. Nivedha noted how she encouraged students to identify the types of reasonings provided by different stakeholders involved in the conservation issue. However, that was not enough to help students understand the underlying values for those conflicting arguments or to critically appraise the possibilities for a community providing scientific reasoning and the scientists and governments producing economic reasoning against the usual assumptions.

In response to these challenges, we developed several strategic approaches. A particularly effective strategy involved instructors sharing their vulnerabilities. Nivedha described how she opened up about her conflicting values around killing animals and eating meat-based diet: *"I was sharing how there is misalignment even between my beliefs and the practices I do... I was sharing that there is a little bit of hypocrisy in how I think about certain things"*. This approach helped create safe spaces for discussion, with Nivedha noting that *"after that, some students joined that discussion and Okay, yeah."* Emmanuel created distance from personal judgment through carefully constructed scenarios about sacred forests. At the same time, Nivedha observed that when questions were posed hypothetically, *"Then it was like helping them engage more because they are not talking about reality."* This approach allowed students to explore complex issues while maintaining emotional safety. We also found that building emotional connections through understanding could transform students' engagement with conservation issues. Tajinder described this evolution: *"First student took those species as we have on their beauty... but when I explained, when we explained the importance of those species, in the end, their perspective totally changed. They feel sympathized as well as*

empathize towards that species". Emmanuel noted how discussions about values sparked curiosity and engagement among learners. Creating structured yet supportive discussion spaces became crucial to our approach. Nivedha developed a systematic method: "I separated them into segments and time to keep them moving through the stages of inquiry. I was able to support them better in this arrangement".

This structure was complemented by personal attention, as she "went to each group and asked them generally what they felt about the case study and what kind of message they got from the article." The effectiveness of these strategies became evident in student engagement. Emmanuel observed, *"The student response was very great... The conversation was rich and rich I went. Other groups were raising concern and commenting on that group's presentation".* Students began demonstrating a deeper understanding of cultural perspectives, as Nivedha noted when, *"Students highlighted them during group presentations. Some students could identify the positive role of the taboos in Indonesian islands that prohibited the hunting of water lizards".*

Our journey revealed that successfully navigating emotional and value-based tensions in teaching sociocultural aspects of science required recognizing their complexity and developing responsive, adaptive strategies. As Tajinder reflected, *"We need to find that bridge through which we can make an interest... in the students".* This bridge-building process demanded careful attention to both the emotional barriers students faced and the pedagogical approaches that could help overcome them, leading to more meaningful engagement with science's social and cultural dimensions.

Fostering Student Relationships with the Natural World

Our data revealed profound differences in how instructors and students related to the natural world, highlighting the significant impact of cultural and environmental contexts on teaching and learning about endangered species. These differences created both challenges and opportunities in our efforts to teach the social and cultural embeddedness of science. The contrast between instructors' and students' relationships with nature emerged as a fundamental teaching challenge.

Coming from cultures with more direct environmental connections, we initially struggled to

understand and adapt to our students' *"technology-mediated relationship with nature."* Nivedha articulated this cultural divide clearly: *"We come from cultures which is much closer to nature like our house and the outside environment is not very different..., but here it is completely different. We are inside. They live in environments which are completely technologically controlled"*. Emmanuel's experience further illustrated this gap when he noted students limited direct exposure to wildlife: *"I asked them if they have ever seen this kind of animals in the locality these days, and then the response was that they've never seen some say they've never seen them. They only see them in videos and some online"*. This disconnection from nature manifested in several ways that affected student learning. Students showed stronger emotional connections to familiar domestic animals than endangered species, as Emmanuel observed: *"Most of them were talking about dog and cat... they have some kind of emotion attached to this kind of animal."* Tajinder noticed how this limited exposure affected student engagement: *"So how, if they don't know, if they don't know the importance of that particular species, like for the whole community... how they can feel connection with that"*. Even when opportunities for nature connection existed, students seemed hesitant to engage. As Nivedha noted: *"Even though there are several zoos and national parks here... I did put some open-ended questions like, have you been to any zoos? Or is there any like that? But there was not much response around that"*.

Recognizing these differences prompted us to develop various pedagogical strategies to bridge this natural disconnect. We incorporated visual tools and multimedia resources to make distant natural phenomena more accessible. Tajinder reflected on the effectiveness of video resources: *"I showed them a video... through which students can understand with a different perspective from local community people, businessman, and the government or the policy lens with more visual effect"*. Emmanuel utilized storytelling about sacred forests and traditional ecological knowledge from his African background, noting how these narratives helped students understand different cultural relationships with nature: *"Africans don't play with it... and then relating to things relating to how the species aspect I was actually relating to stories in Africa, and how Africans deal with saving species, and how they even see some of these animals to be gods"*.

Our growing awareness of the nature disconnect led to important realizations about our teaching approach. Nivedha reflected critically on missed opportunities: *"Even though I was aware of that. I did not try to make that very explicit, and I did not provide opportunities for*

students to critically reflect on this artificial separation from the environment". This recognition prompted discussions about alternative teaching approaches, with Nivedha suggesting: *"Maybe we should have gone down to that near that creek in our campus... Or yeah, near certain trees where there are several insects and birds, and ask them to maybe talk about species, the differences and all of that"*.

Bridging this nature of disconnect required careful consideration of engaging students effectively. Tajinder emphasized the need for a thoughtful approach: *"We need to find that bridge through which we can make an interest... in the students. Maybe through that video, through some interaction, through some interesting facts to showing them the importance of environment, the animals more than humans in some context"*. This sentiment was echoed in discussions about making environmental education more relevant to students' lived experiences while acknowledging their technological context.

The experience highlighted the importance of understanding and adapting to students' relationship with nature when teaching environmental science concepts. As Nivedha reflected: *"I think that kind of separation, the distance from the environment, I think, should be addressed more."* Our findings suggest that teaching sociocultural aspects of science effectively requires carefully considering and bridging these different relationships with the natural world, creating meaningful connections between students' lived experiences and broader environmental concepts.

Understanding the Role of the Instructor

Our analysis revealed a profound transformation in our teaching role as we worked to integrate social and cultural aspects into science education. Moving from traditional instructors to facilitators represented a change in teaching strategy and a fundamental shift in how we understood and approached our role in the classroom. The transition was initially challenging, marked by our recognition that conventional teaching approaches were not effectively engaging students in sociocultural discussions. Tajinder captured this evolution vividly: *"In the start, it's quite like struggling to push students to call like start the discussion... at that time I felt like my role should be more facilitator than a teacher"*. This realization deepened as we understood that *"the role of teacher is not sufficient for this class... the turn the role of teacher into facilitator plays a very important role during this*

activity, because the teacher only provides the knowledge, and the facilitator help student to develop their understanding in the real-time discussion". Our instructional goals underwent a parallel transformation that reflected this shift in role. As Nivedha reflected: *"I think first it was more about, okay, this is the right way to see science... But after the first session, it changed more towards like student-centered form... I was thinking through what kind of things I can make social and cultural aspects of science more relatable to students, and by learning this, what personal outcomes I can give for them"*. This evolution marked a move from content delivery to facilitating meaningful engagement with sociocultural aspects of science. We developed various strategies to support student learning as we embraced our facilitative role. Emmanuel adopted an active participation approach in student groups: *"I was moving from small group to small group to discuss with them... I just told them that I'm part of every group. So, when I come to your group, we sit at the same table... put the issue down, let's look at latency"*. This strategy helped break down traditional teacher-student hierarchies and encouraged more open discussion. Scaffolding emerged as another crucial facilitation technique, with Nivedha describing how *"We came up with some scaffolding questions to support students' group work for their presentations, and I separated them into segments and time to keep them moving through the stages of inquiry. I was able to support them better in this arrangement"*.

The transition to facilitation presented several significant challenges. Students' expectations of traditional teaching sometimes created resistance, as noted by Tajinder: *"Students demand a lot of push from us when we're repeating the things, and we are saying you have to answer."* Time management became a critical concern, Emmanuel noting that *"Time was not favorable to us."* We also struggled with balancing content delivery and facilitation, though we discovered that reducing direct instruction improved outcomes. As Nivedha observed: *"I think the part of the reason why the second class was better... is like the content part was very less, and we minimize that a lot... Just a few things to just kind of recollect. And then we immediately started with the group work"*.

The teachers also needed to be role models in these difficult conversations, which require vulnerability. In the example where Nivedha shared her views about hunting and her diet practices: *"It's also emotionally a bit taxing, right? Because you're going. You're going to give a big opinion and then that they were like holding them back like they refrain from sharing like because these are big things. Right? So, what if they are wrong, or what if their*

view is considered bad, or understood negatively, and I was there, so I could sense they were feeling that way. So, in the second section, I shared my personal opinion about hunting and how I eat meat. But I see. I mean, I'm not okay with killing off animals. So, when people hunt. I feel like you, you want to kill an animal for your entertainment or something, but I am also a person who eats meat." She is displaying vulnerability with her students, which is also an implicit message that they will not be judged for their views and that the teacher is not an ultimate authority in the classroom.

Our growth as facilitators was significantly enhanced by collaborative reflection and learning. Regular team meetings allowed us to share strategies and refine our approaches. Tajinder expressed the value of this collaboration: *"Our teamwork did a good job... I really appreciate that. I enjoyed. Actually, I enjoyed it. And I learned a lot of things from this collaborative opportunity"*. This cooperative approach helped us develop more effective facilitation strategies and navigate the challenges we encountered. The impact of our facilitative approach became evident in increased student engagement and deeper discussions. Emmanuel noted, *"The student responses were very great... The conversation was rich and rich. Other groups were raising concern and commenting on that group's presentation"*. Nivedha observed similar success: *"Students highlighted them during group presentations. Some students could identify the positive role of the taboos in Indonesian islands that prohibited the hunting of water lizards"*.

Nivedha also noted the moments where she noticed strategies from other instructors – like presenting hypothetical situations to students (Emmanuel) and using video as the initiator of discussion (from Tajinder). *"The unique strategy from Emmanuel is giving them a hypothetical situation, right? So, which is, like, really, really, you know, give gets us some responses, right? So, I think that's a really good one because they feel kind of freer to answer because it is not a straight-out science question, or so they can be kind of very flexible in that response. I think.. that kind of elicits their thoughts in a much more authentic way because it is a very imaginary situation"* (recorded reflection). In hindsight, Nivedha realized that while she could identify and plan for certain things in advance, there was some gap in implementation. This is also her first time teaching the course, while Tajinder and Emmanuel have taught it before for two semesters.

Our experience demonstrated that transitioning from traditional teaching to facilitation was

essential for effectively teaching science's social and cultural embeddedness. This shift required us to develop new skills, adapt our teaching strategies, and create learning environments that supported student exploration of complex sociocultural issues. The success of this approach was evident in both the quality of student engagement and the depth of understanding they demonstrated, suggesting that facilitation is crucial for helping students navigate the intersection of science and culture.

Addressing Non-Science Narratives

A significant challenge that emerged from our data was navigating the complex terrain of integrating non-science narratives into scientific discussions about endangered species conservation. This theme revealed students' difficulties in accepting non-traditional scientific perspectives and our evolving strategies as instructors to bridge these epistemological divides. Students' initial resistance to non-scientific narratives manifested strongly in their responses to cultural and spiritual aspects of conservation. Emmanuel's experience highlighted this challenge when he introduced traditional forest protection practices: *"One of the popular answers that I heard from two groups was like, this is a religious issue... Is this a spiritual issue? So, we do not want to go there much because he is doing it to protect his gods. Not scientific"*. This resistance was not merely passive; students actively questioned the relevance of spiritual or cultural practices to scientific conservation. As Emmanuel noted in his reflective journal, one student explicitly challenged, *"What does God and spirit have to do with saving crabs? This doesn't make sense to me"*. These responses revealed what Tajinder recognized as a deeply ingrained view that *"science means doing only activities... students have that kind of biased thinking. So, science means doing only activities. Or, like, maybe science also having the right and wrong answer"*.

This resistance stemmed from what we identified as a fundamental disconnect in understanding how cultural practices could contribute to scientific knowledge. Emmanuel observed that *"most of them are naive about the idea of science being practicing community level or at the Indigenous level; they don't have much knowledge about that."* This naivety was further complicated by students' formal view of science, as noted when *"they are just looking at. Science in that perspective, science is just something formalized. But if you talk about something outside that box, you are not doing science"*.

However, our data revealed considerable progress in helping students bridge this epistemological divide through carefully structured interventions. Nivedha documented how students began recognizing the value of cultural practices through case study analysis: *"Some students could identify the positive role of the taboos in Indonesian islands that prohibited the hunting of water lizards. The group who chose the Suckerfish also mentioned the philosophy of native Americans, which says every species has been granted the right to life by God and humans should not disturb it"*. This evolution in student thinking suggested that students could appreciate the validity of different knowledge systems with appropriate scaffolding. To facilitate this understanding, we developed multiple pedagogical approaches. Emmanuel employed cultural narratives strategically, noting how *"in Africa when you there are some sacred forest that if you want to enter into such a forest, there is someone as a gate, there's a priest who serves as the is at the entrance of the place... before that permission will be given to you, there is some kind of ritual that they need to perform"*. He used these examples to prompt deeper thinking about the relationship between cultural practices and conservation outcomes. The effectiveness of our approach relied heavily on careful preparation and scaffolding.

Similarly, Nivedha suggested using more accessible entry points: *"Having some fiction-like literature... it's a great way to make them read a different world and interpret it. They also do it more freely when it is like a not very complicated scientific text"*. Our experience highlighted the importance of explicitly connecting cultural practices and conservation outcomes. Emmanuel described his questioning strategy: *"Why do they think this priest must be there to protect this forest... Do they think that this priest has a right to do that? If he has a right to be doing that? Do you think he may have some Evidence?"*. This approach helped students see the practical conservation implications of cultural practices while respecting traditional knowledge systems.

This process taught us that successfully integrating non-science narratives required patience and strategic preparation. As Emmanuel reflected, the goal was to help students understand that *"science is not limited or bound to only one particular dimension. There is another aspect also which plays a very important role"*. Nivedha noted the diversity in sources of conservation narratives: *"Some [narratives] are very data-driven, with formal statistics, while others are deeply cultural, bringing in social taboos and traditions."* These varied perspectives—from activist groups, local communities, and conservation organizations—

highlight the multidimensional ways people understand and approach conservation. By comparing scientific data with cultural narratives, students could "get into that region" where conservation is a scientific issue and a social one." Our findings suggest that while challenging, helping students recognize the validity and value of non-science narratives is crucial for developing a more complete understanding of science's social and cultural embeddedness.

To enhance students' awareness of cultural dimensions, instructors used multimedia resources, such as videos of environmental activism in different regions. Tajinder shared an impactful classroom moment: *"I showed the creek protest video... students noticed that children were actively participating, something they hadn't seen here. It was unique for them—they were observing that youth also engage in environmental activism."* This observation sparked discussions on the interconnected roles of community members across generations in conservation efforts, broadening students' understanding of global environmental responsibility.

Nivedha shared she chose the Ennore case study, which brought out the local community's knowledge and the diverse ways they talked about the animals in their environment – including pieces of art that modeled Crabs in Ennore, legends about the spirits that lived in the Ennore backwaters. Despite the contextual examples, there was much difficulty in helping students navigate the cultural and social arguments. Nivedha, however, recalled a positive experience where one student who mentioned, "When these animals are lost, it is not just the species that is lost but also their culture." This is an excellent understanding of the environment and biodiversity, clearly indicating how the student sees the natural world as inclusive of the social worlds that reside within this environment. This view is encouraged by environmental education scholars (Littlelyke, 2008) so that science teachers can develop an "understanding of the interconnectedness of living things" (nurturing spirituality and a sense of relational identity).

Even though it was not explicitly articulated by any instructor in this case, we were happy to see this emerge. We would like to keep that as our teaching goal since it emulates the social embeddedness of environmental knowledge. Through these reflections, instructors recognized that engaging with non-science narratives allowed students to see conservation as a scientific and social responsibility, encouraging empathy for diverse approaches to

protecting endangered species. By integrating these narratives into conservation education, students could connect scientific understanding with respect for the values and traditions contributing to environmental stewardship.

Discussion and Conclusion

Our collaborative action research has revealed significant insights into the complexities of learning how to integrate sociocultural perspectives into undergraduate science education. Through systematic analysis of our teaching experiences and reflections, we identified key themes supporting and extending existing theoretical understandings while offering practical insights for science educators navigating similar pedagogical challenges. The emotional and value-based tensions in our study align with and extend current understandings of sociocultural aspects in science education. While grounded in Aikenhead's (1996) foundational concept of cultural border crossing, our findings connect with Bricker and Bell's (2014) work on how students navigate different cultural contexts in science learning. Their research demonstrates how students' cultural experiences and learning pathways significantly influence their engagement with science.

Our study extends this understanding by revealing specific emotional barriers that emerge when students encounter diverse cultural perspectives on nature conservation, particularly when these perspectives challenge their established ways of thinking about science. This relationship between emotional engagement and cultural understanding connects to recent research by Rodriguez-Hernandez et al. (2024) on affective domains in socioscientific issues education. Their findings demonstrate how emotional responses influence student engagement with controversial science topics, paralleling our observations of students' hesitations in engaging with cultural perspectives on conservation.

Building on these emotional dimensions, we explored the complexities in balancing epistemic and non-epistemic aspects in NOS instruction, which aligns with Garcia-Carmona's (2024) critique of the overshadowing of non-epistemic dimensions. Our findings extend this understanding by revealing specific emotional and pedagogical challenges in this balancing act. Recent work by Mehta et al. (2024) supports our observation that students often struggle to accept non-Western knowledge systems, highlighting the need for targeted strategies to address this resistance. Our evolution from traditional instructors to facilitators aligns with

Brown and Crippen's (2017) research on how science teachers develop cultural responsiveness in their practice. Their study reveals how teachers must intentionally develop specific knowledge and practices to integrate cultural perspectives into science instruction effectively. While their work focuses on high school contexts, our findings extend their understanding by demonstrating how this transformation manifests in undergraduate science education, particularly when teaching about endangered species conservation. Like the teachers in Brown and Crippen's study, we found that becoming culturally responsive facilitators required developing new pedagogical strategies and reconceptualizing our role in the classroom.

This emphasizes the need for teachers to develop competencies for guiding students through sociocultural aspects of science, reflecting what Lave (1991) terms situated learning. Our experiences underscore the practical challenges and strategies involved in this transformation. Additionally, we noted students' disconnection from nature, which intersects with contemporary research on environmental education. Our study reveals specific implications for teaching about endangered species and conservation. This connects to Bang et al.'s (2018) examination of nature-culture relationships in science education, particularly their analysis of how diverse cultural ways of knowing and relating to nature shape science learning. While they focus on indigenous knowledge systems and their relationship with Western science, our findings suggest these relationships are even more complex in undergraduate classrooms where students' disconnection from nature creates additional barriers to understanding diverse cultural perspectives on conservation.

The tensions we faced regarding the existence of non-science narratives align with what Snively and Williams (2018) describe as the challenges of "braiding" Indigenous science with Western science in educational contexts. Their work emphasizes how indigenous knowledge systems offer a sophisticated understanding of ecological relationships and sustainable practices yet face significant barriers to integration in conventional science classrooms. While Snively and Williams focus on the theoretical foundations for bridging these knowledge systems, our study extends their work by revealing specific emotional and pedagogical challenges that emerge when undergraduate students encounter traditional ecological knowledge in conservation contexts. This practical dimension adds to our understanding of how students navigate between diverse ways of knowing about nature and conservation.

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SECTION II

Chapter 6 - Examining How Teaching NOS with Biology Concepts Influences Preservice Elementary Teachers

Dan McCarthy 

Chapter Highlights

- Increasing potential elementary teachers' Nature of Science understanding of society and culture, laws and theories in a genetics unit.
- Utilizing Mendel's life history can help students develop a better understanding of how science and society are influential to each other.
- Developing an understanding of the difference between scientific laws and theories helps students understand Mendelian genetics.

Introduction

Teaching biology to non-majors has always been challenging. There are processes that can be viewed as very complex, and for most, they also seem to be irrelevant to their everyday life. Genetics is often a topic in biology that is looked at as a complex subject that turns students off. Teaching a non-majors course that is specific for elementary educators, and seeing the shift in how students perceive genetics created concern for me in how they will help students understand genetics. There is a large disconnect in student's understanding of what we can see in genetics (phenotype) and linking it to our chromosomes. This has made me question how I can teach this topic better, to help the students make links between the different aspects of genetics.

Problem Statement

Teachers are often thought of as having minimal training, compared to other professional jobs. Some of this comes from the fact that it is perceived that teachers are trained only to teach to scripts and they are not truly educated in any content (Zeichner, 2014). Elementary educators often are seen in this light because they do not teach “serious” content. Many of the aspects of not teaching serious content is not true, it is perceived as a lack of interest in topics like science. However, the education that the future educators had during their formative years may have influenced their appreciation of science (Campbell et al., 2021).

To increase educators' understanding of science, they must be taught in ways that provide more meaning and understanding. Students in Biology courses often struggle with the high volume of vocabulary, and often do not get time to combine philosophies of science to provide a deeper understanding of the topic. Nature of Science is the processes, discussions, and beliefs we use to understand what is science knowledge (Lederman, 2013 p. 883). Can understanding the Nature of Science (NOS) make understanding content rich topics more understandable?

Background

Having a scientifically literate society has been a goal of science education for decades. Within the most recent standards, *The Next Generation Science Standards*, science literacy is

still a key component(Krajewski & Schwartz, 2014 p. 544). The root of any literacy is understanding what it means to be knowledgeable about a topic. Knowledge can be viewed as the ability to make sense of science and manage technological objects, the ability to make informed decisions on socioscientific issues, and be able to appreciate the value of science as part of culture and the norms of the scientific community (Lederman, 2013 p. 831). The Nature of Science provides a framework to address these aspects.

The Nature of Science(NOS) is a way of understanding what science is and how it works, how society impacts science, and how science is composed of a social group, and how we make scientific knowledge (Clough, 2011 p. 56). Researchers, philosophers, and educators have not come to a consensus on what NOS is exactly. There are many interpretations, but two seem to be the most common frameworks. The Reconceptualized Family Resemblance Approach and the traditional approach(Kurt & Kaya, 2023 p. 2).

For the purpose of this research, the traditional framework will be utilized, as this will provide an appropriate template for use in an elementary classroom. The traditional approach consists of several aspects that have great agreement on their inclusion in NOS. These aspects include that science is: based on empirical evidence, it is tentative, it is subjective, it requires imaginative and creative aspects, and it is a social and cultural influence (Akerson et al., 2000 p. 295). Two other aspects of NOS that must be understood are the differences between inference and observation, and the relationship between laws and theories (Akerson et al., 2000).

In the college setting, very little research has been completed on NOS and how it influences student understanding (Lederman et al., 2023). Generally science is taught as a body of knowledge that must be memorized with little context to how that body was developed (Krajewski & Schwartz, 2014 p.17). As it has been shown with most groups, non-majors, including future teachers, in a science course have a naïve few of the NOS aspects (Krell et al., 2015). It has been shown in research that providing explicit, reflective learning of NOS can have the most improvement on student's understanding of NOS (Akerson et al., 2019).

For non-majors, genetics can be an overwhelming topic to explore. This could be because for most schools there is a concerned with teaching only the content knowledge of genetics(Williams, 2017). Student's often do not feel connected to the material, as it has no

context associated with it(Williams & Rudge, 2016). Through the History of Science, students can develop a context for science and their understandings of several NOS aspects including laws and theories(Kim & Irving, 2010 p. 192).

Mendel is often portrayed in text as a classic researcher that discovered aspects of modern genetics(El-Hani, 2015 p. 173). However, utilizing the history of Mendel, students will be able to explore how society and culture had a major impact on Mendel and his discoveries(Kim & Irving, 2010 p. 192). By having the students learn rich contextual aspects of genetics, they will not just be learning the content of genetics, but aspects of NOS(Williams & Rudge, 2016 p. 409). Through well planned, explicit instruction, NOS aspects including laws, theories, societal and cultural influences in science can be discussed and students allowed time to develop a meaning to each aspect, within the rich context of Mendel's history.

Purpose

The purpose of this study is to examine how teaching NOS theories and laws, and the history of Mendel, in conjunction with Mendelian law of inheritance (independent assortment), Mendelian law of segregation and Theory of Chromosomal inheritance improve pre-service elementary teachers understanding of the NOS aspects of laws and theories, and the social cultural influences on science.

Research Question(s)

Will teaching NOS, specifically the difference between laws and theories, with Mendelian laws, and chromosomal theory of inheritance improve students' understanding of NOS and genetics?

- What impact did including NOS have on students' abilities to describe the difference between the laws and theory?
- How did teaching about the difference between laws and theories during a genetics unit improve students' abilities to describe the differences between laws and theories?
- How does teaching the history of Mendel increase the student's understanding of the social and cultural influences on science?

Method

This research will be conducted in a Non-Majors Biology course that is specific to elementary teachers. This course is a 2-unit lecture 1 unit lab course. The course meets two days a week, one meeting for 2 hours and one meeting for 3 hours. Although this is a lecture/lab format class, it is taught by one instructor and is not taught in a traditional lecture/lab format for other Biology courses. This course is taught at a large university on the west coast of the United States. I will be the researcher and instructor for this course, as I am looking to see how changing my approach to teaching genetics to this population influences student understanding. The new strategy that I will be including in the genetics unit is the addition of teaching NOS explicitly during the class. The NOS tenants that will be focused on is the difference between laws and theories and science and society. As I have been the only instructor of this course for the last several years, this will be a novel approach for this class.

On the first day of instruction for the genetics unit, I had the students do two activities to develop an understanding of the difference between a law and a theory. I had the students complete an activity called Library books and Mystery tube (Bell, 2008 pp. 113 and 124). I was worried that these activities might not hold the student's attention as they are designed for elementary students. However, the students did spend more time on the Mystery tube than I expected. The whole concept of what was going on in the tube was very confusing to the students and they did seem to get a little frustrated with not being able to figure it out. Once I completed the demonstrations, I had the students discuss in their groups which one was representing a law, and which one was representing a theory. What I did realize as I walked around the class was that students did not have a good grasp of the difference between observation and inference, yet another Nature of Science attribute. After giving the groups most of the class time to discuss the differences and which one represented a law or theory, I brought the class together for a full class discussion and clarification.

The second day of instruction was focused on Mendelian genetics. I did a formal lecture on the vocabulary that is involved in Mendelian genetics, and then we did Punnett square activities to work through how we use this information. We talked about many inherited characteristics, such as eye color, hair color, and baldness. I was surprised at how many of the students did not remember hearing any of these concepts in their previous schooling. Because of this recognition, it also led to many questions from them about what their potential

offspring could look like. I had them explore this individually while practicing more Punnett squares about the characteristics they are interested in.

To develop an understanding of the Law of Segregation and the law of Independent assortment, I had the students complete three hands-on-digital labs from their online learning platform. These activities utilized Punnett squares, and looked at either a monohybrid or dihybrid cross in order to ask specific questions about how the characteristics are passed to the offspring in order to develop the Laws that we now use. They did struggle with this concept, at first I thought it might be the fact that this was the first class back after spring break. After some questioning from me, I discovered that they did not remember how chromosomes are passed from one cell to another or to a gamete. This was in a previous unit, I may need to focus on that unit next, so we did a quick refresher. After the refresher, the students did begin to develop how the two laws are different and why we consider them laws. Once I felt this was well established, I had the students, in groups, look up Chromosomal Theory of Inheritance. As a homework assignment they needed to reflect on how the two genetic laws that they just learned about and the theory are different and how they are connected.

To explore the social and cultural impacts on science, I had the students research Gregory Mendel's life history to see if it matched what they already knew. I had the students develop a visual presentation; they could use any form they wanted. They needed to include three parts for the presentation. The first part was to show what they already knew about Mendel. They have already had online homework and reading that covered this material. The second part was to research more deeply about Gregory Mendel and create the second part of the presentation around what they discovered. The third part was to develop a reflection on the differences between the two presentations that they already created and how they could explain the differences. The students had a harder time thinking about what else they could research about Mendel that was not in the textbook. I gave them some pathways around researching what Mendel was trying to study versus what we hear about, the years surrounding the publication date and when the information was used in society for the first time. Although this did help them move forward in the research, I feel it came at a cost because that is all they researched and then they moved to creating the presentation. I worry that they are still at the point that they only do what is told, and they have not developed a more developed curiosity attitude.

I concluded the genetics unit by looking at human genetics. For this I used two Howard Hughes Medical Center (HHMI) activities. The first activity explored sickle cell disease and how it was linked to genetics, and the second was how humans have so many skin tones. After completing the two activities and worksheets I had the students write a reflection on how these two activities can relate to what they learned about Mendel's life history and science.

Results

Data Collection

Three data sources were collected.

- *Questionnaires*- The questionnaire contains two parts, the first part is questions based on the VNOS-C survey. These statements evaluated the student's understanding of NOS. The second part of the questionnaire is a self-developed survey called Mendelian Genetics Inventory. This is an open-ended survey identifying the growth in student's understanding of Mendelian genetic terms. (See Appendix A)
- *Multiple-choice quiz*- This quiz was developed by selecting questions related genetics from the textbook test bank. This was used to produce a quantitative value of growth in students understanding of genetics. (See Appendix B)
- *Instructor Journal*- Throughout the intervention I maintained a journal. In this journal I took notes of what was accomplished each day, what the students' reactions to the lesson, and how I felt about each lesson.

Data Analysis

Ten out of 20 students signed consent forms to participate in the research. Of those ten students, nine students completed the pre-instruction survey and quiz. When the instruction was complete seven students completed the survey and quiz. One student elected to have their data removed from the research halfway through the lesson. This gave me a total of eight data points for pre-instruction and seven for post-instruction. I elected to turn total responses into percentage to compensate for this difference. The questionnaires are coded individually for NOS understanding and for the students' understanding of genetics. For student's understanding of NOS, the modified VNOS-C questionnaire responses will be

grouped into three different codes, Naïve, developing, and informed views. Student responses will be compared to examples from Views of Nature of Science Questionnaire: Towards valid and meaningful assessment of Learners' concept of Nature of Science of each level of understanding to ensure accurate placement (Lederman et al., 2002 pp.514-516). Table 1 shows how the class was assessed for each of the questions about NOS.

Table 1. Percent of Participants coded in Each Category

Nature of Science Question	Naïve	Developing	Informed
1. In your view, what is Science? What makes science different from other forms of inquiry (philosophy)?			
Pre	57.14%	28.57%	14.29%
Post	16.67%	50.00%	33.33%
2. After a scientist develops a theory (atomic theory), does it every change? Defend your reason			
Pre	14.29%	42.86%	42.86%
Post	0.00%	16.67%	83.33%
3. Is there a difference between scientific law and scientific theory? Provide an example			
pre	42.86%	57.14%	0.00%
post	16.67%	83.33%	0.00%
4. Some claim that science is infused with social and cultural values. That is science reflects the social and political values and intellectual norms of the culture it is practiced in. Others claim that science transcends social and cultural values in which it is practiced.			
Pre	28.57%	14.29%	57.14%
Post	0.00%	0.00%	100.00%
5. Are Mendel's laws or chromosomal theory of inheritance considered more proven?			
Pre	71.43%	28.57%	0.00%
Post	50.00%	16.67%	33.33%

The class did have improvement in their overall understanding for each of the NOS attributes. The instructor journal was used to evaluate how well I believed each teaching period meet the goals for that day. It was also used to document how engaged the students were in each activity. Allowing one avenue of determining if the activity would be used in the future.

The first question (see Table 1) is asking student's understanding of science being empirical. Pre-instruction there were more students with a Naïve view of science's empirical nature. An example of a response that was coded for Naïve is "*I believe science is the study of our world's natural material. Whereas studies like philosophy and psychology are the studies of behavior and how humans interpret that material*". In this response the student believes that science is about the facts and tangible aspects, and not the process. After instruction a student responded "*What makes science different from other forms of inquiry or philosophy is that it involves conducting experiments, gathering data, and drawing conclusions about what happens*". This response was coded as Informed, as the student recognized that science is about the collection of data, through experiments, not about the answers that the data provides.

The second question (see Table 1) is assessing students' understanding of science being tentative. I was happy to see that even pre-instruction there were many students who had already been exposed to this attribute and understood it. A student response that was categorized as Naïve in for this question was "*If it's a well thought out theory that many people helped with it should not change*". After instruction the same student responded, "*After a scientist develops a theory, the scientist is not going to change it but others will try to discredit the theory so the scientist will have to fight the theory to prove that their theory is correct*". This was categorized as developing, because the student was beginning to understand that science can change, but they could not get to the idea that it might be the same scientist.

The third question (see Table 1) proves to be one of the harder concepts for the students to learn. Pre-Instruction many students believed that theories are opinions and laws are fact. They also believed that theories become law eventually. Post-Instruction, more students showed a developing understanding of the difference, but none of the students had an informed understanding of the difference between laws and theories. One student could not understand that theories in science do have considerable evidence behind them "*Scientific*

theories are concepts in science that have not been definitively proven.” The fifth question was a follow up to question three to see if students would understand the difference between laws and theories better within the context of Mendelian genetics. The data shows that most students could not combine the two concepts. When asked about laws and theories, post-instruction only 16% of the students remained in the Naïve category. However, when combined with genetics, 50% of the students remained in the Naive category.

Question four (see Table 1) seeks to understand if students believe that culture and society have an impact on science. Before instruction a majority of the class already, 57%, already had an informed understanding of this. Student’s common theme for an informed understanding pre-instruction was that scientist are part of society *“Science is infused with social and cultural values since scientists are influenced by their society.”* Post instruction all students had an informed view of social and cultural embeddedness of science, with statements such as *“I believe that science is infused with social, political, and intellectual norms. This is because scientists are human, so they will have their own opinions, biases, and values that may shape their work in the field.”*

The responses for genetic understanding (see Table 2) will be coded into three different categories, naïve, accurate, or informed. Naïve groupings will be used when responses do not reflect correct science or meaning for the topic that is being questioned. The term “Accurate” will be used when the science is correct, but there is no apparent linkage to NOS. Informed coding will be used when the response is scientifically correct and the correlation to correct use of laws or theories is applied.

Table 2 shows that the students did increase their understanding across the board for all three questions asked in the survey. A majority of the students did reach a developing understanding of genetics, but for the most part the students did not reach a level of understanding of the difference between laws and theories that they could incorporate those NOS attributes into their answers. The one exception to this, when a student described the chromosomal theory of inheritance they stated, *“This theory explains how traits are passed down from parents to their offspring through chromosomes.”* This student was able to explain that a theory is used to explain evidence that is inferred compared to evidence that is observed.

Table 2. Percent Response Rate for Each Category for Genetics Understanding

Genetic Understanding Questions	Naïve	Developing	Informed
What is Mendel’s law of segregation?			
Pre	42.86%	57.14%	0.00%
Post	20.00%	80.00%	0.00%
What is Mendel’s law of inheritance?			
Pre	85.71%	14.29%	0.00%
Post	20.00%	80.00%	0.00%
What is chromosomal theory of inheritance?			
Pre	71.43%	28.57%	0.00%
Post	33.33%	50.00%	16.67%

Figure 1 supports the evidence that a majority of the students increased their understanding of genetics. For the students who did complete the post instruction genetics quiz, all but one showed an increase in their ability to answer questions about genetics. One student earned a lower score on their post-quiz. I think this could be due to one of two reasons: they started overthinking about the answers as they tried to incorporate their new understanding of laws and theory. The other possible reason is that, as this was a quiz taken at home, they researched the answers for the pre-quiz and then opted to take the post-quiz without researching the correct answers.

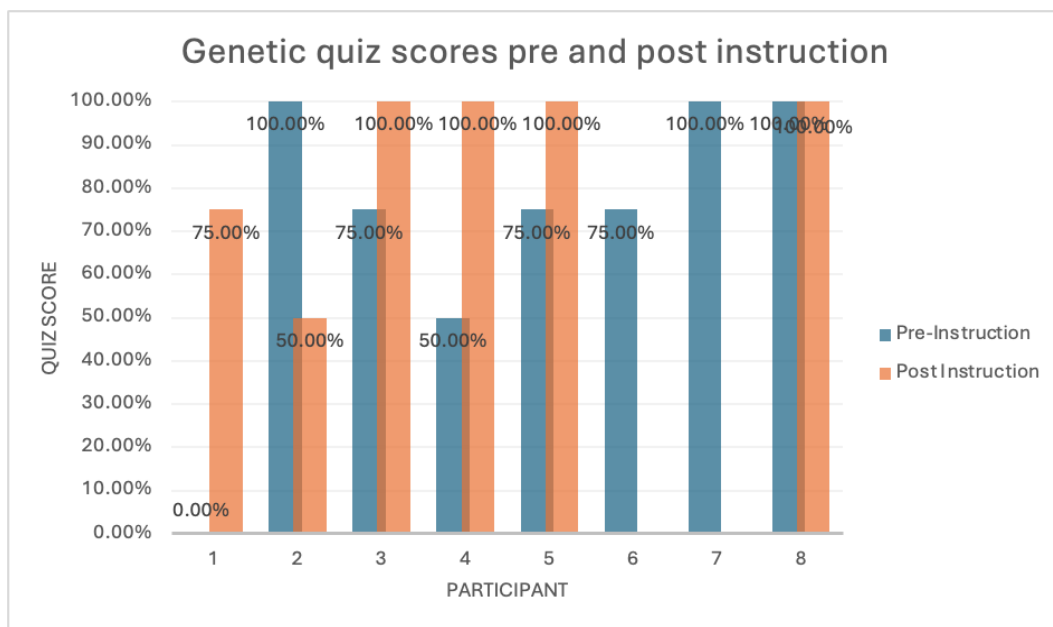


Figure 1. Pre and Post Instruction Quiz Scores for Each Participant

Conclusion

Preservice elementary educators have a tall task at hand when developing their content knowledge for each of the subjects they will be required to teach. It is essential that their experience in each of the content courses that they are taking to develop this knowledge is not only of high quality but can provide them with examples of how to approach different subjects. Genetics can often be a difficult topic for non-biology majors to understand or even be interested in learning about. Student's often think of genetics as a known science with a well told history. Having student's research about the history of scientists that are significant to genetics can increase their understanding of genetics (Williams, 2017 p.58). This is particularly effective in advancing student's understanding of how Culture and Society has an impact on our understanding. Using Mendel's history when studying genetics is an effective pathway to develop students' understanding of society's role in science. Student's learn that society, both at large and within the community of researchers, views can change over time (Kim & Irving, 2010 p.189). For the pre-service elementary educator, the understanding of how society and cultural influence science can change overtime will help them teach science better, by understanding that how our scientific knowledge does change is dependent on societal views and data.

Using Mendel's personal history as a platform to develop a deeper understanding of NOS is effective, however it does pose the risk of being too limited. In future classes, looking at many different genetic scientists' personal history may prove to be more effective. This can be accomplished by having each student research a scientist that means something to them. They could do a search with two parameters, one being genetics and the second parameter of their choice which could include culture, race, ethnicity, sexual preference or any other personal criteria. This has the potential to be more effective in at least two ways. First, because there will be many more scientists, what students talk to each other about or present will provide a larger picture of the impact of society on science. Second, because students are selecting something that is personal, they will feel a greater connection to science and learning.

To increase content knowledge for NOS aspects and genetics content it is best to teach them together (Krell et al., 2015 p.345). Mendelian genetics has both laws and theories within its content. These are often taught without regard to what is the difference between a law and a

theory at the college level. This creates many misconceptions about what is more important, or developed in the student's eyes (Dass et al., 2011 p.25). Providing explicit instruction in NOS while teaching the concepts of genetics students' understanding of what the difference between a law and a theory and how it describes genetics in different ways (Akerson et al., 2019 p.408). Student's understanding was increased in a very short amount of instructional time, leaving room to explore the topics at a greater depth. Students' understanding of the genetics concepts seems to increase at a quicker rate as compared to an in-depth understanding of laws and theories. It would be a best practice to introduce NOS, particularly laws and theories, earlier in the course to give student's more time to develop a greater understanding of NOS and more practice applying it to their science content.

Recommendations

This research shows that there are benefits to teaching aspects of the Nature of Science and genetics together. This research also shows that even though there was an increase in content knowledge of both genetics and the Nature of Science, it did indicate that more time should be dedicated to understanding the difference between laws and theories. Future research should look at the difference between emphasizing the difference between laws and theories and for one unit versus an entire semester improves students' understanding.

Limitations

This research was conducted at a large university on the west coast of the United States. The course is for non-biology majors that are planning to be elementary teachers, containing the same content as a traditional non-majors biology course with efforts to incorporate how to teach biology as much as possible. Compared to other non-biology courses at this university the class size is small at 20 students as compared to a traditional 80-120 student course. The instructor for the course teaches both the lecture portion of the course and the corresponding lab, allowing for more flexibility of how the course is interwoven between those two aspects of the class.

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Appendix A

Nature of Science and Genetics' Questionnaire

Add your responses to the questions below and save the file. Upload the file into canvas under the tab questionnaire. Remember you are volunteering your data, you can freely elect to not complete the survey

Part 1.

1. In your view, what is Science? What makes science different from other forms of inquiry (philosophy)?
2. After a scientist develops a theory (atomic theory), does it every change? Defend your reason.
3. Is there a difference between scientific law and scientific theory? Provide an example.
4. Some claim that science is infused with social and cultural values. That is science reflects the social and political values and intellectual norms of the culture it is practiced in. Others claim that science transcends social and cultural values in which it is practiced.

If you believe that science transcends social and cultural values defend your answer with examples.

If you believe that science is infused with social and political and intellectual norms defend your answer with examples.

Part 2.

Mendelian Genetic inventory

5. What is Mendel's law of segregation?
6. What is Mendel's law of inheritance?
7. What is chromosomal theory of inheritance?
8. Are Mendel's laws or chromosomal theory of inheritance considered more proven?

Appendix B

MULTIPLE CHOICE – complete this quiz to the best of your ability. Remember you do not have to participate in this research and can freely elect to not complete the quiz

1. The alleles of each gene packaged into separate gametes summarizes Mendel's law of
 - A) segregation.
 - B) random fertilization.
 - C) population dynamics.
 - D) crossing over.
 - E) independent assortment.

2. When Mendel crossed tall (Tt) plants with tall (Tt) plants the offspring
 - A) did not grow and reproduce.
 - B) were always short.
 - C) were always tall.
 - D) were always medium height.
 - E) were mostly tall individuals and a few short individuals.

3. If the two alleles for a particular gene are different the gene pair is
 - A) homologous.
 - B) heterozygous.
 - C) homozygous.
 - D) dominant.
 - E) recessive.

4. Phenotype means the
 - A) number of gametes in an individual.
 - B) number of chromosomes in an individual.
 - C) combination of alleles in an individual.
 - D) genes an individual has.
 - E) observable expression of the genes in an individual.

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Chapter 7 - The Effects of Explicit-Reflective Instruction of the Social, Cultural, and Tentative Aspects of the Nature of Science, on Students' Understandings in Atomic Bonding

Deborah Nowakowski , Valarie L. Akerson 

Chapter Highlights

- Increasing high school students' use and understanding of observation and inference.
- Engaging experiences can help students use creativity and imagination to explain observations.
- Collaboration helps students explain observations, develop inferences, and make informed decisions.
- Models help students understand the tentativeness of science and how it can change as new information becomes available.
- Collaboration helps students understand how different funds of knowledge produce different conclusions given the same empirical evidence.
- Collaborative activities promote the relevancy of cultural and social aspects in scientific inquiry and discovery.

Introduction

Student engagement and understanding of the Nature of Science are important aspects in recruiting and retaining post-secondary students in scientific fields of study. These students are needed to fill the highly technical and scientific professions that are part of our global economy. Teachers have a responsibility to engage students and instruct them on the creative, inferential, everchanging characteristics of the Nature of Science. This study is an Action Research Study that examines the effects of student engagement, collaboration, and comprehension of the aspects of the Nature of Science, using explicit-reflective instruction in a freshman Integrated Chemistry and Physics class during an atomic bonding unit.

Science in general is very difficult to teach because many students' preconceptions about scientific phenomena interfere with students' learning of correct scientific principles or concepts (Driver & Easley, 1978; Driver & Erickson, 1983; Fler, 1999, Palmer, 1999; Taber, 2000). These misconceptions may arise from the various contacts students make with both their physical and social world, personal experiences, interactions with teachers, peers, and the media (Gilbert et al., 1982; Gilbert & Zylberstajn, 1985; Griffiths and Preston, 1992). Chemistry is even more difficult to learn because the topics are very abstract (Ben-Zvi et al., 1988), and the language used in chemistry consists of everyday words that have a different meaning specific to chemistry (Berquist & Hekkinen, 1990). There also exists many misconceptions regarding bonding because of the many chemical concepts students have to master in order to predict the type of bonds created in a given situation (Özmen, 2004). These include: electronegativity, ionization energy, geometry of the molecule, molecular structure and stability (Özmen, 2004). One misconception in any of these areas can contribute to a multitude of misconceptions in chemical bonding.

Extensive misconceptions also exist regarding the Nature of Science even though it is part of the Next Generation of Science Standards (n.d.). Many studies that incorporate NOS into the classroom have been conducted over the years, yet these misconceptions still exist. Not only are there student misconceptions regarding NOS, there are also teacher misconceptions regarding NOS. These misconceptions in some cases are related to the fragmented method in which scientific knowledge is taught (Carey, 1986). Although there are many studies that incorporate NOS aspects into the elementary and secondary science classrooms, there is an absence of studies which incorporate the instruction of NOS aspects with the subject of

atomic bonding. This action study attempts to assist students to conceptualize aspects of NOS and link these concepts to the improvement of student understanding of both science and chemistry.

Purpose of Study

The purpose of the study is to determine how freshman Integrated Chemistry and Physics (ICP) students comprehend and utilize the aspects of the Nature of Science when these aspects are explicitly taught and students reflect upon them in daily atomic bonding activities.

Research Questions

Does explicit instruction and reflection regarding NOS characteristics in classroom instruction of a unit on atomic bonding, increase student understanding of cultural and social aspects of the Nature of Science?

Does explicit reflective instruction regarding NOS of a unit on atomic bonding, increase student understanding of the tentativeness of science?

Does the understanding of NOS characteristics increase student understanding of the need for creativity among ICP students when working on atomic bonding activities?

Theoretical Background

Student understanding of the Nature of Science (NOS) has been an important component of education for over 85 years (Abd-El-Khalick, Bell & Lederman, 1998; Duschl, 1990; Lederman, 2013; Meichtry, 1993). There are several reasons for developing an understanding of NOS. One reason is students need to have an extensive knowledge of science in order to make educated decisions in science related public policy (Carey & Smith, 1993). According to Hansson et. al. (2021), science scholars such as Yacoubian and Hansson (2020) “have suggested that to serve educational aims and values related to democracy and social justice, science teachers should challenge stereotypical images of science and scientists” (p.795). NOS literacy is so important, it is a key aspect of the Next Generation Science Standards (NGSS). According to Lederman (2014), “NOS is embedded within the dimensions of

science and engineering practices and crosscutting concepts within the NGSS” (p.8).

Another reason for NOS literacy is the need for students with scientific and technical skills to fill the many professions in this area. Today’s professionals must have the ability to invent, communicate, make predictions and inferences, and problem-solve (Turiman et al., 2012). According to Potter (2002), by the year 2050, up to one third of the workforce will be working in professions that require technical and scientific skills. In fact, “ some researchers have viewed the widening wage gap between high school and college graduates as evidence of a growing demand for college-level skills and knowledge” (Hilton, 2008, p.63).

Although there is great importance placed on student understanding of the Nature of Science, there is no consensus on the definition of Nature of Science (Backhus & Thompson, 2006; Lederman, 2013; Lederman et al., 2002). According to Lederman et al. (2002), “NOS 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” (p.497). Even without a common definition for NOS, most leading NOS researchers agree on common aspects of Nature of Science. These include: science is based on empirical evidence, science is tentative, science is subjective, creative, and imaginative, science is socially and culturally embedded, and scientific knowledge is derived from observations and inferences (Folino, 2001; Lederman, 2013; NSTA, 2020). These aspects are important in fostering the creative, collaborative, and culturally embedded aspects of today’s job requirements.

Unfortunately, even though science literacy has been considered important in education for decades and is now part of NGSS, many students and some teachers still have little understanding of NOS (Akerson, Abd-El-Khalick & Lederman, 2000; Carey, 1986; Lederman, 2013; Lederman et al., 2002; Moss et al., 2001; Wahbeh & Abd-El-Khalick). Some science teachers are still teaching science as a static, step-by-step procedure that requires little innovation and is an inflexible process, which attracts only a limited group of students and repels many others. Professions that require scientific knowledge are seen as solitary positions, performed by individuals with superior intellect.

Student engagement is another problem in many classrooms. Student engagement has been directly linked to reduced dropout rates, higher classroom grades, better performance on standardized tests and individual well-being (Corso et al., 2013). There are three types of

student engagement: Behavioral Engagement, Emotional Engagement and Cognitive Engagement (Fredricks, et al., 2004). The combination of all three types of engagement produces the most meaningful academic and personal outcomes (Fredricks, et al., 2004). Unfortunately, by the time students reach high school age, 60% are chronically disengaged and less than half of these students want to be at school (Corso et al., 2013). This poses a significant problem in developing students who are both engaged and literate in the Nature of Science.

Success has been noted by Akerson (2000) and others in using Action Research to develop instructional methods that engage students and teach them the aspects of NOS. Action Research is used to improve educational practice through the creation, implementation and revision of instructional interventions (Clark et al., 2020). One of the main benefits of Action Research is it is tailored toward a specific context or situation in the classroom in which progress can be made easily and continuously (Clark et al., 2020).

Action Research has been used by Wabeh & Abd-El-Khalick (2013), and Akerson et al. (2013), to study ways in which students learn and retain the aspects of NOS. Scholars such as Scharmann et al. (2005), Abd-El-Khalick, Bell & Lederman (1998), and Lederman (1992) found NOS literacy is demonstrated most strongly when NOS instruction is explicit, reflective and taught within an existing applied context. Although Action Research studies have been done with elementary science students using explicit, reflective and contextual instruction, (Akerson et al., 2011; Akerson et al., 2013; Wilcox & Lake, 2018), little research has been done on explicit reflective NOS instruction in the secondary Integrated Chemistry and Physics classroom. No research has been conducted on explicit reflective instruction using instruction of an atomic bonding unit.

Method

The method of the study was based on an explicit reflective intervention in which the aspects of NOS were explicitly incorporated into daily instruction and activities. Students were continuously reminded of the five major aspects of NOS that included: science is based on empirical evidence, science is imaginative and creative, science is tentative, science is based on observation and inference, and science is socially embedded. Each activity contained one or more of these NOS aspects.

Researcher

The teacher-researcher was a 61-year old Caucasian female who taught secondary science, including Integrated Chemistry and Physics for eight years. The researcher had previous experience in performing quantitative research and development for two major pharmaceutical companies. Research was conducted by the researcher as a guest teacher over a four-week period.

Participants

Participants were Integrated Chemistry and Physics students from Periods 1 and 2 at Vincennes Lincoln High School. The students were predominantly freshman and this was their first secondary science class. All students who had consent to participate in the study and who completed the activities were included in the study. A total of fifteen (15) students were participants in the study. Nine students were from Period 1 and six students were from Period 2. Two-thirds (10 students) of the participants were female, and one-third (5 students) were male. Thirteen of the students were Caucasian English speaking students, one student was an African American English speaking student, and one student was an African American student who spoke French as his native language, but was competent in speaking, reading, and writing English. There was no information regarding potential individualized interventions such as an IEP or 504 plan.

Intervention

The intervention was incorporated into the 2023 Indiana Department of Education State Standards (Indiana Department of Education, n.d.) for secondary Integrated Chemistry & Physics classes. The intervention was incorporated into standard HS-ICP1-1 which focuses on the use of the periodic table to predict properties of atoms and the number of electrons in the outermost energy level (Table 1). Students predicted the type of bonding that occurred between atoms based on these highest energy electrons with the incorporation of the aspects of NOS. The main NOS aspects the intervention focused on were: science is based on empirical evidence obtained through observation, science is tentative and changes as new information becomes available or as current information is examined with a new perspective, science is imaginative and creative, science is socially and culturally embedded, and science

is based on inference.

Before the beginning of the instructional interventions, students were given the VNOS-D survey and initial data was recorded. The following day, interventions began. The study lasted the entire unit which was approximately four weeks. Four posters of the characteristics of NOS were displayed throughout the classroom as a student reminder. Each day throughout the unit, the teacher-researcher went over the characteristics of NOS at the beginning of the period. Daily experiential activities included some or all of the NOS characteristics. Some of the specific activities included: ionic concentric circle activity performed in groups of 2-3 students (Figure 1), marshmallow and toothpick molecule activity performed in groups of 2-3 students (Figure 2) and metallic electron sea activity performed in groups of 4-5 students (Figure 3). The outline of the entire module is found in Table 2.

After each activity, students reflected on the NOS aspects included in the activity through journal writing. Students were encouraged to draw pictures, connect new learning to prior learning, and reference aspects of NOS they experienced that particular day. The teacher then facilitated group discussion regarding student perspectives regarding their understanding of NOS and how it pertained to the content and activities of the day.

Table 1. IDOE State Standards

HS-ICP1-1 Matter and its Interactions
<p>Students who demonstrate understanding can: HS-ICP1-1 Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] Reference: NGSS HS-PS1-1</p>
<p>Science and Engineering Practices SEP.2: Developing and Using Models Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s). • Use a model to predict the relationships between systems or between components of a system.</p>
<p>Disciplinary Core Ideas PS1.A: Structure and Properties of Matter • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. • The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states.</p>
<p>Crosscutting Concepts CC.1: Patterns • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.</p>

Table 2. Instructional Timeline

Week 1	Periodic Table Structure, Outermost Electrons, and Ionic Bonds Activity: Placement of Outermost Electrons in Orbitals Reflection (Independent, and Classroom) Activity: Valence Electron Drawings Observation and Inference Activity: Ionic Bonding and Lewis Structures Observation, Inference, Creativity, Reflection
Week 2	Metallic Bonds Activity: Free Movement of Electrons in Metallic Bonding Reflection, Observation, Inference Activity: Video. Metallic Bonds and Electricity Observation, Inference, Reflection
Weeks 3 & 4	Covalent Bonds Activity: Lewis Structures of Covalent Bonds Reflection, Inference, Creativity, Observation Activity: Lewis Structures of Multiple Bonded Molecules Reflection, Inference, Creativity, Observation Activity: Molecular Shapes Reflection, Inference, Creativity, Observation

Introduction of NOS Aspects

Students were introduced to aspects of NOS with a comprehensive PowerPoint presentation. The PowerPoint presentation provided relevant examples of inference, creativity, empirical evidence based on observation, the social and cultural aspects of science, and the tentative aspects of nature of science. Each example proceeded with a discussion of the aspect and student provision of additional examples with reasoning for their choices. The PowerPoint presentation can be found using the following link:

https://docs.google.com/presentation/d/1E6Igw5yZy_M-JrUiQ8GnWWPxuYkFVa2j9kyvX8xFo5U/edit?usp=sharing.

Valence Electrons

Students were introduced to the periodic table. The question “Why is the periodic table designed the way it is?” was asked and students discussed potential reasons. The instructor told students the definition of periodic meant repeating and explained the elements were placed in vertical columns or families based on their similar chemical properties and in horizontal rows based on increasing number of protons. The discussion then moved to the number of valence electrons members of each family of elements contain. Students were asked to infer the relationship between the number of valence electrons and chemical properties.

To demonstrate the concept of valence electrons, students were given a concentric circle diagram and skittles. The concentric circles served as a model for the energy levels in the electron cloud. Students utilized inference based on their observations and the location of an element on the periodic table to determine the number of total electrons and their location in each period. Students placed the electrons in the appropriate energy levels (concentric circle), determined the number of valence electrons, and inferred the chemical properties of the element (Figure 1). The teacher asked students the following questions to incorporate the NOS aspects of inference, creativity and tentativeness to this activity. The questions were: “Do we truly know where the electrons are located in atoms? Explain your answer.”, “What aspects of NOS are used to create the atomic model?”, “Can this model change, over time?”, and “Draw an alternate model for the location of electrons of one of the examples from the activity.”.

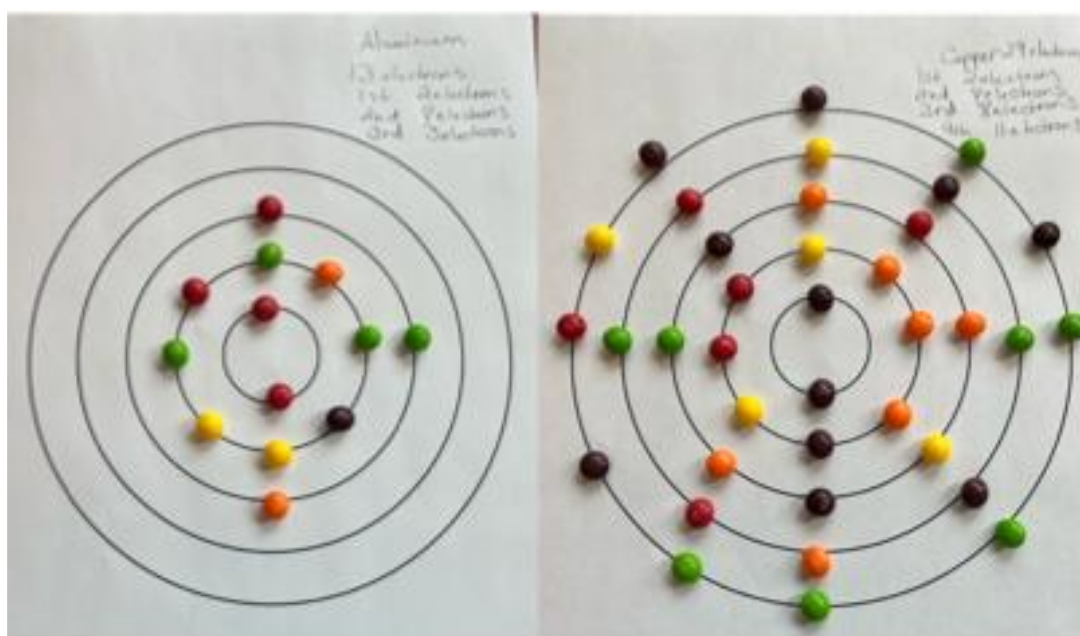


Figure 1. Valence Electron Activity

Students then learned about the octet rule for the outermost electrons (those in the s and p orbitals) to learn about ionic bonds. Based on the number of valence electrons for each element, they inferred the combination of the number of atoms to produce a compound in which all atoms fulfilled the octet rule (except for Hydrogen) using Lewis Structures (Figure 2). Students reflected on NOS aspects they incorporated in this activity. Discussion questions included the following: “What aspects of NOS are used to draw Lewis Structures?” and “How is this knowledge socially embedded?”.

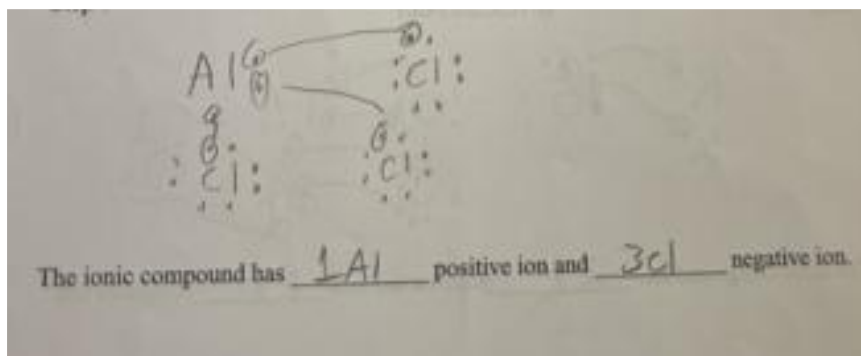


Figure 2. Student Example of Lewis Structures for Ionic Compounds

Teacher observation as a formative assessment indicated that students required additional interventions with this activity. Additional days were used working with students one-on-one and with marshmallows and beads as a manipulative to master Lewis Structures. Another formative assessment included the development of four Lewis Structures. Students then spent two days drawing Lewis Structures of polyatomic ions. Once students successfully completed the formative assessments, metallic bonding was introduced into the unit.

Metallic Bonds

After a brief lecture on metallic bonding, students were given a tray that models metallic bonding. Small magnets were glued to the bottom of the tray in a symmetrical manner. Colored beads were added to the tray and dispersed evenly in the tray as the distribution of electrons around the metal atoms. A group of four students were given a tray and were asked to tilt the tray from side to side, simulating “the sea of electrons” that move throughout the metal atoms (see Figure 3.). Students discussed the following questions: “Do we know where the electrons are at any given moment? Explain your answer in terms of NOS aspects.”, “Describe other models one can use to demonstrate metallic bonds?” and “How does the model you have described follow the empirical evidence provided regarding metallic bonds?”. The teacher then reviewed electricity which was previously covered in the physics portion of the class. The focus of the lecture was the movement of electrons from one point to another. Classroom discussion was facilitated with the following questions in mind: “Infer the types of materials used in conducting electricity. Explain your answer.”, “Infer the types of materials used as electrical insulators. Explain your answer.”, and “How is this lesson socially and culturally embedded?”. Formative assessments were used to test for content mastery.



Figure 3. Metallic Bond Model

Covalent Bonds

Students were introduced to covalent bonds in the form of a lecture. Students learned covalent bonds are different from ionic bonds in that covalently bonded atoms share electrons, while in ionic bonds, one atom gives up electrons, gaining a positive charge and another atom gains electrons, becoming negatively charged. The atoms bond based on electrostatic attraction. The octet rule still applies to covalent bonds. Classroom discussion focused on the following questions: “Based on the empirical evidence and utilization of inference, what other models of bonding could be suggested?”, “Do we know for sure that electrons in covalent bonding are shared? Explain your answer.”, and “Could our model of covalent bonding change over time? Explain your answer.”.

The second day, students practiced drawing single-bonded Lewis Structures. Teacher observation was used as a formative assessment to determine student mastery of covalently bonded molecules. One additional day was spent on drawing Lewis Structures to ensure all students mastered the content. Students were then introduced to the concept of multiple bonds and spent time drawing Lewis Structures with multiple bonds. Completed Lewis Structures were used as a formative assessment. Classroom discussion focused on answering the following questions: “How do multiple bonds accommodate the octet rule?”, “What type of empirical evidence supports the theory of multiple bonds?”, and “Could the model of multiple bonds change over time? Explain your reasoning.”.

Molecular shapes based on Lewis Structures were introduced to students as an experiential activity. Students were given five marshmallows and four toothpicks. Based on the Lewis Structures drawn and the electrostatic repulsion of electrons (bonded atoms exist as far from one another as possible), students produced molecular shapes. They identified shared pairs of

electrons (bonded pairs) and unshared pairs of electrons. In the case of multiple bonds, shared pairs were counted, but the bond was considered as one, but classified as: single, double or triple bonds. Students examined the shapes and discussed the following concepts: “How do these shapes follow the octet rule based on empirical evidence regarding bonding?”, “What NOS aspects are used in developing these models?”, and “How do the shapes of these molecules have social relevance?”.

The summative assessment for this unit incorporated all three types of bonds. It included the identification of the type of bond two atoms made, a drawing of the corresponding Lewis Structure, and identification of the molecular shape the atoms produced (if one is produced). Additional questions incorporating aspects of NOS were also asked as part of the assessment, but were not graded.

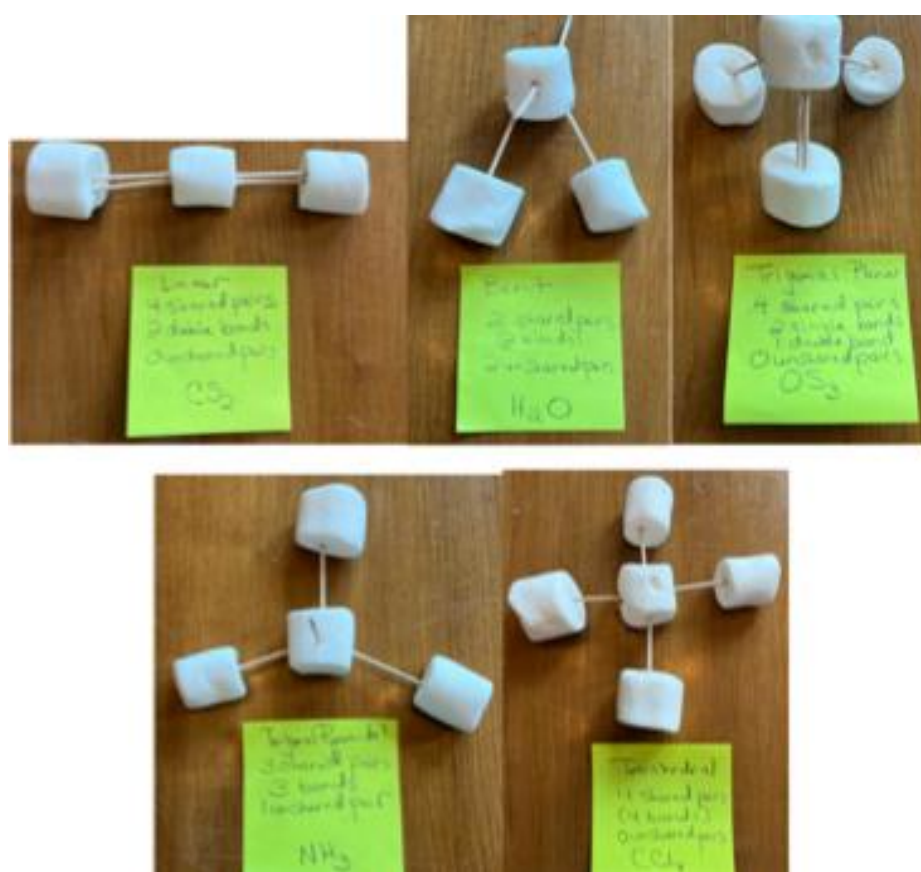


Figure 3. Molecular Shape Activity

Data Collection

The study was qualitative in nature. Data were collected in several forms including: a teacher/researcher journal, student journals, pre and post intervention VNOS-D surveys, and

end of study interviews. The teacher/researcher journal information included observations regarding student mastery of content and understanding of NOS aspects. Student journals were reflections of their understanding of aspects of NOS and its application to atomic bonding. Student interview responses focused on their new understanding of science and its impact on society.

Much of the qualitative data was collected via VNOS-D surveys (Khishfe, R. & Abd-El-Khalick, F., 2002) before and after the intervention (See Appendix A). The questionnaire consisted of seven open-ended questions that evaluated student content knowledge and competency in the nature of science. The survey was a modification of the VNOS-C survey (Lederman et al., 2002) which had been validated by Lederman et al., (2002) and others such as Ayala-Villamil & García-Martínez (2021). Question 1 encompassed a general understanding of science. Question 2 assessed student comprehension of the empirical aspects of NOS. Questions 3, 4b and 6b assessed student understanding that science is tentative. Questions 4a and 7a assessed student understanding that science is based on observation and inference. Question 6 assessed student comprehension that science is subjective and socially embedded . Questions 7b assessed the creative aspects of NOS.

Data Analysis

Pre-surveys and post-surveys were analyzed as Inadequate, Adequate and Informed using the coding rubric established by Akerson (2010). Emphasis was placed on students' conceptions of the five established characteristics of NOS. Any responses considered between two coding rubrics were graded as the lower rubric. All surveys were coded with a number by a gatekeeper to minimize teacher/researcher bias in coding responses.

Observations were analyzed for behaviors indicative of the use and understanding of NOS aspects. These were journaled in the teacher/researcher journal. Classroom discussions were also journaled by the teacher/researcher and used to evaluate student NOS understanding. Teacher-researcher reflections were analyzed using coded themes noting the occurrence of NOS aspects each day. Teacher/researcher reflection also included the discussion of potential interventions required for either content mastery or improved knowledge of NOS aspects.

Daily activity worksheets and student journals were analyzed for NOS understanding using

coded themes as well as content mastery regarding atomic bonding. NOS understanding was coded as Inadequate, Adequate and Informed using a teacher/researcher pre-determined rubric. Worksheets were coded with a number by a gatekeeper to minimize teacher/researcher bias in coding responses.

Results

The results of the VNOS-D pre and post assessment data is found in Table 3. Results in combination with observations, student journal entries, teacher/researcher journal entries, worksheet answers, and interview answers were used to describe student progress in the understanding of NOS. Results were categorized by the five main characteristics of NOS focused on in the intervention.

Table 3. Pre and Post Intervention VNOS-D Survey Data

NOS Aspect	Pre-Intervention Reply %	Post-Intervention Reply %
Basic understanding of science		
Inadequate	36	8
Adequate	57	42
Informed	7	50
Science is based on empirical evidence		
Inadequate	79	58
Adequate	21	17
Informed	0	25
Science is tentative		
Inadequate	43	17
Adequate	57	69
Informed	0	14
Science is based on observation & inference		
Inadequate	39	13
Adequate	54	67
Informed	7	21
Science is subjective & socially embedded		
Inadequate	71	42
Adequate	29	50
Informed	0	8
Science is creative & imaginative		
Inadequate	71	25
Adequate	14	42
Informed	14	33

Basic Understanding of Science

Student adequate/informed responses to the basic understanding of what science encompasses increased from 64% to 92%, while the percentage of informed responses increased from 7%

to 50% of students surveyed. The quality of the responses to the survey in general in this area demonstrated a deeper comprehension of science after the intervention. Example pre-intervention adequate responses included:

Science is the study of the universe and the elements of the world (Student 15).

Science is a subject that talks about cells, earth, life (Student 8).

Science is something that you learn how things work like energy, chemical, weather, things like that (Student 12).

Post-intervention responses included a deeper understanding:

A subject and topic people have researched things based on (Student 7).

Research, a way of knowing something (Student 9).

...is a study of how things work like chemical and physical (Student 12).

There was only one pre-intervention response that exemplified informed understanding of science:

A knowledge about the physical and chemical universe and things that go on (Student 1).

A much more comprehensive understanding was demonstrated in the post-intervention informed understanding of science:

Science is the study of the behavior of physical and natural world theory, observation, experimentation and the testing of theories (Student 2).

The pursuit and application of knowledge and understanding of the natural world (Student 6).

The study of structure and behavior of the world (Student 1).

Most students no longer thought of science as a subject they learned in school, but a form of exploration to gain knowledge about the world. Some students even included aspects of NOS that tied to science such as observation and experimentation (Student 2).

Science is Based on Empirical Evidence

There was also a similar improvement in student understanding regarding the empirical aspects of NOS. Student adequate/informed understanding of the empirically based aspects of

NOS increased from 21% to 42%. Informed student understanding increased from 0% to 25%. Student individual responses demonstrated a deeper understanding of NOS.

Pre-intervention adequate responses:

Science is different from other subjects because it's fun and you can learn a lot more than you think like when you do experiments and you can learn more about the world (Student 3).

Science is different because it includes a lot more experiments (Student 4).

Science is based on empirical evidence (Student 6).

Post-intervention adequate responses included:

Different from other subjects because science strives to be detached and unbiased in its pursuit of understanding (Student 9).

Well science is different than the other because it talks about different things that make things work like oxygen mixing with others (Student 12).

There were no pre-intervention informed responses. However, post-intervention informed responses included:

Science is different than other subjects because we use observation and imagination other than being taught how to do something and it doesn't change (Student 2).

You use evidence to come up with it (Student 1).

Students also demonstrated their knowledge regarding the empirical aspects of NOS in their worksheet responses. One of the worksheets for ionic bonding asked the following question: *Do we know for a fact that these atoms are binding in the way we predicted?* Student responses represented their knowledge of the empirical aspects of NOS although they did not specifically use the term empirical evidence. These responses included:

Due to all the research that scientists get to find out the way things work (Student 15).

Through the experimental measurements we make (Student 6).

Science is Tentative

The VNOS-D data and other forms of data showed a great amount of student growth in their understanding that science is tentative. Adequate/informed student VNOS-D responses

increased from 57% before the intervention to 83% after the intervention. Informed student VNOS-D responses increased from 0% to 14%. Adequate pre-intervention responses included:

Yes, they are always learning new things which can definitely change the future (Student 13).

Yes I do think that the more they find out the more the world changes (Student 8).

Post-intervention adequate responses included:

I think it might change in the future because nothing is certain and everything is always changing (Student 2).

There was an absence of pre-intervention informed responses, but post-intervention informed responses included:

Yes cause more data can be found (Student 1).

Yes I believe that what scientists know can change the future because the new things that they know can add new things to the future (Student 3).

Student responses to questions on worksheet activities also demonstrated an understanding of the tentative aspect of science. On one of the worksheets, students responded to the question: *What do these changes in the periodic table suggest about science?* Students answered using the tentative aspects of science. Example replies were:

It is never going to always be the same (Student 14).

Changes happen every day (Student 11).

Students also exhibited understanding of the changing environment of science in their journals. On April 2nd, Student 1 noted: Science is constantly changing. Student 8 on this same date noted: Science changes every day that's why we always have something to learn.

Science is Based on Observation and Inference

Student comprehension of the observational and inferential aspects of NOS also improved post-intervention. Only 61% of student responses were adequate or informed prior to reflective, explicit instruction of NOS. This improved to 88% post intervention. The most common responses from students who exemplified adequate and informed knowledge prior

to the intervention were:

Adequate:

By studies and fossils (Student 14).

Fossils have appeared in rocks and several other places (Student 1).

Informed:

They found fossils in the ground and with that they can figure out what they look like (Student 4).

Post-intervention responses were slightly more detailed:

Adequate:

All direct evidence from fossil fuels and sediment (Student 1).

Because there is physical evidence by fossils (Student 10).

Informed:

They don't know for a fact but from fossils and other things, they can make an educated guess (Student 13).

Students also illustrated knowledge of observation and inference in worksheet activities. On one of the worksheets, the question, *Do we know for a fact that these atoms are binding in the way we predicted? Why or why not?* was posed to students. Student answers exhibited their comprehension of this aspect of NOS:

No, because we cannot see the atoms we could only predict by the way we know little things about them (Student 2).

Due to all the research that scientists get to find out the way things work maybe because nothing is ever for sure of what we think (Student 15).

Students also demonstrated understanding during the interview process. The question, "What characteristics do you think a scientist needs to be successful? Explain", was posed to participants. The following responses demonstrated knowledge of the inferential and imaginative aspects of NOS:

Think outside the box....being open minded. (Student 1).

Resourceful. I'd have to do it the way I think but a lot of people think differently (Student 14).

Science is Subjective and Socially Embedded

Students illustrated a significant increase in comprehension of the subjective and social embeddedness of science. VNOS-D adequate/informed responses increased from 29% to 58% and the informed responses increased from 0% to 8%. Exemplar pre and post adequate and informed responses were as follows:

Pre-intervention Adequate:

Honestly it's just a guess or estimation (Student 1).

They are probably not very certain considering the fact that no one can see into the future. Weather people normally go off weather patterns, but these can change easily within the next few hours (Student 4).

There were no informed responses from the pre-intervention VNOS-D.

Post-intervention Adequate:

They are very accurate due to all the facts, but everyone knows that the weather is unpredictable (Student 1).

Weather forecasts are based on educated guesses and statistical models of similar conditions from past weather events (Student 9).

Post-intervention Informed:

They sometimes use facts and also use their opinions to make predictions (Student 12).

Science is Creative and Imaginative

The pre and post-intervention VNOS-D responses illustrated the most significant growth in student understanding of the creative and imaginative aspects of science. The adequate/informed responses of students increased from 24% to 75% and the informed responses increased from 14% to 33%. Student typical responses included:

Pre-Intervention Adequate:

Yes, because they use their imaginations to come up with lots of stuff (Student 15).

Pre-Intervention Informed:

They probably imagine what is like if one chemical was different then would it have a different reaction (Student 1).

I think so because if they didn't how could they come up with how the dinosaurs died? They would have to use a little of their imagination. They most likely got their facts and used their imagination (Student 4).

Post-Intervention Adequate:

Yes, they used their imagination when trying to figure out what dinosaurs look like (Student 2).

Post-Intervention Informed:

Yes because you have to use your imagination to come up with different ways to do stuff when they are testing their hypothesis (Student 1).

Yes they do when they use their imagination when thinking of new things and putting data together (Student 13).

Students also discussed the use of imagination in their journals. One student was very surprised that imagination and creativity were a part of science. He reflected on these ideas in the following excerpt:

I learned that science is a lot more complicated than it seems, like it's more creative than you think and that you can use your ideas all you want (Student 8).

Discussion

Explicit-reflective incorporation of NOS aspects in an atomic bonding unit in two Integrated Chemistry-Physics classes demonstrated increased understanding of all aspects of NOS based on post-intervention VNOS-D surveys, as well as, classroom discussions, NOS related questions posed in activities, student journal entries, and student interview responses. On average, students improved their understanding of aspects of NOS and science in general by 30%. Students gained the most understanding that science is creative and imaginative.

Improvement in this area increased by 47%. This improvement was not only demonstrated in the VNOS-D surveys, but in journal entries. Student reflections remarked their surprise in the discovery that scientists use creativity and imagination in creating models to describe natural phenomena. Students also applied this new knowledge to create alternate models of Lewis Structures during ionic, and covalent bonding activities.

Students demonstrated the least improvement in their understanding that science is based on empirical evidence. The improvement in this area based on the VNOS-D survey increased by only 21%. Students also failed to discuss how scientific inferences were based partially on empirical evidence in classroom discussions, their journals and activities. The researcher attempted several different ways during the unit to incorporate the definition of empirical evidence into discussions and activities. Students appeared to understand that inferences and scientific decisions were based on observations and other forms of data, but they didn't seem to correlate observations and experimentation to the term empirical evidence.

The incorporation of NOS aspects also increased student knowledge of atomic bonding. Students performed better on daily activities and had fewer misconceptions regarding the content based on classroom discussions and teacher reflections. There was less time spent on re-teaching content than in previous years, particularly in the areas of metallic and covalent bonding. Students appeared to have an easier time applying concepts they learned in conjunction with aspects of NOS, in this unit than units prior to the intervention.

Much of the intervention focused on group work and collaboration as one of the aspects of NOS. Based on teacher/researcher observations, students appeared to engage in more collaboration in this unit than in previous units. Teacher/researcher observations noted that students spent more time listening to one another and were more eager to try different ideas before choosing one as a group. When given a choice, students preferred to work together in a collaborative setting than individually as a result of the NOS intervention.

A significant increase in the demonstration of creativity and imagination was demonstrated by students after the implementation of NOS aspects into the atomic bonding unit. Many of the students chose to use drawings or building models to master unit concepts. More students preferred to use drawings over the use of discussion or written responses to answer activity questions.

Students also gained knowledge in the cultural aspects of science. They learned their cultural backgrounds and previous knowledge shape the ways in which they make inferences and draw conclusions from data. Their beliefs, traditions and interests dictated the specific aspects of scientific knowledge they desired to gain and the methods they used to expand their knowledge bases.

The intervention helped students expand their understanding of the social aspects of science. Students learned that science shapes society and how people view the World and one another. They also learned that science urges students to continue their journey of discovery of themselves, humanity and their surroundings. Scientific inquiry is constructed based on social needs and issues, and society is shaped by scientific discovery. Through the intervention, students in this study gained knowledge in the interrelation between the two.

Conclusion and Implications

The action research study was conducted in a secondary NGSS based Integrated Chemistry and Physics classroom. There were several caveats that needed to be noted in this study. One, participants with IEPs and 504 plans received the same instruction and activities as all other students. These students did not ask for additional time or resources to complete any of the NOS related activities.

Second, some participants had multiple absences during the four-week study. Based on school policy, students were not required to complete any activities they missed during their absences. This may have affected the rigor of the intervention. Student absences also reduced the amount of data available for analysis during the study.

The study's rigor was also impacted by three days in which students did not attend school during the study. Students did not attend classes the day of the solar eclipse on April 8th. Two days of classes were also canceled due to an electrical outage. School was held online in an abbreviated version on these days, which did not allow for the inclusion of the NOS interventions.

Although similar explicit-reflective NOS instruction studies (Akerson et al., 2000; Akerson et al., 2013; Akerson et al., 2019; Scharmann et al., 2005) have been performed in elementary

science classrooms, few studies have been performed in secondary science classrooms, and no published studies have been performed specifically in a secondary Integrated Chemistry Physics classrooms during a unit on atomic bonding. The study produced similar results as other explicit NOS instruction studies, but since this was only one study, more studies must be performed to validate this action research study.

Future recommendations include studies that enlist a larger group of ICP students. The same study performed over multiple years would also further validate study results. In future studies, students requiring additional accommodations (students with IEPs and 504 plans) should be identified and perhaps modifications of activities implemented as part of the study. School schedules should also be taken into consideration (time period without remote school days) before implementation of the study to create a consistent environment for students.

Recommendations

In future instruction of atomic bonding in ICP classes, the author recommends the use of the same experiential activities to address NOS aspects, specifically the Valence Electron Activity, the Metallic Bond Activity and the Molecular Shape Activity. Students who participated in these activities successfully mastered the content, as well as gained knowledge in NOS aspects. In the future, The Metallic Bonding Activity should include an experiential activity regarding electricity. There are simulations such as Everycircuit or Phet that would effectively integrate the concept of metallic bonding with electron flow demonstrated in electricity. This would provide students with a clear picture of the relationship between metals and electrical conductivity.

Since the current intervention was ineffective in teaching students the term empirical evidence and its relationship with observation and inference, the author recommends the introduction of an activity connecting observation, empirical evidence and inference. Activities such as TrickyTracks or AACT's Observations vs. Inference activity (<https://teachchemistry.org/classroom-resources/observations-vs-inferences>) would assist in student understanding of the relationship between observation and inference, Activities teaching the concept of empirical data should be included such as the video Empirical Evidence-Definition, Types & Examples (<https://study.com/academy/lesson/empirical-data-definition-example.html>) and simulations such as Data Nuggets or DataClassroom to give

students background knowledge so they can effectively scaffold the concepts of NOS.

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Appendix A

NOS-D Survey

Name _____ Period _____

Please answer these questions to the best of your ability.

1. What is science?
2. What other subjects are you learning?
How is science different from other subjects?
3. Scientists are always trying to learn about our world. Do you think what scientists know might change in the future?
4. How do scientists know that dinosaurs really existed? Yes or No
How certain are scientists about the way dinosaurs looked?
5. A long time ago all the dinosaurs died. Scientists have different ideas about how and why they died. If scientists all have the same facts about dinosaurs, why do you think they disagree about this?
6. TV weather people show pictures of how they think the weather will be for the next day. They use lots of scientific facts to help them make these pictures. How certain do you think the weather people are about these pictures? Why?
7. Do you think scientists use their imaginations when they do their work?
If **No**, explain why?
If **Yes**, then when do you think they use their imaginations?

Appendix B

Valence Electron Activity

Name(s) _____ Period _____

Use the diagram to place electrons (Skittles) in the orbitals.



1.
 - A. Sodium
 - B. Copper

C. Aluminum

D. Carbon

2. Do we know that the electrons are really located in these areas? Why or Why not?

3. Draw a different model (from above) of electron orbitals.

4. Why did you choose this model?

5. Do you think your model is better than the above model? Why or why not?

Appendix C

Metallic Bonding Activity

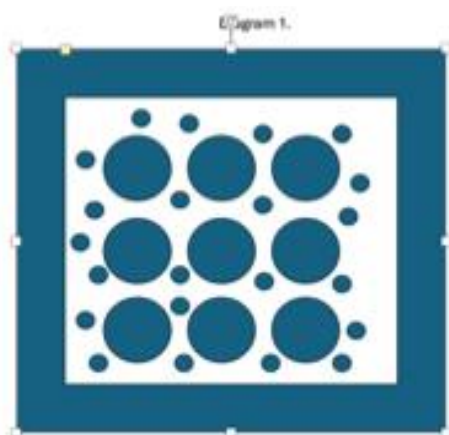
Name(s) _____ Period _____

Metallic Bond Activity

This activity is meant to demonstrate the potential location of metallic nuclei in relation to the electrons.

Each student will be given a plastic tray with nuclei (which are depicted by stationary Skittles and electrons which are depicted by the Nerds). See Diagram 1.

1. Move the plastic tray from side to side. What do you notice about the electron placement?
2. How accurate do you think this model is? Explain your answer.
3. Draw an alternate design that represents your understanding of metallic bonding.



Appendix D

Molecular Shape Activity

Molecular Shape Activity

Name _____ Period _____

Materials

1. 5 marshmallows
2. 4 toothpicks

Instructions

- Draw a Lewis Structure and Structural Formula for each molecule unless it is provided.
- Determine the
 - Number of bonds from the center atom
 - Number of unshared pairs on the center atom.
- Based on the information predict the shape name.
- Make the molecule with marshmallows and toothpicks.
 - Each toothpick represents a shared pair of electrons.
 - A double bond with 2 shared pairs would be represented by 2 toothpicks.
- Turn each in one at a time for your teacher to check as you finish each one.

1. H₂O

Lewis structure

Structural Formula

Bonds on center atom

Unshared pairs on center atom

Name of Shape

2. CCl_4

Lewis Structure

Structural Formula

Bonds on center atom
Unshared pairs on center atom
Name of Shape

3. OS_3

Lewis Structure

Structural Formula

Bonds on center atom
Unshared pairs on center atom
Name of Shape

4. CS₂

Lewis Structure

Structural Formula

Bonds on center atom

Unshared pairs on center atom

Name of Shape

5. NSe₃

Lewis Structure

Structural Formula

Bonds on center atom

Unshared pairs on center atom

Name of Shape

6. Do we know the electrons are really where we say they are? Why or why not?

7. Why do you think the structures you drew are correct?

8. Design and draw a model of an alternate Lewis Structure for H₂O.

Why do you think this is a good alternate model?

Appendix E

Student Interview Questions

Interview Questions

1. What did you learn about the Nature of Science during this study?
2. Do you look at scientists differently? Why?
3. What social aspects do you think a scientist needs to be successful? Explain.
4. What characteristics do you think a good scientist needs to have?
5. What type of environment would be good for a scientist to work in?
6. Would a job or career in science interest you? Why?

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Chapter 8 - The Effects of AI on Student Understanding of NOS Concepts: Science is Tentative, is Creative, and is Affected by Society and Culture

Caitlynn Richardson 

Chapter Highlights

- AI, particularly intelligent tutoring systems, can enhance students' understanding of science.
- Incorporating AI to facilitate the explicit-reflective NOS instruction can help students connect these concepts to real-world scientific content and processes.
- AI tools like SchoolAI's chatbots can prompt students with questions and scenarios that foster deeper discussions and reflections on NOS aspects, including the tentativeness, creativity, and socio-cultural influences of science.
- Teachers face challenges in integrating NOS into the curriculum such as lack of time and lack of resources, but educators can efficiently incorporate NOS activities without sacrificing significant instructional time using AI.
- The study's findings suggest that AI tools can positively influence students' understandings of NOS. Pre- and post-test evaluations using VNOS-D show that students who interacted with AI demonstrated improved comprehension of NOS.

Introduction

Improving how students view the nature of science has been agreed upon as a central goal of science education (Abd-El-Khalick & Lederman, 2000). Driver, Leach, Millar, and Scott (1996) described several reasons why the nature of science has earned its place at the forefront of science education, explaining that understanding NOS is vital for such endeavors as making sense of science and appreciating science in its roles in culture and decision-making. As such, much research has been conducted investigating the best methods and strategies to accomplish this objective. It is necessary to incorporate NOS instruction in the K-12 classroom using content-related explicit-reflective practices and intentional questioning before and after goal-driven inquiry.

In my classroom, each student should engage in science concepts through frequent collaboration while actively cultivating critical thinking skills. A progressive teaching philosophy, in which students are in control of their own learning, is integral to a science classroom. To prepare students for academic success and to help them develop essential life skills, they must interact with science concepts and understand the nature of science itself. Students must be exposed to and immersed in science through explicit-reflective practices and intentional questioning, both before and after goal-driven inquiry. Features of NOS—such as the tentativeness of science, the differences between observations and theories, and the role of science in society—should be present in middle school science for students to become proficient in scientific literacy.

When students recognize key scientific processes, they will be able to ask and answer questions, understand phenomena, articulate scientific issues, and evaluate scientific information (Akerson, Carter, Pongsanon, & Nargund-Joshi, 2019). In addition, students who are exposed to the nature of science while learning science content have an increased interest in science classes and careers. Content-related explicit-reflective practices and intentional questioning before and after goal-driven inquiry are both research-based methods that can support students in developing a firm grasp of the nature of science and science content. My goal as a teacher is to enhance my students' scientific literacy and comprehension, so it is important to foster a dynamic learning environment where students can learn the fundamental skills of scientific inquiry and critical thinking through inquiry, questioning, and reflection.

Purpose

Aspects of NOS that are accessible and important for students in K-12 have been accepted and purported through current research. NOS features should be present in middle school science for students to become proficient in scientific literacy. If students can truly recognize the integral processes of science, they will be able to ask and answer questions, understand phenomena, articulate scientific issues, and evaluate scientific information (Akerson, et al., 2019). In addition, students who are exposed to NOS in their science classrooms have an increased interest in science classes and careers and an increased understanding of the strengths and weaknesses of science overall (Clough, 2011).

One prevalent way to increase science understanding is through an explicit-reflective approach. In explicit instruction, elements of NOS are taught in a direct, structured way. Both Abd-El-Khalick and Lederman (1998) and Akerson, et al. (2000) found that explicit methods of teaching NOS were effective in improving both the views of students and preservice teachers. Reflective activities allow students to discuss the target aspects of NOS and require students to participate in conversations relating the NOS concepts to science content.

The purpose of this study is to examine how utilizing intelligent tutoring systems to teach the nature of science (NOS) in middle school science classrooms impacts students' understanding of the specific NOS concepts, including tentativeness of science, creativity in science, and the role of society and culture in science.

Research Question

How can the integration of AI chatbots as intelligent tutoring systems influence students' understanding of the nature of science ideals - including tentativeness, creativity, and socio-cultural aspects of science - in the context of an 8th-grade science curriculum?

Literature Review

It is challenging for teachers to find time to incorporate NOS into the curriculum, and it is even more difficult to find time to do so in ways that students are exposed to explicit instruction on aspects of NOS and have time to reflect on what they have learned. In

classrooms that are heterogeneous in ability, it can be even trickier. To help combat this problem, teachers can incorporate technology that is very recently integrated into today's world: AI.

Artificial intelligence (AI) has been defined as the application of software that allows computers to simulate humans and their actions. AI has been found to be successful in healthcare, finance, transport, and other sectors, however, research on AI in education has been limited (Murphy, 2019).

Computers have been used for over thirty years in education, but it has not often been individualized. Instead, it has been script-like and unable to take individual abilities into account (Beck, Stern, & Haugsjaa, 1996). Since the beginning of computer usage, we have seen rapid improvements in technology, and the AI market was expected to grow by 48% between 2018-2022 with no signs of slowing (Zhang & Aslan, 2021). With the advent of ChatGPT and other AI tools, there are numerous opportunities to evolve teaching and begin to engage all learners (MacKenzie, Rademaker, Lindeman, Shugart, & Iammartino, 2023). Although many concerns are arising, such as plagiarism, dependency, and privacy issues, teachers will have to be innovative as AI becomes more prominent within society.

AI algorithms have come a long way and have gone from being made ahead of time with no real personalization to being adaptable in real-time in order to meet individual needs (Yang, 2021). As such, it has the potential to educate, train, and increase performance in human productivity and can provide a precise solution for each individual (Yang, 2021). The heart of AI in education (AIEd) is to make educational, psychological, and social knowledge conceptually precise and explicit (Luckin, Holmes, Griffiths, & Forcier, 2016). It can help us understand how learners gain their knowledge and identify misconceptions quickly (Luckin et al., 2016).

One of the most impressive technologies that has come to the forefront of AIEd has been that of intelligent tutoring systems (ITS). ITSs use AI to model experts and provide one-on-one tutoring with a computer-based tutor that is comparable to a master teacher with both scope and depth, knowledge of teaching, and a powerful communication ability (Woolf, 1991). While at the time Woolf's paper was published there was little progress in communication, the use of deep neural networks (DNN) and "strong AI" capable of cognitive reasoning like

that of humans has increased the ability of a machine to communicate effectively (Murphy, 2019).

After formal evaluations, several systems in a study by Bloom (1984) were able to achieve the two-sigma effect which shows the same improvement that results in one-on-one human tutoring. Shute (1999) showed that ITSs effectively reduced the time it required for learning by $\frac{1}{2}$ to $\frac{1}{3}$. Air Force electronics troubleshooting ITSs allowed students to reach proficiency in twenty hours although it typically took trainees about forty months to achieve this in a typical classroom setting (Lesgold, Lajoie, Bunzo, & Eggan, 1988). Students who used LISP, an ITS, at Carnegie Mellon University completed exercises in 30% less time and scored 43% higher on the final exam compared to their traditional peers (Anderson, Boyle, & Yost, 1985). Economic students who used the SMITHTOWN program learned basic economic principles in half the time that it would typically take students (Schute, Glaser, & Raghavan, 1989). Chin, Dohmen, & Schwartz (2013) found that an ITS system promoted learning for elementary students and helped them understand new science concepts. In a study of high school students, ITS was found to help high school students connect math to interests that ultimately increased their learning (Walkington & Bernacki, 2019). Tai & Chen (2020) found that intelligent personal assistants, similar to ITSs, were able to increase EFL students' confidence and decrease their speaking anxiety. Students who were asked to depict what an AI classroom might look like expected AI-assisted learning to take place in the classroom to support instruction and to be able to communicate with humans (Lai, 2021).

AIED has the capability to facilitate interactions, increase engagement, adapt to student needs, and improve learning outcomes (Zhang & Aslan, 2021). ITS enables one-on-one tutoring, something that would otherwise not be attainable due to a lack of tutors and lack of affordability (Luckin et al., 2016). Teachers should use AI tools as a catalyst to transform their teaching and to meet the needs of all students (Luckin et al., 2016).

With this in mind, my goal was to see if I could use AI to help with the challenges of incorporating NOS into the classroom. I wanted to find an AI that could serve as an ITS, but also that would be something my students would enjoy interacting with. One of the AIs that came to the forefront was the website SchoolAI.

Although I searched the website SchoolAI for information about the type of AI model the

website utilized, I could not find any information regarding the AI itself. However, I did locate a chatbot called “AI in Education Coach” provided by the site that I could ask questions about how to use the AI within the classroom. I asked the AI in Education Coach chatbot, “What type of AI model does SchoolAI use?” and was met with the following response:

“As of my last update in April 2023, specific details about the AI model used by SchoolAI, such as its architecture or the technology behind it, are not provided in publicly available information. However, I can offer some insights into the general types of AI models that educational platforms like SchoolAI might employ. Educational platforms, including those that offer student 'Spaces' like SchoolAI, typically utilize a combination of AI technologies to provide a personalized and interactive learning experience. These can include:

- Natural Language Processing (NLP): This allows the AI to understand, interpret, and generate human language. In an educational context, NLP can be used to analyze students' written assignments, provide feedback, facilitate language learning, or enable intelligent tutoring systems that interact with students in a conversational manner.
- Machine Learning (ML): ML models can be trained on large datasets to recognize patterns and make predictions. In education, ML can personalize learning experiences by adapting content to suit the learning pace and style of individual students. It can also analyze data on student performance to identify areas where they might need additional support.
- Recommender Systems: Based on algorithms that filter and recommend content, these systems can suggest learning materials, activities, or courses that are most relevant to the student's needs, interests, or performance level.
- Computer Vision: Though less common in strictly educational contexts, computer vision can be used in interactive learning environments, such as virtual labs, where gesture or object recognition can help simulate real-world interactions.

SchoolAI's use of AI, specifically through offering student 'Spaces', incorporates elements from these technologies to create an engaging and adaptive learning environment. These 'Spaces' could be designed to facilitate personalized learning pathways, encourage collaborative projects, and provide teachers with insights into student progress and areas needing attention. It is important to note that while AI

can significantly enhance educational experiences, it is not a replacement for human interaction. The role of teachers remains crucial in guiding, interpreting, and contextualizing AI-driven insights and in fostering a supportive and engaging learning environment” (AI in Education Coach, 2023).

Based on this information, I feel comfortable categorizing the SchoolAI model as a chatbot that serves as an ITS. As stated previously, ITSs can increase student engagement, motivation, and success, but chatbots have been limited in the number of studies that concern them. To see the effectiveness of a chatbot utilized as an ITS in improving students’ views of NOS aspects, I decided to use SchoolAI’s model for my research focus.

Method

Setting and Participants

I currently teach in a rural public school. The school services fifth through eighth grades, but I am responsible for 100 8th grade students. Seventy-eight of the students are taking 8th grade science. Twenty-two of the students are taking honors high school biology. Students who received free/reduced lunch comprise 33.4%. Approximately 89% of the students at my school are white. Approximately 16.7% are students with disabilities, and 11.6% are considered high-ability. Of the students in my classroom, 13 agreed to take part in the study. From this group, 12 of the students completed both the pre-and post-test evaluation and were included in this research study. Eleven out of the twelve students, or 91.7%, were white, and two out of the twelve students, or 16.7% identified as Hispanic.

None of my students were considered high-ability, but two out of the twelve (16.7%) had individualized education plans and two out of the twelve (16.7%) had 504 accommodations. Seven of the students (58.3%) were female, while the other five were male. All students were offered the opportunity to participate in the study. Parental permission was required to participate. Although only twelve students agreed to participate in the study, the rest of the students were still exposed to the activities as they were integrated into my curriculum. The identities of the students who agreed to participate in the study were unknown to me at the time, as my critical friend, Logan Inman, was responsible for collecting the permission forms.

Teaching Strategies Implemented

Finding time within the curriculum to teach NOS concepts is a challenge for educators. However, it is clearly important. To try to solve this problem, I will not be giving up more than fifteen minutes of class for the following NOS activities. In a typical timeline, these activities would be spread out throughout the year to help balance the time needed to teach content and the time needed to teach NOS. My classes are sixty minutes long. The activities were designed to be completed within the last ten minutes of class. Using AI, I incorporated the current unit we are learning about into the NOS prompts given to the SchoolAI to help a more seamless transition for students between content and NOS. Table 1 provides a list of each day’s activities, along with NOS elements emphasized using AI.

Table 1. Overview of NOS Activities

Lesson	Activity	NOS Aspect
1	<p>“The Tentative Nature of Science” video (3 mins 45 secs)</p> <p>Engage with AI throughout the video (AI-generated questions and responses)</p>	Science is tentative
2	<p>Topic Explorer</p> <p>Engage with AI in a 5-minute conversation about different theories that have changed over time</p>	Science is tentative
3	<p>“Your Amazing Creative Brain” video (3 mins 54 secs)</p> <p>Engage with AI throughout the video (AI-generated questions and responses)</p>	Science is creative
4	<p>Topic Explorer</p> <p>Engage with AI in a 5-minute conversation about</p>	Science is creative

times scientists have needed to be creative

Answer questions on a half-sheet

5	<p>“How Culture Affects Personality” video (6 minutes 24 seconds)</p> <p>Engage with AI throughout the video (AI-generated questions and responses)</p> <p>Consider ways students’ cultures may affect their views at school</p>	<p>Science is impacted by society and culture</p>
6	<p>Topic Explorer</p> <p>Engage with AI in a 5-minute conversation about ways that both society and culture have influenced science</p> <p>Answer questions on a half-sheet</p> <p>Compare answers with a partner</p>	<p>Science is impacted by society and culture</p>

To help explicitly teach students the various aspects of NOS as well as allow them time to reflect in this short amount of time, I utilized ‘Spaces’ from SchoolAI. ‘Spaces’ refer to virtual environments designed to facilitate learning and interaction for students. Teachers use specific prompts to tailor the ‘Spaces’ to various needs, whether it is personalized learning, interactive content, or instant feedback. The AI records each of the individual conversations that students have and shares them with the teacher. It also creates insights and analytics about student performance and engagement levels.

To keep the activities simple and to make sure I was not spending too much time planning the activities, I planned to have students watch a short video about the aspect of NOS I wanted them to learn and then have them engage with the AI to discuss what they learned. A

quick search on YouTube gave me three different videos for students to watch. After choosing the video, I created a Space for students to explore the topic with the AI. For the first aspect of NOS (tentative nature of science), the students did not have a written assignment to complete. I noticed that the level of engagement was lower than I was expecting, so for the second and third aspects of NOS (creativity and socio-cultural), I included a quick worksheet for students to complete as they interacted with the AI. This also helped students who were struggling to converse with the AI have questions to ask it.

Tentative Nature of Science

The first video, “The Tentative Nature of Science,” was created by Angela Metcalfe (2016) and had a duration of 3 minutes and 45 seconds. The video explains that science is a way of understanding the natural world, but it is tentative and subject to change based on new evidence. It provided historical examples like the geocentric to heliocentric shift in the universe's model. The importance of maintaining a flexible and open mind when approaching scientific inquiry was also explained. Students watched this video as an exit ticket and were expected to engage with the AI throughout the video as it asked questions about what they were watching.

In the following classes, students were asked to join the Space created as their exit ticket. The AI was given the following prompt: “I want my students to understand that science is a way of knowing and understanding that can change over time. I want them to explore different historical cases where there was a shift in scientific understanding. For instance, I want them to learn about how our understanding of atomic theory, germ theory, heliocentric theory, cell theory, and plate tectonics has changed over time. Please encourage them to ask questions and give them timelines of how the theory has changed as well as what scientists were involved. They are 8th graders, so this should be a lower-level language and easy to understand.” I gave students approximately five minutes to chat with the AI. The responses were recorded within the Space by the AI.

Science is Creative

The second video, “Your Amazing Creative Brain,” was created by Brainfacts.org (2022) and had a duration of 3 minutes and 54 seconds. The video explains that creativity is

essential for society's advancement. It delved into the human brain's flexibility and plasticity when it comes to creativity, as well as what factors can affect creativity. The video also encouraged embracing creativity and an exploration mindset to unlock potential. Students watched this video as an exit ticket and were expected to engage with the AI throughout the video as it asked questions about what they were watching.

In the following classes, students were asked to join the Space created as their exit ticket. The AI was given the following prompt: "I have 8th-grade students. I would like them to explore creative scientific discoveries. They are going to ask you for at least 3 creative discoveries. Please come up with a bunch of fun discoveries they might be interested in. It could be modern or older discoveries." I gave students approximately five minutes to chat with the AI. The responses were recorded within the Space by the AI. For this aspect, students also received a half-sheet of paper containing questions for students to use to help them engage with the AI. They were prompted to ask the AI what creativity was and what three creative scientific discoveries exist. After they answered the questions on their half-sheet, students were asked to think about whether or not scientists need to be creative and why or why not.

Science is Affected by Society & Culture

The third video, "How Culture Affects Your Personality," was created by Practical Psychology (2019) and had a duration of 6 minutes and 24 seconds. The video explains that culture influences both personality traits and behaviors and gives numerous examples of how this could occur. The video explains that culture influences personality traits and behaviors and gives many examples of how this could occur. Students were encouraged to think about how understanding cultural influences can provide insights into personal beliefs and behaviors. Students watched this video as an exit ticket and were expected to engage with the AI throughout the video as it asked questions about what they were watching.

In the following classes, students were asked to join the Space created as their exit ticket. The AI was not given a prompt for this Space. I gave students approximately five minutes to chat with the AI. The responses were recorded within the Space by the AI. For this aspect, students also received a half-sheet of paper containing questions for students to use to help them engage with the AI. They were prompted to ask the AI for examples of how culture affects science and how society affects science. They were then asked to think-pair-share

with their neighbor to compare examples that they were given by the AI.

Data Collection

Students were administered the VNOS D (Elementary/Middle School Version) before the beginning of the activities. The results were analyzed and recorded as a pre-test to assess the students' current notions of NOS. At the end of the study, students took the VNOS D again as a post-test to assess how the student's understanding of NOS changed over the course of the activities. After each administration of the VNOS D, 10-20% of the students partaking in the study were interviewed. These students were selected in accordance with which students would willingly participate in the interview process and completed by my critical friend, Logan Inman. The interview process allowed me to gain a better understanding of the answers that the students gave on the VNOS D. See Table 2 for VNOS items and the coding rubric used. The VNOS-D assessment can be found at the end of this chapter.

Table 2. VNOS Items & Scoring Methods

NOS Aspect	Questions on VNOS-D	Scoring
Scientific knowledge is never absolute or certain. This knowledge, including "facts," theories, and laws, is tentative and subject to change. Scientific claims change as new evidence, made possible through advances in theory and technology, is brought to bear on existing theories or laws, or as old evidence is reinterpreted in the light of new theoretical advances or shifts in the directions of established research programs	#3, #4b, #5, #9	Students'/Teachers' views of NOS aspects are categorized into naïve, transitional, or informed based on the following criteria: Naïve: Student's/Teacher's response is not consistent with any part of NOS aspect.
Scientific knowledge involves human	#6, #7	

<p>imagination and creativity. Science involves the invention of explanations, and this requires a great deal of creativity by scientists.</p>		<p>Transitional: Students'/Teachers' response is consistent with some, but not all, parts of</p>
<p>Science as a human enterprise is practiced in the context of a larger culture and its practitioners (scientists) are the product of that culture. Science affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion.</p>	<p>#10</p>	<p>NOS aspect. Informed: Student's/Teacher's response is consistent and addresses ALL parts of NOS aspect.</p>

After the completion of the study, I used the annotated scoring guide developed by N. Lederman, Abd-El-Khalick, Bell, Schwartz, J. Lederman, and Kyung Ko (2002). Questions #3, #4a, #4b, #5, #6, #7, #9, and #10 are of particular interest as they focus heaviest on tentativeness, creativity, and social and cultural embeddedness (Lederman et. al, 2002) to score both the pre-test and post-test. Using the scoring rubric developed by Lederman et. al (2002), each student was rated as naive (response is not consistent with any part of the NOS aspect), transitional (consistent with some, but not all of the NOS aspect), or informed (response is consistent and addresses ALL parts of NOS aspect). Unfortunately, there were no training sessions conducted by the development team available prior to the administration of VNOS D. After the administration of VNOS D and corresponding interviews, I looked for trends in ratings for each target aspect to get a sense of how the AI strategy either helped develop my target aspects or not.

Throughout the activities, SchoolAI records the transcripts of the conversations that students have with the AI in the ‘Space’ given. I randomly selected students within the testing group to read and record conversations with the AI. These conversations gave me a promising idea

of how seriously the students are taking the assignment, what misconceptions they may have, what knowledge gaps may exist, and what topics they are especially interested in. It allowed me to track their learning progression as they discussed the aspect of NOS they are learning about with the AI. In addition to transcripts, I took samples of student work throughout the process. Finally, I maintained a teaching log to keep track of instruction and formative assessments to help me gauge student learning.

Data Analysis

My critical friend assigned each student a number to help maintain anonymity during the evaluation of both the pre-and post-VNOS test. As such, I assigned each student as naive, transitioning, and informed anonymously for both tests. To analyze the student views of the tentative nature of science, creativity of science, and the socio-cultural impact of science, I reviewed questions #3, #4b, #5, #9, #4a, #6, #7, and #10. I also transcribed the anonymous interviews conducted by my critical friend and used the responses to help guide my analysis of the pre-test and post-test. I then compared the analysis of the students' NOS understanding pre-instruction to their understanding post-instruction. I then tabulated the number of students who I considered naive, transitional, and informed in their views for both pre-and post- instruction.

All student work written on paper was also collected and assigned numbers by my critical friend to keep my students anonymous as I evaluated their responses to questions on their worksheets. I coded each response to the questions and recorded them to identify if students were engaging with the AI and if it was helping them learn about the aspects of NOS assigned each day. Unfortunately, SchoolAI does not display anonymous data, so the student work collected through my teacher account on SchoolAI was not anonymous. I used this data to help gauge whether students were actively participating in conversations with the AI or whether they were off task. I also used this to see if students would form their own questions to help clarify the AI's responses.

I utilized a teacher journal to keep track of my instructional methods, student engagement, and any challenges or adjustments I needed to make. Throughout the research project, we began iLearn testing. This interfered with some of the instructional times I had had planned, so I took note of these changes in my journal. I also took time to make observations about

how students were responding to both the AI interface and the different NOS-related activities. I also noted any difficulties students faced in understanding the NOS concepts and any technological issues we came across. For instance, one of the days, SchoolAI was unable to host the amount of traffic coming through its website, and students were unable to access the video. We had to push back the video to a later time. I used this log as qualitative data to complement the VNOS-D results from the pre- and post-tests.

Results

Tentative Nature of Science

Prior to instruction, the majority of students were found to be considered transitional in their views of the tentative nature of science (see Table 3). This may have been partially biased as I immediately began introducing concepts of NOS at the beginning of the semester when I was introduced to the aspects of NOS by Dr. Valarie Akerson in my EDUC-Q 612 course, a Topical Seminar in Science Education: Nature of Science. During the semester, I made sure to be intentional about how scientific ideas have changed as new technology and new discoveries have occurred. In particular, I made sure to emphasize how atomic theory changed as science progressed from the time of Aristotle through James Chadwick. Because of this, I am not surprised that the majority were transitional. Only one student in the pre-test was found to be naive, but this student had left the answers to her pre-test questions regarding tentativeness blank. In the post-test, she answered the questions in a way considered to be transitional.

During instruction, students were expected to complete an exit ticket called “Video Explorer” through SchoolAI. In a Video Explorer activity, a teacher is able to insert a url to a YouTube video, and the AI will automatically engage the student with questions and conversations pertaining to the video. For instance, the video I chose to explicitly teach the tentative nature of science was called “The Tentative Nature of Science” (Metcalf, 2016) and was particularly concerned with the dynamic process of science. It explained that scientists must be open to new ideas and willing to modify theories in light of new evidence.

Once the students began watching the video, the Video Explorer AI prompted them to have conversations about what they were watching. With one student, the AI asked, “Reflecting on the video, what do you think about how scientific ideas have evolved?” In another

conversation, the AI prompted “The part about evidence changing our understanding is pretty cool, isn’t it? Have you ever had a moment where something you learned totally changed how you thought about something, like a personal ‘Aha!’ moment?” The student then went on to explain a personal experience they had where their thought process had changed.

The video aspect of the lessons was intended to instruct the students explicitly about the tentative nature of science in a brief period of time. The AI feature allowed for students to reflect on what they had watched and helped them make connections to their individual experiences in a way that would have taken up more class time had I attempted to individually speak with them about what they saw and then prompted them to respond. The explicit nature of the video and the reflective conversations aligned with what has been found to be best practices for teaching NOS (Abd-El-Khalick & Lederman, 1998).

In a subsequent lesson, students were asked to simply have a conversation with the AI in a “Topic Explorer” space. In a Topic Explorer space, teachers can give the AI guiding prompts to focus the conversation. I asked the AI to encourage them to ask questions and give them information about scientists and times involved in the theories they were discussing, but I wanted students to choose a theory that interested them, so I didn’t ask the AI to discuss a specific theory. Instead, I asked it to give them an option of 10 scientific theories that have changed over time and then let students choose. The AI-generated ten different scientific theories that were diverse enough to reach various learners. It would have taken me a lot more time to choose scientific theories and then learn all of the evidence and data involved in modifying the theory over time. The AI was able to do it instantly.

Students chose theories like cell theory, the theory of continental drift, the theory of natural selection, heliocentrism, atomic theory, and germ theory. In the conversations with the AI, I was also given information about how engaged the students were. For instance, one student was “exploring deep questions linking to scientific evolution.” Another was “engaged in a deep dive on cell theory development.” One student was particularly interested in cell theory. She prompted the AI to tell her what people originally thought about the cell theory. The AI responded, “Before cell theory was established, many people believed in spontaneous generation - the idea that living organisms could arise from non-living matter. For example, it was thought that maggots could spontaneously appear in meat.” She then went on to ask more about cell theory. The AI responded, “Several critical observations shaped cell theory.

In the 17th century, Robert Hooke first observed cells in cork, and Anton van Leeuwenhoek later observed single-celled organisms, which he called “animalcules.” Over time, scientists like Matthias Schleiden and Theodor Schwann recognized that both plants and animals are made of cells, and Rudolf Virchow observed that all cells come from pre-existing cells. These observations helped debunk spontaneous generation and established that all living things are composed of cells.” This level of detail and personal interest given to this student would not have normally occurred within the regular class setting.

Table 3. Tentativeness of Science Results

	Pre-Instruction VNOS	Post-Instruction VNOS
Naive	2	0
Transitional	9	8
Informed	1	4
N = 12		

During the post-test VNOS, no students were considered to be naive in regard to the tentative nature of science. While the majority were still considered transitional, 3 students were considered to be informed. When asked “After scientists have developed a scientific theory, does the theory ever change?,” one student responded “Yes, because that’s what a theory is - a possible answer to a question. People used to believe that the sun rotated around the Earth until somebody proved that the Earth rotated around the sun.” Another pointed out that this was possible because “they could get better equipment to run new tests and prove if the theory is right or not.” When asked how sure scientists were about the way dinosaurs looked, one student responded “Not certain at all. There is no saying if a dinosaur had scales or rough skin. For all we know they could be pink and fluffy.” When asked if they thought scientific knowledge may change in the future, one student responded “Yes. Science advances every day. People did not have a cure for chicken pox back in the day, but now they know what they are doing. People didn’t know what to do with infected wounds, so they’d cut off their limbs. Now we know what to do.” No student responded that science was stagnant and never changed. All students were able to articulate that science changes over time.

Science is Creative

After evaluating the pre-test, it was found that 4 of the 12 students were naive when it came to creativity in science (see Table 4). One student explained that creativity could impede science. They said “no, it [creativity] can take away from tests.” Another student mentioned that the model of the layers of the Earth *exactly* represented how the inside of the Earth looks because “scientists have proof of it.”

During instruction, students were once again expected to complete an exit ticket called “Video Explorer” through SchoolAI. The video I chose to explicitly teach creativity in science was called “Your Amazing Creative Brain” (Brainfacts.org, 2022). It discussed that creativity is essential for society’s advancement. Once the students began watching the video, the Video Explorer AI prompted them to have conversations about what they were watching. During the video, the AI asked one student, “That part about imagining alternative paths is fascinating, isn't it? Can you think of a moment when you used your imagination to solve a problem creatively? How did that make you feel?” The student responded that they didn’t know, so the AI went on to break the concept down. It responded, “Totally understand, it can be hard to pinpoint a moment on the spot. Sometimes, I think of creativity like using a cheat code in a video game to get past a level. Ever felt like you found a clever shortcut or a unique approach in a game or real life that felt kind of like using a cheat code?”

In the following lesson, students were expected to engage in a five-minute conversation with the AI. I told them their goal was to discover times that scientists had to be creative. The AI software once again kept me informed of how students were progressing in the conversations. For instance, one student was “exploring the role of creativity in science and questioning its importance for scientists.” Another was “asking for 3 creative scientific discoveries.” The AI gave the student three scientific discoveries that I had not previously known about. For example, it discussed how George de Mestral produced the idea for Velcro by observing how burrs stuck to his dog’s fur and how Percy Spencer came up with the idea of the microwave on accident when a chocolate bar in his pocket melted near radar equipment.

When a student asked the AI if scientists need to be creative, it responded, “Absolutely! Scientists need to be very creative. They often face problems that no one has solved before,

or they need to think of new ways to look at things. Being creative helps them imagine what's not yet known and come up with innovative solutions and discoveries. It's like being a detective and an artist at the same time. Can you think of a situation where being creative might help solve a scientific problem?" Once again, the AI encouraged the student to reflect on the topic.

Table 4. Creativity of Science Results

	Pre-Instruction VNOS	Post-Instruction VNOS
Naive	4	0
Transitional	7	7
Informed	1	5
N = 12		

Students made gains when it came to creativity after exposure to the AI. No students were considered naive after instruction, and 5 were considered informed about creativity in science. Most students were able to articulate that scientists used evidence to make guesses about dinosaurs existing, that the model of the Earth was just a guess, and that scientists must use their imaginations when they do experiments.

One student explained that scientists had to be creative. He stated "Yes, because sometimes (like with trying to figure out what a dinosaur looked like), they have to make their best guess and that sometimes involves using their creativity." Another said that the model of the Earth was not an exact replica because "we have never been past the crust. How can we be sure that's what the inside of the Earth looks like?" Yet another mentioned that "when they [scientists] dig up the bones, they can study them and make inferences on what the bones used to be." No students responded that scientists are never creative or that imagination has no place in scientific endeavors.

Science is Affected by Society and Culture

After the pre-test, most students were considered naive when it came to the idea that science is a socio-cultural endeavor (see Table 5). It was the aspect that students seemed to struggle with the most prior to instruction. Many of the students I teach are members of the dominant

culture in the United States, so it is highly likely that culture and society are things they take for granted. As such, they have probably never considered how science can be influenced by the culture and society which it is taking place in. One student even admitted, “Honestly I don’t even care that much about science and society so I don’t even know.” Another student mentioned that science is separate because “culture is culture.” One student acknowledged that there is a relationship and mentioned that Dutch people and German people are “going to have different ways of doing things like they value different things,” but also said that “it doesn’t necessarily mean that science impacts that.”

Because students seemed to have less of an understanding of how science, culture, and society are interrelated, I chose a longer video to give more explicit instruction on what culture was, what society was, and how that can impact a person’s decisions. The video, “How Culture Affects Your Personality” (Practical Psychology, 2019), was almost twice as long as the other videos, but still under my goal of ten minutes. The video starts by stating that culture influences personality traits and behaviors, and then goes on to discuss individualist and collectivist cultures as well as approach and avoidance cultures and how they impact values that later lead to a difference in behaviors. It ends with explaining the importance of understanding how cultural influences affect personal beliefs and behaviors.

Once again, students were expected to watch the video and engage with the AI during the video in a Video Explorer space. At this point in the study, many students were not excited about the idea of interacting with the AI again, so I had lower engagement with the AI during the video than I had previously. This lesson also took place during iLearn, where we had shortened classes and students were beginning to experience test fatigue. A few students were actively engaged with the AI, but the majority watched the video without interacting with it.

In the next lesson, students were asked to have a five-minute conversation with the AI in the Topic Explorer. The majority of students were engaged that day. Many of the students were shown to be “exploring the impact of culture and society on science” in the AI space interface. When one student asked for examples of how culture affects science, the AI responded, “Culture influences science in various ways. Here are some examples: Indigenous Knowledge: Traditional knowledge from different cultures can offer unique insights and solutions to scientific problems. Gender Bias in Research: Cultural beliefs about gender roles

can impact research methodologies and the interpretation of data. Historical Events: Events like wars or political movements can affect scientific progress by influencing funding priorities and research directions. How do these examples resonate with you?” Another student was interested in how society impacts science. The AI explained that society can impact science in numerous ways, including funding priorities influencing research areas, technological advancements driven by different societal needs, and public opinion shaping scientific regulations.

Table 5. Society and Cultural in Science Results

	Pre-Instruction VNOS	Post-Instruction VNOS
Naive	8	1
Transitional	4	7
Informed	0	4
N = 12		

Post-instruction, many students had improved their views on the idea that society and culture are embedded in science. One student remained naive in their views, but the rest improved. Four students were even considered informed. The student who remained naive stated “no, each one is its own thing,” when asked if there was a relationship between science, society, and cultural values. Other students were able to identify a relationship. One stated, “Yes, they all connect because the way humans behave affects science, and culture and society affects the way that humans act.” Another student stated that “there’s a relationship because society’s cultural values lead to what they want to learn.”

Although many students were able to correctly state that society, science, and culture were connected, many still struggled to produce examples when answering the question.

Discussion

Decades of research has shown that the way that students view the nature of science should be a central goal to science education in order to help students improve their scientific literacy and inquiry abilities (Akerson, et al. 2019). Clough (2011) states that an understanding of the aspects of NOS also increases interest and success in science classes

and science careers. Despite this, students and teachers alike continue to show lower levels of understanding of the nature of science. One problem teachers have in incorporating NOS into their curriculum is lack of time and lack of resources.

To help combat this problem, I devoted less than 35 minutes of class time over the course of 6 lessons to increasing my students' understanding of three aspects of NOS: tentativeness, creativity, and socio-cultural impact. Because research has shown that the most effective way of teaching NOS in the science classroom is through explicit-reflective instruction, I wanted to make sure that my students were exposed to each aspect in an explicit nature. However, I also wanted to stay true to my goal of lowering time and resource constraints. I searched for YouTube videos showing each of the aspects I was interested in teaching and chose one of the first videos that was approved for my district. I incorporated these URLs into the Video Explorer spaces on SchoolAI, and the AI did the rest of the explicit instruction for me. This not only saved me time in planning, but also allowed students to interact with the content one-on-one with a personal AI tutor-based tutor.

Research had previously shown that intelligent tutoring systems acted as one-on-one tutors that were comparable to master teachers (Woolf, 1991). It also showed that the AI was able to connect the content with students' own personal interests. My experience with the SchoolAI intelligent tutoring system supported this idea. Students were able to interact with the content at their own pace and ask for examples that they were interested in. Some students asked for shorter explanations if the tutor gave them long explanations. Some students asked for the AI to relate the content to something they were interested in, like Minecraft or football.

Students were then encouraged to reflect on what they learned while watching the videos by having conversations with the AI in a Topic Exploration space for approximately 5 minutes. I kept the conversations short so they would not take up much class time. The prompts took me a few minutes to write, but overall, the time and resources needed to create these lessons was minimal. The class time they took was minimal as well.

My research supports previous research done in the explicit-reflective instruction is effective at teaching students aspects of the nature of science. Students showed growth in each area of NOS that they were exposed to during instruction. Students were strongest in the tentative

nature of science. This could be because I had already begun to expose students to this idea throughout the school year. However, I also believe that this group of students in particular has a different viewpoint on how science changes because they have experienced scientific advancement in their own lives. They were able to see the development of the mRNA vaccine in real-time throughout the COVID pandemic, and they have experienced the advancement of AI and other technologies. Because they have been able to see science change and evolve in real-time, I think this aspect of the nature of science is somewhat easier for them to understand and explain.

The AI successfully improved students' understandings of creativity in science and society and culture in science. One of the main benefits that I have observed throughout this study is that the AI has access to numerous examples that would take me a long time to identify and learn. For instance, I would never have been able to expose my students to the number of theories that the AI offered to teach them in the Topic Explorer about tentativeness. While I have a basic understanding of each theory due to my position as a science teacher, the AI was able to answer in-depth questions about each theory and explain the timelines, scientists, and evidence evolved at a level that would have taken me hours to obtain. The AI also enabled my students to see science through a different lens that I do not have access to as a member of the dominant culture. It is difficult for me to give students examples of how society and culture has impacted science on a personal level, but the AI was able to do so in seconds.

Implications for AI in Science Education

From this work, it is plain to see that incorporating intelligent tutoring systems into the classroom can be beneficial for teaching students the aspects of the nature of science in response to challenges of time and resources. These AI systems have the potential to not only increase students' understandings of NOS but can increase both personalized and enhanced inquiry-based learning for students as well as improve scientific literacy and critical thinking skills.

AI can help teachers tailor educational content to meet the individual needs of their students, especially in heterogeneous settings. The AI system can instantaneously adapt to a student's learning pace and style. It can also provide unique examples that engage students' personal interest that would normally take teachers an extremely long time to do on their own. If a

student is failing to grasp fundamental concepts, the AI system can provide alternative ways to explain the content as well as notify the teacher that the student is not ready to move on. For students grasping concepts and needing enrichment, AI systems can provide extra material to help push students the extra mile.

Another benefit of AI in education is that it has access to large databases of information that a regular classroom teacher would need time and resources to learn on its own. This allows AI to come up with examples and scenarios that normally would take a prolonged period of time for teachers to create. AI can simulate complex scientific experiments and phenomena, allowing students to engage in virtual labs and scenarios that could be impractical in a physical classroom and that are individualized to student interest. Because of this, the understanding of the iterative and tentative nature of scientific inquiry can be reinforced through AI-driven examples, much like my students were able to do in this study. Where a teacher may struggle to find interesting articles or videos to help reinforce not only NOS understandings, but also regular classroom concepts, AI can provide unique information for students to learn.

AI is becoming more prominent in the classroom, and teachers have more access to student-based AI. While in this study, students utilized SchoolAI, there has been an increase in educational AI programs since the popularization of ChatGPT. MagicSchool AI is another tool that can help teachers develop curriculum, differentiate for students, and create NGSS-aligned assessments. In addition, many platforms that teachers commonly use are providing AI options. Quizizz now has an extension that will create a quiz automatically from any website as well as provide justification for students if they miss the question. Khan Academy now has Khanmigo, an AI that helps teachers save time on preparing lessons and give students personalized tutoring.

Future Research

As AI becomes more prominent in education, it opens a variety of paths for future research. This study only focused on the short-term effects on AI-driven learning on student outcomes for a brief period of time. It would be interesting to see what the long-term effects of AI tutoring systems on student outcomes. Another controversial aspect of AI is how ethical AI in the classroom is for students and teachers. The equity, privacy, and potential for

reinforcing biases could also be studied. In addition, this technology is new for everyone, especially teachers who have not been exposed to AI previously. With its increasing popularity, AI is not going away. It will be necessary to begin to train teachers on the use of AI by students in the classroom and on the use of AI by teachers. Researchers could investigate best practices for preparing teachers to effectively integrate AI tools into their science teaching. Finally, one aspect I had not considered prior to the study was how students would feel about using AI for their own personalized learning. Because they have grown up with chrome books in the classroom, I had assumed that students would not mind having conversations with AI. However, my students quickly grew tired of working within spaces on SchoolAI. Research about student views towards AI learning could be explored.

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Appendix

VIEWS OF NATURE OF SCIENCE

(VNOS D+)

Name: _____

Date: / /

Instructions

- Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question.
- Some questions have more than one part. Please make sure you write answers for each part.
- This is not a test and will not be graded. There are no “right” or “wrong” answers to the following questions. I am only interested in your ideas relating to the following questions.

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Chapter 9 - Incorporating Social and Cultural Aspects of Nature of Science in a High School Physics Course

Victoria Tabibi 

Chapter Highlights

- This chapter addresses an attempt to apply Nature of Science (NOS) concepts to better support high school students' understanding of scientific concepts that are used in a physics course.
- We reflect upon the purpose and benefits of introducing NOS, and prior studies that show success in introducing NOS.
- We discuss the action research completed in a high school physics course, and the results of the study.
- We analyze data to understand what we can gather from the data.
- We provide recommendations that could be used in future studies.

Introduction

The 2023-2024 school year was my 3rd year as a physics and earth science teacher in Norfolk, VA at Lake Taylor High School. Because earth science is not my primary subject, given that the only experience I had was as a student myself, for the purpose of this study I decided to focus on my physics classes. With that being said, I'd like to acknowledge that physics is typically considered a higher level course in high school. I am often praised when I introduce myself as the physics teacher, however, I believe that the appeal of physics is only labeled as this "higher power" due to the incorporation of mathematics concepts. Physics can be just as challenging as any other high school science course and the reality is that beauty is in the eye of the beholder. Science as a whole is a subject that is misrepresented by students, and society for that matter. Each year when I have given my students their introduction survey, the number one response to the question "how do you feel about science," is "I want to like it, but it's too hard." This has been the biggest piece of evidence in my own experience that truly describes how students view science class. It clearly intrigues them, but there's something about it that causes some to build a wall of resistance. Perhaps we're not teaching it in a manner that allows students to have a clear understanding? In instances where students do not show interest in science, are there ways to make the content relevant so that they are interested? This leads us to the incorporation of Nature of Science (NOS) in the classroom. The concept of NOS is not one that many, in my experience, have an understanding of.

Focus

Problem Statement

Norfolk Public School's curriculum guide for certain science classes such as earth science, biology, and environment science, provides the following statement regarding NOS:

Science is not a mere accumulation of facts; instead, it is a discipline with common practices for understanding the natural world. The nature of science describes these common practices employed by scientists and it reflects the intrinsic values and assumptions of scientific knowledge. The nature of science explains the functioning of science, what science is, how it develops and builds the knowledge it generates, and the methodology used to disseminate and validate knowledge. Regardless of the career that a student chooses to pursue, all students should be science literate with an understanding of the nature of science and the scientific knowledge and skills

necessary to make informed decisions.

As mentioned above, this statement is only in select science curricula, for reasons I am unaware of. While NOS is defined even in these select curricula, I have not experienced any type of meeting, training or professional development on the topic. I share this information to reinforce that perhaps the use of NOS is what our students need to gain a better understanding of science concepts. Taşkin Ekici (2022) states “... preparing teachers for teaching nature of science is surely a prerequisite for helping students at any level develop understanding of nature of science,” (p. 77).

Purpose

The purpose of this study is to understand how incorporating social and cultural aspects of NOS, through the use of an explicit-reflective approach, in a high school physics science class can better support the students’ understanding of scientific concepts that are used in a physics course. This aspect of NOS is merged with the use of culturally responsive teaching (CRT) strategies that are used regularly in my classroom. The strategies of CRT incorporated into the classroom involve using students’ cultural knowledge, prior knowledge, and individual learning preferences to facilitate the teaching-learning process (Paulick, Quinn, and Blain, 2024). The merging of these two concepts encourages student’s voices in the classroom and makes science relevant to them, so that they feel more motivated to learn. This is a comparative study between my two physics courses, with one having those NOS aspects incorporated and one without. While the main NOS aspect focused on in this study is the social and cultural embeddedness of scientific knowledge, there is also an incorporation of the imagination and creativity, as well as the tentative nature of scientific knowledge (Lederman et al., 2002).

Research Questions

In this study, I work to find the answer to the following question: how does the explicit reflective incorporation of NOS, specifically cultural and social aspects, encourage students’ voices in the science classroom, and influence students’ understanding of physics concepts in a high school course?

Background/Theory

Khishfe (2023) and Demirdöğen and Aydın-Günbatır (2021) describe the benefits and growth within students' understanding through the explicit-reflective approach of NOS. Khishfe (2023) also included an argumentation aspect in her study, however I chose not to include that approach. Witucki et al. (2023) provided some inspiration to use a similar explicit-reflective approach in order to introduce NOS concepts through "reflection questions, in-class discussions, historical narratives, and autobiographical stories" and related these to scientific research (p. 1). Considering these studies, the outcomes all showed a positive impact through the use of this explicit-reflective approach. Sloane, Wheeler & Manson (2023) share that this approach has shown to be the most effective when it comes to improving students' understanding of NOS (p. 3). I felt confident with taking this approach because I believe it suits my style as a teacher unlike the use of argumentation as described in Khishfe (2023). While integration of argumentation has importance in science education, as described by Khishfe, it is not something I have incorporated in my own classroom. For the purpose of this study, I did not want to introduce another method in the classroom, on top of the NOS concepts being fresh in my classroom. In addition, from what I've gathered through my readings, explicit-reflective instruction appears to support a culturally responsive teaching approach, which is an important aspect of my personal teaching philosophy.

One additional factor to note is that many of the studies on NOS that incorporate this explicit-reflective approach, as well as NOS in general, focuses primarily on the use of it during teacher preparation. This is something that I have personally reflected on and I found that this pattern is something that stood out to me. This sparked some curiosity because I believe that K-12 teachers cannot truly incorporate NOS if it's not something that is taught to them during their teacher preparation program. While the articles I've read show this incorporation of NOS in teacher preparation programs, one cannot assume that this instruction exists in all preparation programs. Lederman (2007) states, "It is safe to assume that teachers cannot possibly teach what they do not understand," (p. 858). With Lederman's statement in mind, this leads me to conclude that the reason why the vast majority of studies I have found are focused on teacher prep, is because we cannot take NOS instruction into the classroom without the teachers themselves being well prepared. Based on the studies I've stumbled upon, it's clear that NOS has been around for some time, but why have we not streamlined it by this point? It's clear that it has a purpose in our field, given its mention in my district's

curricula as well as in the Next Generation Science Standards (NGSS). While this question is not suited for my study in particular, I can't help but wonder why we are mentioning NOS in various curricula, why it's taught in select teacher programs, why there is research showing the benefits of its application to support students learning, and yet it's something that seems to be hidden in the dark.

Procedures

Intervention

The two classes that took part in this study were my first block and third block physics classes, both taught on the same day, back to back. My first block class consisted of 25 students on the roster, however this class in particular had the most attendance issues, so the daily attendance varied anywhere between 17-23 students. My first block was used as the control group, because due to the attendance issues I faced in that class, I anticipated that they would not be the optimal group with whom to incorporate NOS concepts. My third block consisted of 23 students and while I had attendance issues in that class as well, it was not nearly as consistent as my first block. Unfortunately, we have severe attendance issues at my school as a whole, so that would be a factor regardless. My third block is the one in which I incorporated the NOS aspects through explicit-reflective instruction.

Both classes were taught the same content from the waves and sound unit of physics, and were provided with the same notes, practice problems, labs, assessments and demonstrations. My third block class completed 3 additional assignments, which included the VNOS-B pre and post test, as well as a NOS activity. My third block class had two additional days of this unit due to the addition of the VNOS-B and NOS activity. By completing a comparative study, the goal was to compare my first and third block's assessments, both formative and summative, throughout the process and determine if there are any differences in their understanding of our physics concepts. In addition, I was interested in seeing how the addition of NOS concepts could make a difference, generally speaking, when it comes to the scientific concepts used in a physics course.

The routine I have developed for teaching concepts in my physics class is through the use of workbooks in which the notes are provided, which students fill in as I present up front, there are examples that I walk the students through and have them copy down, and lastly there are

practice problems that tend to mimic the examples completed. However, the use of the workbooks is not the sole method I use in my class to gauge my students' understanding; we also go through labs and investigations, and a mix of additional practice based on the needs of the students. I have been given free reign by my administration to teach physics how I want and at the pace I want, given the guidelines of the curriculum provided by the district, so I truly shape the class to the needs of the students. This freedom is solely because physics does not have a standardized test in my district. I used the timeline in Table 1.

I opted to focus on the aspects of imagination and creativity in science and the tentative nature of science, in addition to the social and cultural aspects. Once again, because I have been given the flexibility with what I teach in physics and how I teach in physics, I believe this also suits my style with what I like to do in my class and what type of discussions I like to engage in with my students. I also believe that discussing these aspects of NOS could make the topic more relatable and allow for students to see science in a different light.

Method

Data Collection

As mentioned above, the timeline had been adjusted due to one day in particular with excessive absences in all of my classes. This led to there being an impromptu “day-off” between the second and third physics lesson. As described above, my first block class consisted of 25 students on the roster, while my third block class consisted of 23 students. Following the completion of the unit and once the consent forms were returned, 12 students from my first block class and 7 students from my third block consented to using their data. Table 1 describes the timeline for this unit, including the dates and topics that were discussed on those days.

Table 1. Timeline for Waves & Sound Unit

Date	Block 1	Block 3
4/15/2024	N/A	VNOS-B Pre Test & NOS Activity
4/17/2024	Intro to Waves	
4/19/2024	Universal Wave Equation	

4/23/2024	Day “off”	
4/25/2024	Waves Gizmos	
4/29/2024	Speed of Sound & Doppler Effect	
5/1/2024	Doppler Shift Lab	
5/3/2024	Boundary Behavior & Quiz	
5/7/2024	Interference & Resonance	
5/9/2024	Music of Physics	
5/13/2024	Remediation & Makeup Day	
5/15/2024	Test Review	
5/17/2024	Test Day	
5/21-5/23/2024	Makeup Day / VNOS-B Post Test	Makeup Day

As shown in the table, this unit spanned approximately 14 class sessions, over the period of a little over a month. Throughout the unit, my students completed practice problems, labs (some in the form of Gizmos), a quiz, and a test. My third block class also completed both the VNOS-B pre- and post-test, as well as a NOS activity. Prior to the NOS activity, described further below, I went through a lecture/discussion with my students to introduce the various tenants of NOS. The lecture began with the following question: Why do science teachers often show Bill Nye videos to discuss scientific concepts? The question was posed as a way for students to consider how Bill Nye has been a prominent figure in the science community and education. Several of the students responded with comments such as “everyone knows Bill Nye,” and “he’s a celebrity in science,” and also “if it’s not Bill Nye or Magic School Bus, I don’t want to watch it.” This led into a discussion on how as a society we have associated Bill Nye as being a huge part of science learning and that he had woven into our everyday lives. In addition, we discussed our society’s interest in entertainment allowing for scientific knowledge to be presented in a manner that is more relevant and acclimated with what our interests are. The NOS activity, inspired by Stadermann & Goedhart’s activity in quantum physics (2022), consisted of the following prompt: “Alone or with a partner, choose a physics/science phenomenon then discuss and write notes on how you think culture and society contributed to these discoveries. Consider the time frame the discovery occurred.” The activity was completed following the lecture, and were provided with several examples related to their prompt. Other documents that were used for data collection included an attendance log, teacher-researcher log, and once the unit was completed, a document to

calculate the averages of the scores for each formative and summative assessment.

Data Analysis

Each piece of data was evaluated and averaged out throughout the process, and they were separated by the two different blocks. Both classes have students with varying levels of the content taught throughout the year, and with the limitations that exist due to the sample size, the levels of understanding vary even more. The scoring for all but the VNOS-B pre- and post-tests and the NOS activity were based on accuracy. When it came to the VNOS-B pre- and post-tests, I referred to the rubric developed by Lederman, in which the student's views were categorized as naive, transitional or informed. When given VNOS-B tests, I emphasized to my students that I wanted them to write down what came to mind after they read the question. I shared that for this activity there was no right or wrong answer. As students turned in their activity, I asked if they had any questions about their responses or if there was anything I could talk with them through, but none of them had anything to share. The VNOS-B took students, at most, 30 minutes to complete. From my teacher-researcher log, I noted that many of them gazed around the classroom while completing the activity, however I was unsure if this was because they were trying to find an answer from somewhere in my class, or if it helped think about the questions deeper. In addition, the NOS activity was graded in a similar manner, when it came to understanding if the student actually responded to the question presented to them.

Results

Over the course of the unit, my block 1 class completed 10 assignments, while my block 3 class completed 13 assignments. Table 2 below describes the average score for each of those assignments, with the exception of the VNOS-B Pre- and Post-tests and the NOS activity.

Table 2. Assignment Average Scores

Date	Block 1	Block 3
Intro to Waves/Types of Waves Practice	97.73%	100%
Universal Wave Equation Practice	88.73%	83.2%

Waves Gizmos	98.13%	85%
Speed of Sound Practice	91.67%	82.14%
Doppler Effect Practice	87.5%	74.29%
Doppler Effect Gizmos	96.5%	91.43%
Quiz	80.94%	71.21%
Resonance Practice	88.89%	85%
Physics Of Music Practice	83.33%	84.47%
Test	77.01%	77.08%

Reflecting upon the scores for each assignment, my expectation was that my third block class, who received the NOS instruction and reinforcement throughout the unit, would benefit from that instruction, and as a result it would contribute to their scores. Initially, when reflecting upon the scores, I felt discouraged in that I did not see results anywhere near my expectations. I then considered that perhaps the sample size of each class, considering how low the numbers were, contributed to the skewed results.

Throughout the unit in my third block class, when reinforcing the NOS aspect of culture and society, specifically with concepts such as the doppler effect, resonance and physics of music, my students demonstrated higher levels of understanding by asking questions beyond the scope of our lecture. When we discussed the importance of each of these physics concepts with the NOS aspects, especially with the connection to real life applications, the class engagement increased during these discussions.

Table 3. VNOS-B Results

Question #	Pre-test	Post Test
1	Naive: 4 Translational: 3 Informed: 0	Naive: 5 Translational: 1 Informed: 1

2	Naive: 5 Translational: 2 Informed: 0	Naive: 4 Translational: 2 Informed: 1
3	Naive: 6 Translational: 1 Informed: 0	Naive: 3 Translational: 3 Informed: 1
4	Naive: 6 Translational: 1 Informed: 0	Naive: 5 Translational: 1 Informed: 1
5	Naive: 3 Translational: 4 Informed: 0	Naive: 5 Translational: 1 Informed: 1
6	Naive: 4 Translational: 1 Informed: 2	Naive: 3 Translational: 3 Informed: 1
7	Naive: 6 Translational: 1 Informed: 0	Naive: 4 Translational: 2 Informed: 1

Table 3 describes the results of the VNOS-B pre- and post-tests, describing the amount of naive, translational and informed responses for each question. When taking an aerial snapshot of this data, there are some minor differences between the pre-test responses and the post-test responses. Many of the pretest naive responses to the questions were “I don’t know” and “I don’t understand,” rather than actually attempting to answer the question in some manner. The pretest results in which students had a translational understanding included many statements where students answered part of each question, but not the whole question. One response to question 5 of the VNOS-B stated “yes because after [scientists] find something they have to brainstorm different ways it can help humanity.” I feel that this response, as well as similar ones, understood the general idea that scientists don’t simply develop these ideas out of nowhere, but rather they take time and put effort into analysis. The pretest results only

showed a couple informed views, both to question 6. The students had similar responses in which they answered the question straightforwardly and provided examples, with one response being “Yes, knowledge would be a fact, an opinion would be what I think. Example of knowledge: chemistry is a type of science. Example of an opinion: chemistry is the best type of science.”

When analyzing the results of the post-tests, I found that there was one informed view for each question, though not all from the same student. For example, the informed response to question 7 stated “everyone interprets data differently. It’s all based on what they believe. It influences their thoughts which eventually could lead to facts.” Once again, many of the naive results were responses that were blank, or simply said “I don’t know” or “I don’t understand.” Like the pretests, many translational responses included statements that partially answered the questions or statements that were on track, but didn’t quite answer the question exactly such as “yes a theory is thought to be proven while a law is stated as a fact.” Many of the translational responses included responses that made me feel that they were on the right track, but didn’t quite hit the nail. These results make me feel as though it wasn’t necessarily the discussion of NOS that led to their responses, but rather they had seen the question for a second time and spent more time elaborating on their thoughts. Once again, I feel that if I had a larger sample size, and if the results of the post-tests show more informed thoughts, I’d possibly attribute them our lessons and discussions.

In addition, my students completed a NOS activity with the following prompt: “Alone or with a partner, choose a physics/science phenomenon then discuss and write notes on how you think culture and society contributed to these discoveries. Consider the time frame the discovery occurred.” While I provided examples for my students to understand how they were to respond, I did not have a single student effectively answer the question, so much so that the context of most of their responses, did not fit the question at all, to the point where I wondered if they had looked up the question online, and wrote what they found. One student in particular discussed that in the earliest centuries, people thought that events occurred for religious reasons, with eclipses being one event. She mentioned that people in that time believed that eclipses were a bad omen. She further discussed that in the early 19th century, more research was done on astronomy and scientists actually began to understand how eclipses occur. She wrapped up her response by sharing that while society was inclined to attribute these events to religious phenomena that many still believe, scientific discovery

explains why such an event occurs. Unfortunately, this student was the only one who had a response that actually answered the question. . I believe that may have been a flaw to how the prompt was presented, and if I were to do it again, I would have a lengthier NOS lecture and discussion prior to the activity to get their mind thinking.

Discussion

Reflecting upon readings of Khishfe (2023), Demirdöğen & Aydın-Günbatar (2021), Witucki et al. (2023) and Sloane, Wheeler & Manson (2023), I recognize that I should have spent more time focusing on introducing NOS, perhaps just another day, so that my students can understand the various aspects, specifically culture and society. While I provided my own examples of the advancements in science based on current events (current events), it may have allowed my students to have a better understanding if I reflected upon Demirdöğen & Aydın-Günbatar’s article with them and how the authors actually used media reports to encourage the understanding of NOS. As discussed in the articles mentioned above, there are benefits to introducing students to NOS. I believe I may have been overzealous when it came to how quickly the students would gather and understand the concepts, and I wasn’t as explicit in my instruction as I could have been. Based on the results of the NOS views, I do feel that engaging more discussions with the explicit/reflective approach could have benefitted my student’s understanding of NOS concepts.

The incorporation of NOS concepts in the science classroom would not be beneficial if the teachers are not prepared to implement them. Gerondio et al. (2024) share that the “inadequate conceptions” of NOS in the classroom could be due not only to teachers not attempting to teach NOS in their classrooms, but also not having the appropriate preparation and resources to be able to do so (p. 841). Similar to the scenario that I have experienced with the lack of representation of NOS in the curriculum from my district, the authors describe that this is a common experience elsewhere. With that being said, I reflect once again upon Lederman’s statement, “it is safe to assume that teachers cannot possibly teach what they do not understand,” (2007, p. 858). This statement holds so strongly for the case of a study such as this, and anyone who wants to incorporate NOS concepts into the classroom because the results may not be favorable if the instructor of a class does not feel confident teaching NOS, or has previous experience learning how to do so.

Morrison, Raab & Ingram (2009) further describe how the National Research Council recommends that there be opportunities for science teachers to attend professional development to enhance their understanding of NOS concepts. This will then support science teachers' ability to teach NOS concepts more confidently and effectively. Along these lines, my research has allowed me to understand that I don't have as much of a grasp of NOS as I anticipated, at least not enough to see many takeaways as a result of the study. I feel that I understand NOS more-so than some of my colleagues who has not learned about NOS exclusively, but I while I feel I have enough knowledge to generalize in a manner to introduce the concepts to my students, I don't believe enough knowledge is there to introduce the concepts and reinforce them enough to make an impact.

Conclusion

Presenting NOS to my students is something I have never done in the past, nor is it something that we are required to do as science teachers in my district. From the results of my own study, and from others referenced to throughout this chapter, I do believe there is a benefit to incorporating NOS. Ideally, I would like to introduce NOS from the start of the school year, so that they are concepts my students and I can reference throughout the school year. By understanding NOS as a whole, I believe this gives more explanation to science's relevance. Specifically when it comes to the culture and society aspect of NOS, students can further understand how and why science concepts are understood and how that can then be applied to benefit us in the real world.

Recommendations

As a result of this study, I have a few recommendations, with one being to incorporate NOS consistently throughout the school year and specifically emphasize how society and culture has an impact on our scientific learning. The incorporation and discussion of NOS could, in theory, take place during various activities in the classroom such as during lessons, labs and even research prompts given to students. By limiting NOS discussions to the duration of one lecture or even a few, even by limiting it to just one unit, there are fewer opportunities for students to grasp the concepts. I believe it is beneficial to make the content relevant to events occurring in our everyday lives, however that is a strategy that I advocate for in a science classroom on a daily basis. The incorporation of discussing NOS concepts could allow

students to make that connect between real-life events and what occurs in the classroom. As a physics teacher, I've experienced students struggling with their motivation and interest with how the content matters in their lives. With how theoretical or math-heavy the content seems, many don't see the purpose in learning more about it. Once again, taking the time to make the content seem relevant not only interests them, but also gives them the opportunity to see how it exists in the real world. Scientific knowledge is not limited to a classroom or a lab.

My next recommendation would be to ensure that the classroom teacher has enough modes and resources to appropriately follow an explicit/reflective approach. This is crucial to go along with the incorporation of NOS concepts. The explicit/reflective approach is described as a method using multiple perspectives through history or philosophy of science, for example, through discussions and reading material (Xiang & Han, 2024, p. 264). While I referenced moments in history related to the particular content taught in class, I feel that if I provided more, maybe in a different format, this would have supported the students' learning. Once again, this approach would have been most beneficial if NOS was incorporated since the beginning of the school year, rather than one unit, in the case of this study. Additionally, there needs to be a strong foundation of the science teacher's understanding of NOS to be able to apply it appropriately in the classroom. This goes hand in hand with the previous two recommendations, as those could not be accomplished without a deep understanding of the NOS concepts themselves.


Lastly, I would be interested in completing a similar study with a bigger sample size. I believe that there would be a vastly different outcome if the sample size was bigger due to working with a wider range of students, each with varying degrees of understanding. I am curious to know what the outcomes would have been in that case, and if there would be any "lightbulb moments" when looking at the results as a whole. In addition, given my setting as a high school teacher, I believe my study could have resulted in a different outcome if I had presented the study to the parents and guardians of my students directly, rather than having the students relay the information for me. Unfortunately, due to the nature of working on a study, there was no way to ensure I knew who had turned in their consent form or not. Nevertheless, if I had presented this study to a larger group of students, perhaps the sample size would have been larger.

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Chapter 10 - Theorizing the Future of Scientific Literacy: Classroom Work from the Philippines

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Chapter Highlights

- With global efforts for the improvement of scientific literacy, continued work must be done to examine nuanced and contextual factors that contribute to its attainment. This chapter details action research conducted in the Philippines towards that end.
- This study was conducted in an undergraduate Science, Technology and Society course. This classroom is contextually rich as it was conducted daily over the summer, with three co-teachers, and with a student profile of mostly non-physical science (i.e. nursing) students.
- Thematic analyses reveal that language must not be taken for granted in the teaching and learning of science. This is particularly vital as much of the adapted knowledge on science is lifted from literature written in the English language.
- Moreover, scientific methods, laws and theories appear non-essential to a scientific literacy in society. Developing a capacity to talk about science and investigate its impacts appear to be detached from a strong emphasis on those matters.
- A tentative conceptual framework called the pulley model is proposed on how teachers may construct science (including Science, Technology and Society) classrooms to support scientific literacy.
- The consensus view of the nature of science was adapted for instruction despite some discussion of the family resemblance approach. This study may contribute to ongoing discussions pertaining criticisms to both, particularly to projects interested in integrating or reconciling them.

Introduction

In the advent of an increasingly complex world, scientific literacy continually shows itself to be an important endeavor to ensure learner success beyond the confines of the classroom. Defined as “the ability to engage with *science-related issues*, and with the *ideas of science*, as a reflective citizen” (OECD, 2019, emphasis added), countries continue to miss meeting its outcomes for scientific literacy. Global data from large scale assessments TIMSS (Mullis et al., 2020) and PISA (OECD, 2017), for example, show broad lapses in science learning outcomes despite continued educational interventions by governments, scholars, and partners to ensure otherwise. This chapter examines how a school in the Philippines approaches this matter.

Science, Technology and Society (STS) is a recent General Education course offering for higher education in the Philippines, introduced in 2013 through a government memorandum (CHED, 2013) after the country’s first year of implementation of the K-12 system. General Education courses offer various topics, such as Mathematics in the Modern World or Purposive Communication, to broaden the program of study of all higher education students in the country. The memorandum specifies STS to be a “historical” course to foster student appreciation of the societal impacts of science and technology. Informed by Western trends particularly in the 70’s and 80’s (see Solomon, 2012) of an interdisciplinary, human/social, and political treatment to science, STS as a general educational pursuit is often touted as part of education reforms to support scientific literacy (e.g. Autieri et al., 2016). As an educational offering, STS attempts to get at that outcome by using science to facilitate explicit linkages between classrooms and actual society (Rubba, 1991). Perspectives such as this may explain and motivate the inclusion of an STS curriculum into Philippine higher education.

Still, a discussion on science in society may take away from learning about other aspects of science such as epistemology, and this may impact outcomes for scientific literacy. At least for STS, a specific preference for the object of study is *scientific practice* (Alsop & Gardner, 2017), whose political/cultural profile (touching the first italicized component in scientific literacy, “science-related issues”) may not necessarily align with the usual institutionalized commitments of contemporary science education circles with the Nature of Science (NOS, touching somewhat the second component, “ideas of science”). In a way of saying, explicit NOS instruction, usually positioned around epistemology in many American traditions,

allows a teacher to make science less opaque to students, but we do not expect that particular NOS instruction to have the same social or political flavor tackled in an STS lens. If a country such as the Philippines were to begin making mandatory STS where an interdisciplinary science is primary and NOS is secondary (if at all present), would this still support student understanding of scientific knowledge?

We turn to Ateneo de Davao University to explore this question. The university is a large private institution in Davao City, southern Philippines, with a curricular emphasis on public engagement and student leadership. In STS, this meant students would deal with socioscientific issues directly, asking from them not only to know and reflect on science, but also to discuss, propose, and potentially act. This project sought to tackle these outcomes as well as theorize the experience to work toward student success. Can one improve views about the nature of science in an STS course? And, regardless, how might that effort inform the teaching for scientific literacy?

Method

Perspectives

Which nature of science?

Whereas educational inquiry on an STS course intuitively should pursue guidance from the STS tradition, the research questions of this project motivate an immersion in the science education literature, borrowing episodes from both the classical nature of science (*consensus view*; e.g. Lederman & Lederman, 2019) and the Family Resemblance Approach (FRA; Irzik & Nola, 2011). Here, we sought to anchor qualitative investigations against the well-articulated material on NOS by Lederman and colleagues, allowing a means to collect data that could be better comprehended through the prior efforts in the NOS literature.

This consensus view of NOS is a collection of epistemic features about science, summarized in Table 1 as shared by VAScoR guidelines (Abd-El-Khalick et al., 2023). Despite its prevalence, the consensus view has received heavy criticism throughout its tenure, being called naive (Hodson & Wong, 2017) or outmoded (Allchin, 2017). Criticism is usually centered on the consensus view's (perceived) simplistic encapturing of the whole of science, coupled with simplistic questioning by the associated Views of the Nature of Science (VNOS) questionnaire, leading to an oversimplification of the teaching and learning of

science. Hodson and Wong (2017) further elaborated that the “great danger is that items in the approved list [of the consensus view] become oversimplified by busy teachers and taught as truths about NOS, with consequent narrowing of the curriculum.” We primarily use the consensus view because it has been found through research (e.g. Papadouris & Constantinou, 2014) to be accessible to students at the K-12 grade level (which proved important for us teaching to non-majors), and are non-controversial in terms of most philosophies of science incorporated in these ideas (Abd-El-Khalick et al., 1998, p. 418). Readers interested in the criticism of the consensus view are invited to read the literature cited in this section.

Table 1. Aspects from the Consensus View of NOS

NOS aspect	Description
Myth of "The Scientific Method"	There is no singular scientific method to generate scientific knowledge.
Creative	Creativity is involved in the creation of scientific knowledge.
Tentative	Scientific knowledge is reliable, but evolving and never absolute.
Inferential	Many scientific knowledge is not directly observed but rather inferred through manifestations.
Scientific theories	Scientific theories are well-established articulations that explain and predict natural phenomena, and generate inquiry.
Scientific laws	Scientific laws are mathematical or verbal expressions that describe natural relationships or attributes.
Theory-laden	Scientific knowledge is generated by theory-driven scientists and theory-mediated observations.
Social and Cultural embedded-ness	Scientific knowledge affects and is affected by society and culture.
Empirical	Scientific knowledge is based on, and is consistent with, empirical observations.
Social NOS (internal sociology of the scientific enterprise)	Scientific knowledge is corroborated between scientists, improving its objectivity.

Critics have been more partial (although not always) to the Family Resemblance Approach, as it is more philosophically robust by analyzing similarities between sciences (e.g. chemistry and physics) under no assumption that each is describable by a singular set of properties. Still, FRA may be more difficult to teach and comprehend compared to the consensus view (Kampourakis, 2016), with FRA's proponents responding that FRA is both compatible with the consensus view and avoids a discrete description of science (Irzik & Nola, 2023). Irzik and Nola however have conceded that while empirical work on FRA thus far is encouraging, more work needs to be done to address the criticism of the FRA being developmentally inappropriate. The positionality of this project in terms of which NOS formulation to adopt is that despite controversy in the consensus view, its literature and instruments are well-articulated. Moreover, its criticisms are also well-documented. Due to the former, adoption of consensus view materials supported inquiry and analysis, and any potential harms alluded to by the latter, such as those mentioned by Hodson and Wong, are mitigated by cognizant decisionmaking and reflection during investigation. This project was interested in teaching first and theorizing second, and hence we pursued the consensus view due to the empirical support useful for our teaching. We put careful notice not to fall into the pitfalls raised by its detractors. Additionally, due to an awareness of the articulated concerns about the consensus view, this choice can contribute to discussions on how the consensus view works in context, and whether it holds despite those. Still, due to those widely reported concerns, we drew inspiration from the FRA for classroom planning and discussions (such as the scientific reward system) to capture better those (particularly non-epistemic) aspects of NOS that are integral to an understanding of a science in society and in life.

Analytical Lens

In terms of our positionality on data, we pursued a guiding perspective from recent commentary on scientific literacy which called for a global focus to identify the *fundamental essence of science* (Lederman et al., 2024). Particularly, this project was motivated to ask which of these matters about science (across multiple conceptions of NOS and even beyond) that students need to know to become adequately literate, and which of these matters regardless of knowledge need not be articulated at all for literacy. We aim to propagate here a position of critical analysis of ordinary science education inquiry through using scientific literacy as the guiding value.

Context

This study was conducted in-person during the 2024 summer term in Ateneo de Davao University. One educator, Tony, was supposedly the sole teacher for the STS course, yet he was recently assigned a university-wide administrative role and was in transition during this period. Due to his new and extant commitments, two other teachers became attached to this course. The second teacher, Doris, was the coordinator of the STS course offerings and the department chair of the environmental science program. The third, Le, was a PhD student from Indiana University and a former instructor in Ateneo de Davao University. He led the implementation of this research project. Each of the three co-teachers had scheduled sessions, but the course was mostly run by Tony who covered approved STS curricula. The course was conducted for 110 minutes every weekday for six weeks. Out of 45 enrolled students, 29 were majoring in nursing, 7 in business, 5 in engineering/science, and 4 in the humanities/social sciences.

This setting proved contextually meaningful for investigation. First, it was in a non-American context but largely drew literature and structure from American ideas, and this dynamic was interesting to reflect upon. This was particularly relevant with the university's emphasis on service to Mindanao (the southern Philippine island group which Davao City is in). Second, the disruptive lack of a fixed teacher disallowed the development of a deep teacher-student relationship and thorough out-of-class inquiry, including interviews. This was interesting to consider as it had been easier to default to disjoint teacher-led lectures, which may reflect the reality of other time-limited content rich classrooms. Third, the intensive summer schedule may have contributed to low engagement. Accounting for dropping, truancy during data collection, or not consenting to have data for analysis, only 28 students at the end of semester were generated *participant profiles* for analysis. The unfavorability of the conditions for this STS course supports some strength to the arguments made from this project compared to an ideal classroom, as the findings of the latter may struggle to be relatable to specific teaching contexts such as this.

The Action

This study was designed to be a mixed-method action research project, following internal needs to (1) improve student ideas about science, and (2) generate insights for the revision of

the STS curriculum. Scientific literacy was not a metric being directly assessed for graduates, but it has recently become internally relevant and is being considered to be emphasized as an outcome of the STS course. With the university’s emphasis on leadership and engagement, it expects some of its graduates (as seen historically) to become part of local government or companies, or become entrepreneurs, and scientific literacy (with corresponding values) are seen to be crucial in this work. Originally in the STS curriculum, students could apply science and technology concepts in context by proposing and presenting an S&T project to address issues in the region, but space is still open to incorporate “ideas of science” aside from just engaging in “science-related issues,” taking after OECD’s definition of scientific literacy. Hence, the action implemented was the explicit discussion of Filipino socioscientific issues (case studies) to enforce an intuitive yet socially rooted understanding of NOS.

Three case studies, as presented in Table 2, were implemented alongside the relevant concepts already in the curriculum. For each case study, Le facilitated a lecture/discussion, and afterwards students were asked to reflect and answer questions to make connections to the consensus view of NOS (explicit in the first case, and tacit in the latter two; FRA guided how these were crafted and later discussed). A preliminary lecture on these NOS aspects was also conducted prior to the first case study and integrated into a philosophy of science module already in the STS curriculum. This module did not originally contain any mention of NOS at least in the formulations familiar in the science education literature.

Table 2. Reflective Case Study Details

Module	Case study	Description	Questions
Philosophy of Science	The development of <i>lagundi</i> medicine	In order to reduce costs in importing medicine, Filipino scientists turned to folk knowledge to discover which medicinal plants could be developed and commercialized, leading to <i>lagundi</i> cough medicine.	How was [specific NOS aspect] seen in this case study?

The Fourth Industrial Revolution	The court rulings against genetically modified Filipino crops	With the development of modified crops to address contextual needs in the Philippines (particularly, microbe-enforced Bt Eggplant to mitigate pesticide use and Golden Rice to mitigate nutritional deficiency), the Supreme Court ruled in favor of detractors claiming that these were harmful.	<ol style="list-style-type: none"> 1. Filipino scientists claim that Bt eggplant and Golden Rice are “safe.” Why do you think they can say that? 2. Do you find the criticisms about the safety of Bt eggplant and Golden Rice convincing? What would need to happen for you to reconsider your opinion? 3. If future court rulings on genetically modified crops follow a similar pattern, how might Filipino scientists adapt with their research strategies? 4. What motivates Filipino scientists to pursue research on genetically modified crops despite anticipated public opposition and legal challenges?
When Technology and Humanity Cross	The construction of the coal-fired power plant in Davao City	To meet anticipated increase in energy demands in the region, a controversial coal-fired power plant was planned and built in Davao City with significant pushback from multiple groups.	<ol style="list-style-type: none"> 1. All parties recognize the consequences of using coal. Why do you think there is disagreement when the scientific knowledge about coal is already known and understood? 2. Do you think the public opposition would have changed if there were no

knowledge yet about cleaner energy sources? Why?

3. Based on your interpretation, who benefits from “scientific knowledge” and/or “technology” here, if any? Why?

4. If you were a scientist or engineer in Davao researching energy and its technologies, what might you research taking this issue in account?

Data Sources

A *participant profile* is a collection of an individual’s in-class submissions throughout the term. The main parts of the profile were pre- and posttest responses to the Views of the Nature of Science D+ (VNOS-D+; Lederman & Lederman, 2010), which was selected since it was designed to be completed in a shorter period. VNOS-D+ asked students various questions related to their ideas about science and scientist work, with each question potentially eliciting responses attributable to an aspect of the consensus view of NOS. The tests were administered in-class at the start and end of the term and were coded following VAScoR guidelines, which considered each VNOS submission holistically, instead of strictly considering individual items for particular NOS aspects. Final VNOS ratings would correspond to one the qualitative descriptions Silent, Naive, Fragmented, Partially Informed, Informed, and Advanced.

The second data source was a drawing of a scientist (Chambers, 1987) which was elicited early in the course to discuss and address immediate stereotypes about scientist personhood. Outputs were analyzed based on stereotyped scientist features (Finson et al., 1995). The third data source included two exit tickets based on explicit nature of science instruction, allowing students to tell the teacher what they learned, what they wanted to learn more about, and any other comments they may have. The fourth data source is a worksheet, which contained the

questions in Table 2 and a reflection (“*Reflect on how your perspective on the relationship between science, technology, and society has evolved so far. What key insights have you gained?*”). The *lagundi* case study was done individually, but the latter two NOS worksheets were done in groups (to facilitate discourse), so those two were not collected as data for the participant profiles but did inform theorizing later on. Student data sources were anonymized and digitized before coding.

Lastly, Le’s teaching reflection journals over five weeks were collected and used to contextualize findings. Although some scoring guides (VAScoR and the Draw-a-scientist Test [DAST] Checklist) were used to code parts of a participant profile, insights presented here were generated from a comprehensive look of full profiles. Overall, data was analyzed through iterative coding, thematic analysis, and triangulation. A schematic of the qualitative investigation and how theory building was constructed is provided in Figure 1.

Validity and Reflexivity

This project is in its very core a qualitative, interpretative project. It is introduced as mixed methods above as the usage of scoring guides generated quantitative data. Particularly, since VAScoR allows the generation of numeric scores, it could be a convenient way of showing improvement on student outcomes which could be inferred to be caused by the enacted action. However, we would like to emphasize a likely bias in quantitative results as there is no external rater, and no established interrater reliability. Only Le coded and there are likely tacit biases skewing ratings to enforce a desirable effect on behalf of the action. All material was coded in NVivo, aside from DAST checklists which were prepared in physical copy. Despite this significant drawback, we report these quantitative results regardless for completeness.

We emphasize that we ourselves do not hold these quantitative findings as sufficiently valid. Instead, we use these quantitative findings to fuel our interpretative work (as in Figure 1), and our perspectives and positionality in this paper only sought to use these numeric data to understand but not generalize. We advise readers not to interpret our numeric results as some form of statistically powerful metric for wider generalization, even for generalization about the students in this study. We facilitate this by presenting data in a way that aids qualitative work, instead of in a manner that offers conclusive statistical statements otherwise expected

from validated quantitative designs.

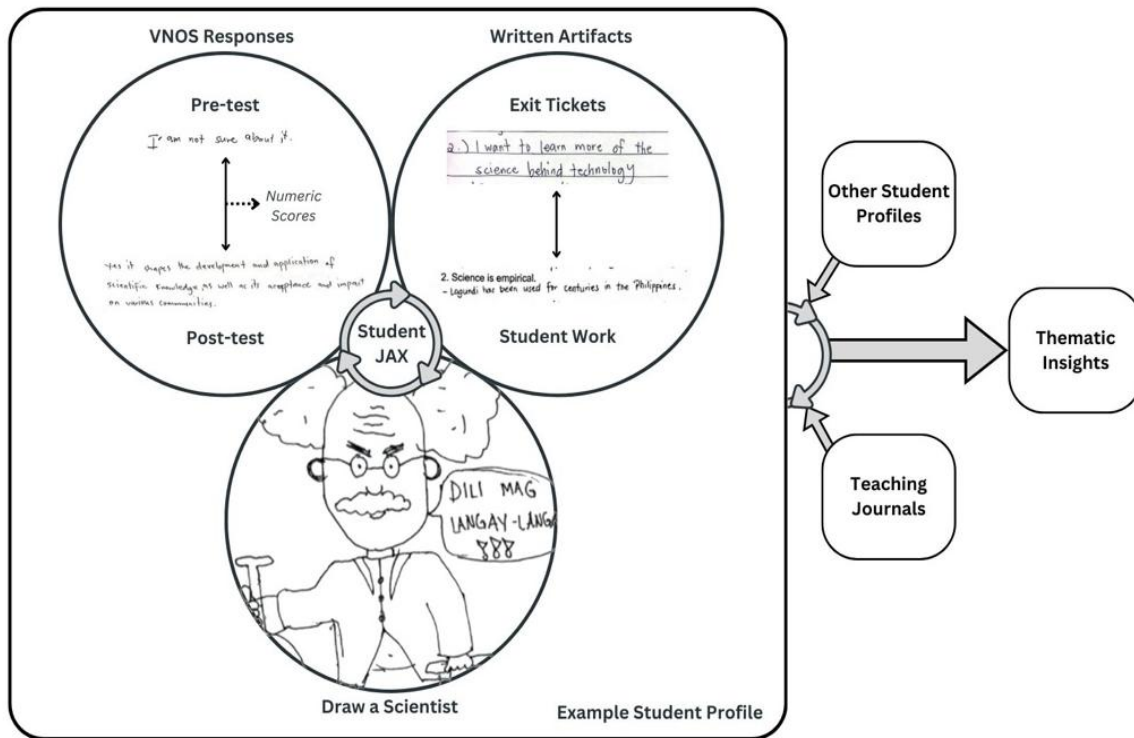


Figure 1. Schematic of the Qualitative Investigation

As qualitative work, we invoke the standard of trustworthiness as the major criterion of validity in this project. Trustworthiness as defined by Lincoln and Guba (1985) is characterized by credibility, transferability, dependability, and confirmability. We aim to showcase these foci by documenting and sharing in this piece, to the best of our ability, any lapse that may impact those matters. To enforce dependability and confirmability, we established rigor in the study by collecting as much relevant data as possible, and triangulating those to formulate and substantiate our claims through thick description. In the process of conducting this project, we have collected, digitized, and anonymized 393 pages worth of student work.

Results

Quantitative Results

Whereas this project's first research question is concerned with a potential improvement of students' views of the nature of science, we feel hesitant to plainly report as the answer to this question the proportion of students with increased raw VAScoR ratings (out of 50 possible

points) due to our reflexivity statement above. We frame here some quantitative results in order to contextualize our findings in the next section.

The first perspective to consider is whether students in general not only increased their absolute scores for VNOS, but also in general achieved a desirable level of articulation. We operationalized this goal by requiring a rating for a particular NOS aspect as “informed.” Table 3 presents the results for students being coded as at least informed for a particular NOS concept.

Proportions are provided in terms of non-silent responses. As VNOS-D+ is abbreviated for a shorter implementation time, we could not expect students to choose to talk about all NOS aspects as questions were open-ended, which also fed our intuitions that plainly reporting increases in scores was not an appropriate manner of answering a research question concerned with student improvement. In terms of raw numbers, all NOS aspects (except for *Empirical* due to one student) found more students who displayed at least an informed rating by post-test. All students were able to articulate *Empirical*-ness even before the first case study, and all students also discussed *Creativity* since there was an explicit question about it in VNOS-D+. In terms only of students who *did* talk about particular NOS concepts (i.e. were not “silent” regarding key indicators of NOS described by the VAScoR guidelines), the proportion of students who exhibited at least an informed rating increased for all aspects except *Empirical* (for the same reason as above) and *Social NOS*.

At least in the perspective of these numbers, more students did seem to at least show improvement in their views of NOS by the end of the study. However, due to our positionality being influenced by the search for the fundamental essence of science, we were also particularly interested in whether students began or stopped talking about particular NOS aspects. In other words, we wanted to count which particular NOS aspects students found relevant to tap into and talk about when being faced with questioning about science.

The results of these are made explicit in Table 4. In general, all NOS aspects were found to have a decrease in silent responses except for the *Myth of the Scientific Method* (which remained unchanged at 50%), and *Scientific Laws* (which, although there was an explicit VNOS question about it, was not thoroughly prioritized for discussion by students). The top NOS aspects that students remained silent on were *Scientific Method*, *Scientific Laws*, and

Social NOS.

Table 3. Results for Students with at least Informed (I) Rating

NOS aspect	Pre-test		Post-test	
	Number	Percent	Number	Percent
Myth of "The Scientific Method"	2/14	14	6/14	43
Creative	11/28	39	16/28	57
Tentative	9/26	35	11/28	39
Inferential	13/22	59	19/26	73
Scientific theories	4/21	19	7/25	28
Scientific laws	2/18	11	5/18	28
Theory-laden	5/11	45	11/20	55
Social and Cultural embedded-ness	4/17	24	19/27	70
Empirical	25/28	89	24/28	86
Social NOS (internal sociology of the scientific enterprise)	5/11	45	6/16	38

Values are presented as informed and advanced responses per total number of non-silent responses.

Table 4. Counts of Silent (S) Ratings

NOS aspect	Pre-test		Post-test	
	Number	Percent	Number	Percent
Myth of "The Scientific Method"	14	50	14	50
Creative	0	0	0	0
Tentative	2	7	0	0
Inferential	6	21	2	7
Scientific theories	7	25	3	11
Scientific laws	10	36	10	36
Theory-laden	17	61	8	29
Social and Cultural embedded-ness	11	39	1	4
Empirical	0	0	0	0
Social NOS (internal sociology of the scientific enterprise)	17	61	12	43

Percent is presented across all 28 responses.

Qualitative Findings

We now attempt to anchor the research questions and the quantitative results on key thematic insights generated from this action research project.

Language is a barrier to science teaching and learning

Communicating ideas about science, as well as assessing learning, proved more difficult than anticipated during the summer term due to language barriers:

“...many of them do not seem to have a good grasp of the English language. Unfortunately, English is the medium of instruction, and they must use English to learn STS, so this is an additional layer of complication. There is also an international student in the class so I could not use other languages to clarify some aspects.” (*Le’s teaching journal*)

Like many other universities in the Philippines, English serves as the language to be used for instruction in Ateneo de Davao University. English serves as one of two official languages in the country, being formally taught in curricula as early as first grade and reflects the Philippines’ complicated colonial history. It is, however, not the typical language used for everyday conversation for many. Parallel to English is Filipino, a language also taught as early as first grade, and the other official language of the country. The Filipino language is the standardized form of Tagalog, the main language of pre-colonial Manila in northern Philippines. The people in Davao City more commonly use in conversation a third language, *Cebuano* (colloquially, *Bisaya*), which is the mother tongue of many in the region.

English language competency was an implicit belief we held for students. The text that opens this section was written about the preliminarily responses from the pre-test VNOS. While most responses to the VNOS could be intelligible, there were frequently encountered difficulties in grammar and word choice which made us reflect whether the words we used to communicate the relevant ideas were effective. Students shared the same worry:

“I’m so sorry I can’t understand all because my limited vocabulary.” (*from Ray’s first exit ticket*)

It would not be uncommon for a teacher in Davao City to reexplain a concept in another

language in order to enforce understanding, but Le found he could not do that. On his first day of teaching, upon asking the class he learned not everyone could understand Cebuano as some came from other locales. And while Filipino was still available which could be accessible despite region, he still could not use it to accommodate for Ray, an international student.

Like Ray pointed out, vocabulary proved to be a difficult hurdle. As all the NOS literature used for the lessons were American, word choice was decided for us, but common NOS words such as “inference” or “experiment” were taken for granted and used as if there was already the same understanding between learners and instructor.

“Many students do not seem to be talking ... I cold-called some names and some of the students were not saying the correct things, misinterpreting what observation, inference, empirical, and subjective mean. I am worried how to better enforce the learning to the students.” (*Le’s teaching journal*)

In attempting to explicate the consensus view’s argument about there being no single scientific method, Le referred to how Charles Darwin, a recognizable scientist, was hypothesizing while observing but he was not experimenting during his time in the islands. Ergo, to state that scientific knowledge is built only from experiments is severely lacking if basing on the history of science. With the reflections above, Le went away from class feeling the point was not coming across well. For example, in some student submissions interpreted post hoc, the usage of “experiment” by students may have simply referred to any scientific methodology (i.e. A scientist who is to begin her methodology is to begin her “experiment.”) The syntax of the lessons themselves, having to borrow from philosophers such as Feyerabend and Kuhn, might also have been dense and difficult to parse.

To comprehend this, we borrow the lens of inferentialist, holist semantics. We interpret the teaching and learning of science (the meaning-making in discussions about science) to depend on how we use full sentences composed of subsentential components such as singular terms (Brandom, 2001). Figure 2 is a representation of this difficulty in the teaching and learning of NOS. To explain this simply through an example, one cannot have a concept of *experiment* without invoking other concepts. To talk about the experiment is to comprehend it through sentences, not words, and sentences become greater than the sum of the words that constitute them. But, when the sentences are in dense language, the same meaning would

likely not be retained between participants in that exchange of language, especially when how individual words are understood are also different between communicators. Meaning is obfuscated by unfamiliar language, and we would be lucky if students understood anything at all in the first place. Statements about the nature of science are filtered by language, and the giving and taking of reasons and judgments from the teacher about NOS should not be assumed as trivial.

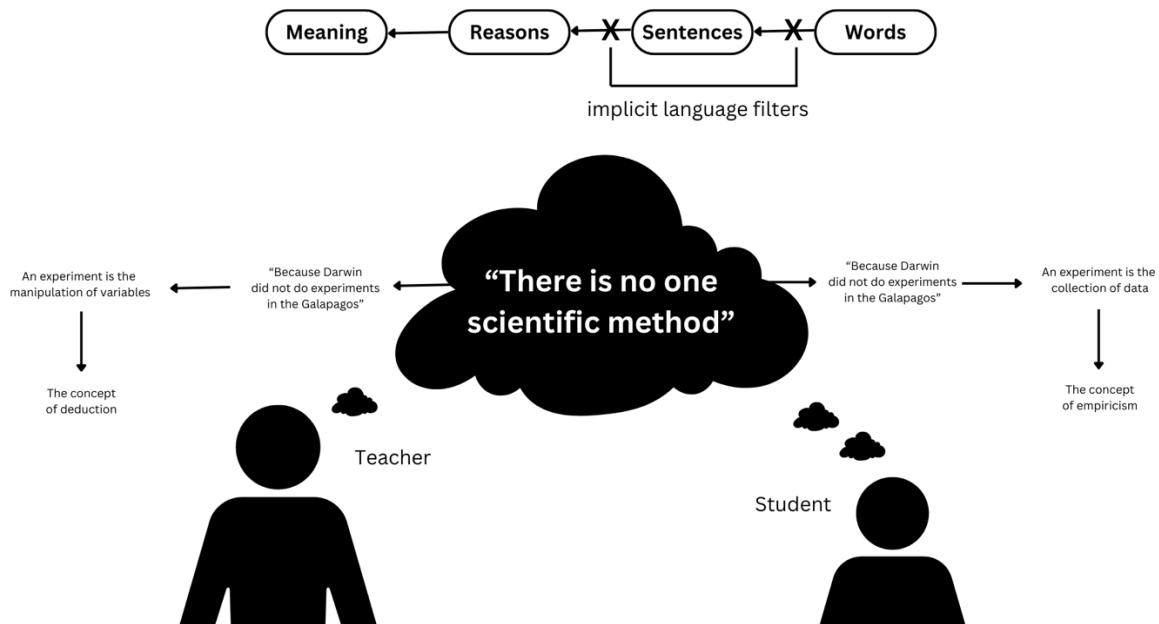


Figure 2. An Illusion of Understanding in NOS Teaching/Learning

Tony was able to enforce learning despite these language barriers by asking students to orally present knowledge through an exam and the S&T project. If left unexamined, teachers and students may be under the illusion of mutual understanding because they are parroting the relevant “correct” sentences, but are actually applying completely different concepts and are arriving to completely different understandings. Le realized that emphasis not only should be on the giving of reasons during class time to support the consensus view’s NOS, but also in clarifying the language and concepts used to make those reasons make sense. This was particularly pressing at the moment as a discussion on applied scientific issues (for STS) could not reasonably progress if there was already an identified dubious understanding of science during the first session. A decision was made to cut out the planned next class period for non-epistemic aspects for science (instead implicitly integrating them in other activities), and refocus and reclarify the language used to justify the consensus view:

“If I went too fast maybe the payout will be lower, and I’d want them to

fundamentally understand scientific language first and foremost before we do anything else. I cannot reasonably assume students will have good learning experiences in other topics if I know myself that the students do not grasp science well itself.” (*Le’s teaching journal*)

This approach, while taking away time to cover still relevant information on aspects about NOS that were not solely about epistemology, did appear to be helpful for students:

“Thank you for understanding, I learn [sic] more than yesterday.” (*from Ray’s second exit ticket*)

“Your way of teaching has reached my comfort.” (*from Flora’s second exit ticket*)

While discussing our teaching, we reflected that this cohort’s context was special, as admission protocols had to be adjusted to be sensitive to the impacts of distance learning on Filipino families due to the pandemic; typical entrance examination requirements (including some English language testing) were temporarily relaxed. Immediately mirroring the words that the NOS literature used, or referring to the justification philosophers crafted that would support those, might enforce a mismatch between what the teacher and student would understand to be true *even if* it appeared that they were saying the same things. Although it is not a new idea to use language that meets the level of the students, we have come to the idea that despite seeming that there is understanding, the philosophical (and, essentially, *foreign*) ideas that underpin the nature of science are easily taken for granted. Ordinarily, understanding would be assumed as true once students start saying the right things (in assessment, for example). A requirement from scientific literacy for reflection on “the ideas of science” makes a focus on this crucial. Our realization was that a solution is time.

Due to the shifting nature of which teacher was available to come into class for a day, lesson plans were tight. But with the recognition that priority must not be placed on breadth but rather on depth, reinforcing word use in the right contexts, time was redesigned to instead focus on clarity of the same concepts over multiple experiences and to encourage understanding. We believe that this approach did help improve understanding of NOS by students. At the very least, students appreciated it:

“...though I still not good at this subject but I still thanks [sic] for your understanding and encourage.” (*taken from written comments alongside Ray’s post-test VNOS*)

Scientific methods, laws and theories are non-essential, or at least treated as such

In attempting to comprehend which of the NOS aspects were resistant to improvement, it seems (as seen in Table 4) that students simply did not talk more about scientific methods as integral to a science, which appear to be directly influenced by explicit, repeated instruction that there is no singular scientific method. Moreover, student learning about scientific laws and theories also were not particularly strong by post-test, with many still articulating incorrect notions (for example, that laws are “proven,” but theories are not) despite explicit instruction saying otherwise. Since in VAScoR the final qualifying rating for *Social NOS* (the second most silent aspect by post-test) is dependent on the rating of *Scientific Laws*, (whereas *Scientific Laws* is dependent on another criterion, *Relationship Between Scientific Theories & Laws*), we forego exploration of *Social NOS* here as it appears to us that its low frequency was confounded by a limitation of the scoring rubric. Additionally, we do not feel that the VNOS-D+ elicited the core elements of this aspect due to only one question being closely related to it (what scientists need to do to convince other scientists), but students tended to focus on other NOS aspects to respond.

In the teaching of STS and in the pivoting from epistemic NOS to case studies, we attempted to get at scientific literacy by working toward developing “the ability to engage with *science-related issues*.” In a sense, we felt it was compelling to talk about NOS in actual contexts of Filipino scientists. We began by dismantling any misconception or mythicization of scientists. In terms of preliminary scientist images, students did generally hold scientists as stereotyped male images with lab coats and facial hair. One of the earliest matters to clarify by the teachers was that scientists are ordinary people such as Doris (a female environmental scientist) or Tony (a material scientist and priest), and that the students themselves too could have become scientists if they wanted to. This early emphasis against mythicized scientist images was implemented to ensure all future NOS-enforced lessons were more relatable and immediate to the students’ contexts. A sample student output and an associated exit ticket response is provided below in Figure 3. (If it matters to the reader, there was a median of four stereotypes from DAST checklist criteria, and a Spearman correlation between scientist stereotypes and gains in VNOS of -0.273. Holding more scientist stereotypes appears to be weakly related to decreasing the gains of views of NOS, but again this is with the caveat that these numeric results must not be taken as generalizable.)



“[I learned] [a]bout the stereotyping between others scientist. Because people tend to see them [like this] as what they are like but generally this drawing is an easiest way to remember the scientist look, but not in reality.”

(taken from Amelia’s Draw-a-scientist and second exit ticket)

Figure 3. Example Scientist Image and Reflection

Returning to the issue at hand, an emphasis on scientific methodology (i.e. what a scientist may do in a laboratory) did not appear vital to discussing the Filipino case studies. In the *lagundi* case study, Filipino scientists turned to folk knowledge in order to screen for potential medicinal plants. In the process of generating scientific knowledge to reach their goals, they interviewed *albularyos* (or alternatively, *herbolario*, which are Filipino witch doctors) to generate a preliminary list of plants worth investigating. A common uncritical understanding of NOS may lead one to be alarmed by this method as it is not “objective” and does not follow the deductive scientific explorations propagated in the previously understood “scientific method,” but this emphasizes the multiplicity of methods that scientists do that echo Feyerabend’s (1993) description of them being “opportunists,” taking advantage of any method possible. Some students considered these interviews with *albularyos* as the “empirical” data that scientists used, although most were able to identify laboratory testing as the correct manifestation of this NOS aspect.

As the term went on, *how* scientists generated their knowledge became less and less relevant to the case studies, as a specific focus on STS places emphasis on how science interacts with social/cultural forces at large. Instead, students seemed to concede that whatever scientists do, due to the empirical nature of science and the norms supporting the mechanisms to predict and explain, makes the scientists believe in their claims:

“[Scientists] can say that [Bt eggplant and Golden Rice] are safe because they have [under]gone many tests and studies showing these crops don’t harm people or the environment. They also follow *strict rules for the testing and development* of the eggplant and Golden Rice.” (from Gino, Jax, Larry, Roan and Warren’s reflections on

the second case study, emphasis added)

With no assurance of any singular scientific method to refer to, it appears instead that the alternative strategy is to trust scientists and the epistemological structures of science, even with the concession of the subjectivity of scientists:

“Whether the criticisms are convincing or not, *it depends on how strong scientific proof [is] that these crops are harmful. And if new studies comes [sic] out showing that they are unsafe [then that is] especially when scientists will change their views and will warn against these crops.*” (*from Gino, Jax, Larry, Roan and Warren’s reflections on the second case study, emphasis added)*

“...there would need to be *compelling evidence from independent studies demonstrating harmful effects on human health or the environment.*” (*from Amelia, Clive, Ray, Valentin and Yasmin’s reflections on the second case study, emphasis added)*

Still, with the explicit mention of the tentativeness of science and the fallibility of scientific knowledge (i.e. there was strong emphasis early on in the term that science gets at the truth, but may not necessarily capture it absolutely or even correctly), some students were also receptive to the idea that more empirical support will alleviate doubts about products of scientific methodology:

“...the criticisms are convincing and for me to reconsider, more tests should be done until it [GMO crops] is deemed safe for the public.” (*from Leon, Norton and Victor’s reflections on the second case study)*

With settling that whatever it is that scientists do as method, so long as those have been empirically supported and done repeatedly, we may use this position to argue how any scientific method at all is not necessarily crucial for being able to engage with science issues. Regardless of not knowing how exactly it is that scientists do things (as this requires content knowledge), students were still able to discuss, reflect, and argue about the scientific knowledge generated by scientists. This ability depends, however, on a strong grasp on the structures making scientific knowledge predictive and internally consistent. Whether explicit instruction of the consensus view leads to this was not clarified in this study.

The idea of the improvement of the quality of scientific knowledge by the repeated and

corroborated work of multiple scientists is reflected by the *Social NOS* aspect, which is why although it was not detected well by the VNOS/VAScoR tandem, we are led to believe there was improvement on this domain. Again, VAScoR's *Social NOS* rating depends on *Scientific Laws*, and it is there that we do find alarm. What students have learned about scientific laws (and, by extension, theories) however were quite detached from the case studies tackled and perhaps in how they would encounter science in life in general. Even during our NOS discussions, we propagated positions of large, foreign, and universally recognized laws such as inertia, motion, or gravitation, and even similarly for theories such as evolution, gravity, or atomic structure. We overlooked this aspect but realized after the first case study that these do not reflect well in the normal science that scientists do, which would be the scientific issues that students would be living through and be scientifically literate about. Students generally were able to describe theories well, although implicitly, in the post-test VNOS by describing how the model of the Earth's layers may not be necessarily exact or observed (as the model itself is a theoretical structure), but is explanatory, predictive, or generative in terms of research questions.

In the *lagundi* example, the big picture idea was that scientists worked toward finding local medicinal sources instead of importing drugs. They were not working toward formulating big picture laws, and although there were theoretical structures within this example, they were implicit and unlike the examples (evolution, etc.) explicitly stated in class. Several students weren't able to explicitly pinpoint anything about theories or laws (asked under one umbrella question) in the *lagundi* example, instead talking about vague, general descriptions:

“Science develops thru history of herbal medicines.” (*taken from Amelia's first case study worksheet*)

“The collaborative effort between traditional knowledge and scientific research has transformed *lagundi* into a modern medicine...” (*taken from Yasmin's first case study worksheet*)

Some students also were conflating laws and models in political language as equivalent to the matters being discussed by NOS:

“Laws or guidelines were created for its [*lagundi's*] safe use in medicine.” (*taken from Gino's first case study worksheet*)

“Utility model applications and licensing agreements were also pursued to protect *lagundi*-based information.” (*taken from Flora's first case study worksheet*)

Some students also discussed as theory scientists' tentative hypothetical conceptions which were more aligned to the concept of theories than those above, but were not necessarily pertaining to natural phenomenon as expected in the consensus view's usage of the word:

“Scientists formed ideas how lagundi works based on the albularyos...” (*taken from Annabel's first case study worksheet*)

“[The Department of Science and Technology] developed a theory that if the people trusted the herbolaryos on *lagundi*, then maybe scientist can find evidence of it being an effective medicinal plant against respiratory problems.” (*taken from Victor's first case study worksheet*)

A highly satisfactory response here would refer to a purely naturalistic formulation. In terms of laws, this case study would not be able to explicate toward the formation of one, although a student could have argued that all the testing done by scientists were subjected to applicable scientific laws. In terms of theories, this example would have formulated models about lagundi that were explanatory, predictive, generative and well-supported by empirical data. Several students were able to say something along the lines of scientists developing *ideas* on how *lagundi* works in the body (these ideas being theoretical structures) but were not able to explicate further. Some students were able to capture the nuances better:

“*Lagundi* was seen to be effective in reducing symptoms which was thought to be as anti-inflammatory.” (*taken from Jax's first case study worksheet*)

“I think the research on *lagundi* might lead or maybe has led to the development of models explaining how the plant's components interact with the respiratory system to alleviate cough. However these models wouldn't be considered scientific laws in the same ways as the physical laws in gravity.” (*taken from Milly's first case study worksheet*)

Collating available data to model *lagundi* as anti-inflammatory, which would allow scientists to explain its properties, predict potential others, and generate new studies, was a perspective that captured the consensus view's position on theories well. But we recognize that this took a lot of out-of-the-box thinking and abstraction. As Milly pointed out, these wouldn't be considered in the same way as those already thought about.

This issue of not being able to explicitly see laws and theories well was similar to scientific methods, and continued to not be seen in the other case studies. This might explain how

students either did not mention laws in the post-test (despite an explicit question differentiating it from theories) or propagated incorrect descriptions about them. Regardless, students were able to discuss and argue well in those other case studies, or at least propagated positions that were reflective of individuals who were scientifically literate, despite these lapses in theories and laws. Our reflections lead us to believe therefore that laws, theories, and methods are helpful but not essential in the development of scientific literacy.

Discussion

As action research, we appeared to have achieved our goal in improving views on nature of science as evidenced not only by quantitative findings, but also higher engagement recorded in teaching journals, and richer responses across student profiles. With the identified lapses in the previous sections, we attempt to synthesize our work into recommendations that may be helpful for the future teaching of STS or for scientific literacy. Keen readers may have noticed that there was no explicit mention of technology so far. While technology was integrated in classroom activities, our focus on NOS for this particular project has made us forego any deep discussion on it to sharpen clarity and focus. Technology and its issues, however, were still integrated in the case studies. We attempted to withhold direct application of a theoretical framework in case it would influence our theorizing, but it may be relevant now to refer to Zeidler and colleagues's (2005) framework for scientific literacy through socioscientific issues education as reflected in Figure 4.

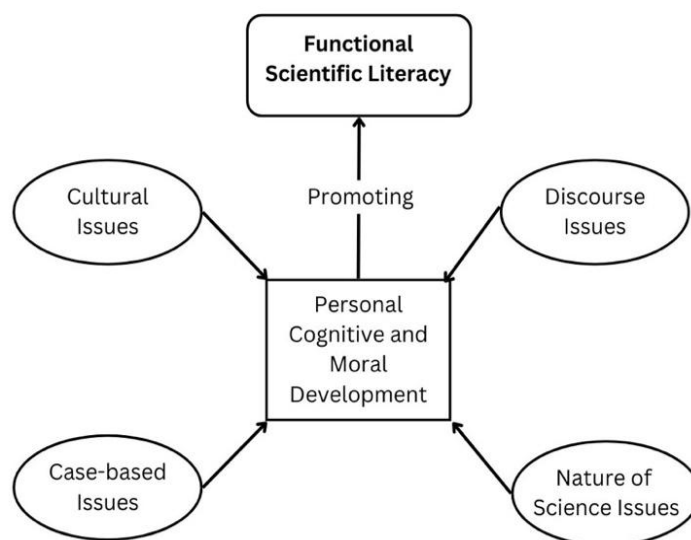


Figure 4. Socioscientific Elements of Functional Scientific Literacy (Zeidler et al., 2005)

This widely used framework attempts to build upon the missing links in STS education to clarify a science education that will get at functional scientific literacy. In many ways, we have attempted to modify our STS course to better capture these components, and instead of replicating the theorizing already done through this model, we instead would attempt to clarify a pedagogical perspective that may guide the pragmatics of an improved STS instruction particularly pertaining to NOS.

The Pulley Model

With our uncovered issues with language and the reliance on foreign ideas (such as Zeidler’s framework, heavily dependent on research in/from American spaces), we reflect here on how it is we can explicitly highlight the filtering of understanding through language. Some relevant entities and abstractions involved in an STS course (or any science classroom dealing with socioscientific issues) are the students, the classroom, the teacher, the relevant knowledge base the teacher taps into, the scientific and technological enterprise, and society at large. Taking all these into account, Figure 5 is our attempt for a tentative model to incorporate our findings into a framework that could guide teacher decision-making. We call this our pulley model.

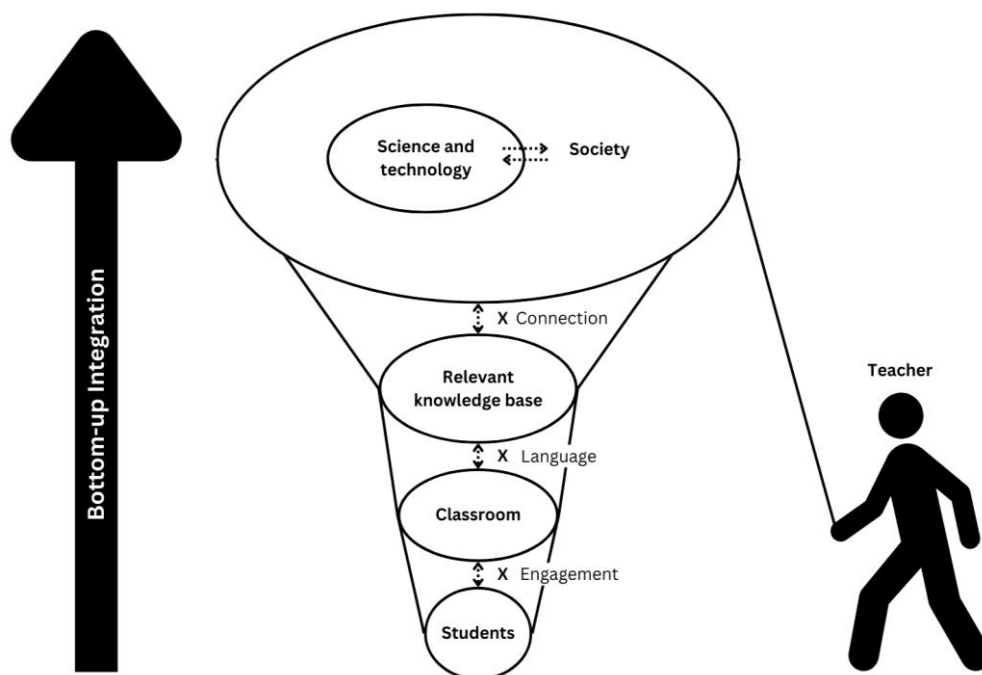


Figure 5. The Pulley Model for Scientific Literacy Teaching

In this model, we explicitly take the teacher out of the context in order to clarify their role in implementing classrooms toward scientific literacy, but this is not to say that the teacher is not at all involved in the internal dynamics of its development. The analogy used in this model is a pulley, where the teacher pulls the bottom-most weight upward. In this model however, the bottom-most weight merges to the next section, which becomes the next bottom-most weight. Overall, the goal in this model is that the teacher facilitates the integration of the bottom-most weights upward, eventually linking everything into society at large.

The dashed arrows are implicit linkages that a teacher can tap into to understand dynamics. Science and technology influence society, and vice versa, as one might take from NOS views. The teacher can then interpret how this relationship generates a relevant knowledge base, such as books and articles, to which instruction can be designed upon. This knowledge base might already be provided for by the teacher, such as those required by the government, and hence the teacher must be mindful that this knowledge base is culturally and contextually embedded. The knowledge base will then be interpreted or delivered as instruction to the teachers' classrooms. The classrooms, although typically one instruction is provided for the whole of it, is composed of multiple students. Students influence classrooms, and classrooms influence interpretations of relevant knowledge base, which is why the dotted arrows there are bidirectional. Lastly, especially in contexts such as Ateneo de Davao University where wider student participation and engagement is an explicit mission, the linkage between the relevant knowledge base and society is also bidirectional, which is to be interpreted that with the knowledge tapped into in class, the students are better equipped to participate in and potentially influence society (i.e. after the classroom is merged into the knowledge base section).

In between these vertical arrows are factors which we call filters that inhibit bottom-up integration. Starting with students, student engagement will filter classroom integration, and teachers should be mindful of student engagement when trying to integrate the whole classroom upward, lest they leave some students behind. Concerns about engagement was a recurring theme across the term, showing instances in reflection journals in all entries, and even in students' written feedback:

“I’m sorry I was not listening that much in your lesson today” (*taken from Lexi’s first exit ticket*)

“You are amazing today I did not sleep in your class because I’m interested in the topic” (*taken from Paige’s second exit ticket*)

“Sorry po if kinda nonchalant kami hehe [I’m sorry if we’re kind of nonchalant hehe]” (*taken from written comments alongside Annabel’s post-test VNOS*)

We do realize that the above goes without saying for many teachers, but we explicate it here to emphasize poor engagement may impact scientific literacy outcomes. The second filter is between the knowledge base used for class and the classroom itself as explained in the first subsection of the qualitative findings. Considerations must be made not only to be careful on what words are used in class, but particularly how the language/culture the words were taken from were used in context. We explained how there could even be an intersubjective understanding of the same sentences, so it may be helpful for teachers to take time and use and reinforce the usage of words and the meanings of sentences especially if the knowledge base is taken from other traditions. It will also be helpful if local knowledge bases would be tapped into, and for scholars it would also be helpful to develop those. In the case of Ateneo de Davao University, this would refer to a specific Mindanawon literature base to consider and explore.

Finally, despite comprehending the concepts in the relevant knowledge base, students may be filtered by poor connections between what was learned and how society works. At least in our action, our explicit inclusions of Filipino case studies allowed the topics to be tangible in more immediate contexts, and we would recommend the same for other classrooms. We also would like to emphasize how connections could be made with society (and display some satisfactory scientific literacy) even if some aspects were disregarded. In our case, we found that scientific methods, laws and theories did not seem to be relevant to the students’ engagement with the case studies, and so a teacher planning lessons should also assess which of the knowledge base used in class is helpful to keep.

Recommendations for Teachers

We include here as a final section a discussion of the pulley model in plain language. We hope that this portion can be immediately helpful to teachers in designing their science classrooms.

What is the pulley model about?

The model tells us that in order to become scientifically literate, students need to be “pulled” upward by a teacher and help them reach various stages. The main goal of the model is to help you think how students could be scientifically literate participants in society, and that requires from them to have the knowledge they will take from class.

What are filters and how might I address them?

Filters make it harder for you as a teacher to pull up a student into the next stage. You should think about how to address these filters in your teaching. The first filter is engagement. Without a student participating well in class, a student could not be reasonably expected to display what we expect in terms of learning and leadership. Some students may not find science topics interesting, so one of your top priorities must be to make sure students are learning. There are plenty of strategies and research on possible effective teaching strategies, and what you should do fully depends on the context of your classroom.

Once you overcome the engagement filter, you should roughly have all of your students unified and learning under one classroom. The second filter is then language. This refers to how a person understands the meaning of words and sentences. Many of the ideas you will use in your teaching will likely come from a foreign author or a foreign group of researchers. When you use their books, articles, and other pieces of information in class, how you and your students understand the meaning of the ideas may not likely be the same. Make sure you and your students use words the same way. Don’t take words for granted and give a definition when possible, and keep on using them over and over in the right context to help students understand how the word is used. Since meaning is explained through sentences, you should also be aware of the sentences you use to explain certain ideas. Make sure to also use different ways of expressing the same meaning over and over. If you only use the same sentence to explain meaning, it might appear that a student “understands” the concept, but in reality they might be understanding it differently and just echoing what you keep saying in class.

It may help to include or refer to knowledge that is local and more approachable. That way, the students may already be in a space where how they process sentences for meaning, and

how they use words, are the same as the author. But this issue with using the language of foreign ideas is also evident in local language. Since students will apply concepts to understand sentences, and we don't necessarily know what concepts students will use, they can still give us echoed sentences even if they did not really understand. Make sure you spend a lot of time talking about the important ideas in various ways.

Once your classroom understands the ideas in the books, articles, and other pieces you use for teaching, the next step is to make that knowledge make sense in the lives of students. The third filter is connection. Learning about an idea is not necessarily seeing how it is important to you personally, and this may be more true in science since it is often not easily talked about. Connect the learnings to the real world through case studies, or implement projects that have students connect the information to real-world problems. Have students take trips, conduct interviews, or do other activities that make the topics not just something that can be learned, but something that can be experienced in real life. Since students are participants in society, when the science becomes personally meaningful, we can make students apply the knowledge and connect to society.

Can't a student just not engage but still be scientifically literate?

Yes, of course. The model assumes that the students are at a level where they still have something to learn in your classroom, and also the model doesn't say anything about other aspects of scientific literacy that may not be tackled in your teaching. The model isn't a thing to capture all instances, but we present it to help you think about what you're doing while teaching science. A student may not engage at all and you will still "pull the pulley upward," and in that case even if other students are working toward scientific literacy, you left that student behind. The model can be used to explain instances like that, but we can't expect it to explain all instances.

Should the model be followed at all times?

Models and frameworks are often simplifications that allow us to understand how it is we feel about and do things. The pulley model helps you understand what to look out for, and what to work toward, but it is a simplified picture of the complicated process of teaching. Use it as a guide, but not as a hard rule. Also, this is a tentative model based on one project, so the more

we use, assess, and talk about the model, the better it would be the next time we, you or some other people will update it.

Conclusion

In this study, we conducted an action research project in order to improve ideas about NOS in an STS course, as well as theorize on potential improvements for STS teaching towards scientific literacy. We found that the inclusion of Filipino socioscientific case studies was helpful for the improvement of the views of the nature of science. We also found that within the consensus view's NOS aspects, scientific methods, scientific laws, and scientific theories were not essential to comprehend and discuss the case studies. Furthermore, we propose a pulley model for teachers to use toward scientific literacy, explicating a guiding framework for the integration of students in society (i.e. becoming scientifically literate) through science learning.

Recommendations

Our framework attempts to synthesize our empirical work and we hope it will guide other educators who seek to implement similar pursuits, and scholars who wish to look into this matter more closely. However, writing a piece of interpretative scholarship, we do not mean to say that these findings are an exact perspective needed to be integrated in all future discussions; it is one of many and we do not wish to override. In presenting findings for science education, we echo the positionality of Filipino editors Gutierrez and Atienza (2023) when they claim to merely forward a singular proposition about STS amongst a multiplicity of opinions. However, we do recognize that ours is a perspective that may also be overlooked by researchers if not presented, and hence communicating this could potentially deepen future scholarship. By communicating these, we hope to influence inquiry in science education and STS, particularly as the community continues to tackle educational issues pertaining to scientific literacy, as it is those international perspectives that impact ours, regardless of them hearing ours or not. Specifically, our findings share context for global work on scientific literacy, allowing us to further investigate non-essential pieces of typical science teaching, and to guide future classroom instruction based on contextually nuanced factors. We thus recommend additional empirical work to challenge or amend on our findings, in order to better clarify how it is that scientific literacy can be made achievable by

teachers within a classroom. A perspective to pursue might be to explore whether other contextually relevant case studies enforce different components of NOS, and whether the aspects deemed non-essential in this project consistently persist in those cases. Another perspective is to consider these reflections in light of the Family Resemblance Approach, and how one might rationalize the language of both NOS frameworks in developing developmentally and contextually appropriate NOS teaching.

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SECTION III

Chapter 11 - Analyzing my Teaching of Nature of Science with a Maker Education Project Focusing on Disability Culture in Biology Labs

Brooke Stewart 

Chapter Highlights

- Maker education projects can emphasize the creativity component of the Nature of Science by allowing students to innovate and giving them autonomy.
- Students look at disability culture through a more empathetic and understanding lenses when asked to research different disabilities and create an accommodation for someone with a disability.
- Explicitly teaching the Nature of Science to high school students can help them become reflective about their own scientific thinking.

Introduction

As a high school science teacher, I am continuously looking for opportunities for my students to think like industry scientists. I allow them to use their own creativity to create hypotheses and design prototypes. I even have my students complete and return to reflections so that they can see how their thinking changes over time. But how often do I track my own intentional efforts to teach my students about the Nature of Science? As explained by Lederman and Abd-el-Khalick (1998), students do not understand the Nature of Science by simply doing scientific processes or by implicit questions. The teacher should make a conscious effort to teach the components of the Nature of Science and this can be done through purposeful reflective questioning (Lederman & Lederman, 2004).

I also want to help my students understand the importance and benefit of making science accessible to people from all cultures. According to the views of the Nature of Science, scientific decisions and discoveries are heavily influenced by someone's culture and their background. Surveys collected by the National Center for Science and Engineering Statistics (NCSES) (2023) show that there is an underrepresentation of people with disabilities in STEM fields. Many researchers consider disability as a culture because of the unique talents and experiences that individuals with disabilities share (Shasteen, 2022). Considering "between 15% and 25% of the world's population lives with one or more forms of disability" (Powell, 2021, p. 221), ignoring the contributions of individuals who identify with disability culture is a large marginalization. Therefore, for this study I propose two research questions:

1. Can I help my students develop an understanding of the Nature of Science through a maker education project?
2. Can I use a maker education project to inspire my students to make science more accessible for members of disability culture?

I will try to answer these questions by challenging my students to create a prototype of accommodation for someone with a specific disability to do a specific task in a biology lab. I believe that there are barriers in biology labs for people with disabilities that have marginalized their contributions, and we can minimize those barriers. These may be physical barriers such as the lack of wheelchair access or hidden barriers such as practices that practices that may worsen someone's chronic pain. My hope is that by working through this project, my students will gain a deeper understanding of the importance of cultural diversity

in science and their potential to help minimize those barriers. I also plan on making intentional efforts to address a few different aspects of the Nature of Science during this project and analyze the impact of my students' understanding of it. This will be through articles that describe the components of the Nature of science. Also with class discussions that will connect the Nature of Science components with their projects.

Theoretical Framework

The theoretical framework of this study draws upon three different topics: maker education, Nature of Science and disability as a culture. Each topic is an important component of this study, and we must first discuss the research already done in each of these areas.

Maker Education

The maker education movement builds upon the ideas of Jean Piaget who believed that children construct their own understanding of the world through their own experiences inside and outside the classroom (Piaget, 1973). There is not a concrete definition of what the maker mindset is, but most makers agree that students are not meant to be passive consumers of knowledge and teachers are not meant to be the all-knowing experts. According to Maaia (2019), it also takes students through a “stuck and unstuck” cycle in which students are constantly having to work through challenges and redefine their designs. Makerspaces have conventionally been found in informal education settings such as museums and libraries, although in recent years maker education has been finding its way into even more K-12 classrooms and it varies widely classroom by classroom (Rouse & Rouse, 2022). Researchers have even found that students who may not typically succeed in traditional educational setting have found success in maker labs where they are allowed to do creative problem solving (Maaia, 2019).

Susanne and Niklas (2023) discuss the tensions that can occur when trying to move maker education, which is typically found in an informal setting, to a more formal setting of a classroom. One of the most predominant being that we as teachers have a set of learning objectives that we are required to cover in our courses and that can limit the amount of autonomy or creativity that students put into their projects. Resnick and Rosenbaum (2013) contend that although there might be making happening in a lot of classrooms, it is prescribed

with instructions and leaves out the creative, problem-solving aspects. There is little room for ‘tinkering’ and/or exploring different paths. With these thoughts in mind, I try to structure my maker projects so that they are as student-led as possible while still reaching the intended learning goals. My role as the teacher while doing these projects is strictly a facilitator.

Nature of Science

Nature of Science easily coincides with the maker movement because an important component of the maker process is allowing you to continuously adapt and modify your initial plans (Resnick & Rosenbaum, 2013). As discussed by Bell (2009), science is tentative and always changing with new ideas constantly arising. As stated earlier, I fear that I am not intentional enough in my instruction of teaching the components of Nature of Science. Previously, I believed that leading my students through inquiry related activities would lead them to the Nature of Science skills that they needed to possess. According to Abd-El-Khalick (2013), inquiry does not always lead to improved understandings of the Nature of Science.

Bell (2009) suggests that there are seven main components of the Nature of Science: tentativeness, empirical evidence, observation and inference, scientific law and theories, scientific methods, creativity, and objectivity and subjectivity. According to Akerson et al. (2000), studies have shown that the explicit teaching of these components is the most effective method, compared to implicit methods. The National Science Teacher Association (NSTA) states in their position statement, “NOS is best understood by students if it is explicitly addressed within the context of students’ learning of science and engineering practices, disciplinary core ideas, and crosscutting concepts” (2020, para. 9).

In the study by Akerson et al. (2000), which took place in a college science methods course, the authors used classroom discussions to lead the students to connect Nature of Science to their experiences in their science-content courses. They also presented their students with readings and then writing reflection questions that asked them to connect the reading with Nature of Science. They label these methods as the explicit and reflective (ER) approach—although, as Schussler and Bautista (2011) notes in their article, there isn’t as much research of using the ER approach in science-content courses.

Diversity Culture

According to Brown (2002), most people identify with more than one culture and the term ‘culture’ tends to have different connotations in different communities. In addition, the term ‘disability’ has many different connotations. In his article, Brown states, “Disability can be represented as a culture, though the range of differences among the disabled is enormous” (2002, p. 2). Although, there is a general agreement that the driving force behind disability culture is that individual disabilities are celebrated and we recognize how they can enrich someone’s life. Companies are encouraged to practice inclusion of people with disabilities by inviting them to be part of their leadership teams and inviting them to be on hiring panels (Brown, 2002). Even if this may be happening, data from the NCSSES (2023) still suggests that people with disabilities are a marginalized culture group in STEM fields. Also compared to other inequities in STEM like gender and race, the underrepresentation of people with disabilities is not as heavily researched (Schneiderwind et al., 2021).

Although studies have shown that there is a large number of students with disabilities who choose to major in science when entering college, there are much less who complete their degrees or go on to a high degree in science (Gin et al., 2022). This might be the result of inequitable education due to teachers being ill-equipped to address the diverse possibility of needs of students with disabilities (Moon et al., 2012). Or perhaps it is because the classroom or lab is not set up to address their needs. According to Shasteen (2022), “ableism plays a large role in the ability of disabled people to access laboratories, fieldwork and conferences, which are all opportunities to grow a scientific career” (p. 2). Moon et al. (2012) describes several accommodations that can already be found in science labs such as braille, wheelchair-height work surfaces and adapted equipment.

Method

Participants

The participants in this study were the students enrolled in my biology 2 class. This class consisted of five females and five males. The ages ranged from fourteen to eighteen. All students in this course had already taken my biology 1 course as a pre-requisite. This project took place at the end of the second semester and therefore the students had already experienced most of the labs in biology 2. For this project, I randomly paired them up into

groups of two.

Data Collection

On the first day and before we began the project, I had the whole class complete the VNOS(C) survey. The purpose of the pre-survey was to gauge my students' initial understanding of the Nature of Science. After my students completed the survey, I presented them with a digital copy of an article by Bell (year) titled. *Teaching the Nature of Science: Three critical questions*. In their groups, I asked them to read only the key concepts section, which highlights the seven components of Nature of Science. I put seven posters up around my classroom and each one had one of the concepts written boldly at the top. I assigned a poster to each pair and I gave them two minutes to use what they read to write a few words that described that topic. After two minutes I had every group move counterclockwise to the next poster and add their own thoughts to that poster. We kept doing this until each pair visited each poster. Once they returned to their original poster, I asked the pair to share out the words that were written on their poster.

As an opening hook for the project, I gave students data from NCSES (2023) that showed the statistics of the number of women, minorities and individuals with disabilities in STEM careers. I had students take notes of the data before we had a Socratic seminar style group discussion as a class. During the seminar, I asked students why it is important that we make science more accessible to individuals with disabilities. I also asked the students to think about some of the challenges that people with disabilities may have with some of the activities or labs we had done throughout the school year. I took notes of the conversation in my own field notebook.

I presented my students with a research question: How can we be more inclusive of individuals with disabilities in the field of science? I asked them to brainstorm some accommodations that would make any of our biology 2 labs or activities more accessible to an individual with a disability. I gave each group some sketch paper and advised them to sketch out their ideas. Their sketches needed to include drawings and written explanations. Then as a group they had to use one of their ideas to create a physical prototype using materials and modality of their choice.

I gave my students three 45-minute class periods to work on the project. At the end of each period, I had the students answer an exit ticket with a few questions that asked them to reflect on their design process:

- Day 1 - How did you come up with your original idea? Did you feel like you had to be creative to come up with a design? Why or why not?
- Day 1 - Do you know anyone with a disability? If yes, did this background knowledge help you when designing your prototype?
- Day 2 - How did you learn more about disability culture (the different types of disabilities)? How did learning this new information change your ideas/plans?
- Day 2 - Have you changed anything about your original design? Why? Was it because you learned something new along the way?
- Day 3 - What did you learn during this “experiment”? How will you apply this new knowledge in the future?

At the beginning of the next period, we had a group discussion that covered their answers from the last exit ticket. This gave me the opportunity to explicitly talk about the different components of the Nature of Science (Schwartz et al., 2004). I prefaced the group discussion by presenting them with a Google slide with the different components. Then I asked them to turn and talk with their table partners about how their answers on their exit ticket connected with one or more of the components of the Nature of Science.

On the fifth and last day of the project, I asked each group to create a commercial that presented their projects to a hypothetical potential buyer. The requirements for the commercial were that it could be no longer than 5 minutes, it had to highlight the design and discuss how they created it, and it had to explain which disability their design was supposed to accommodate and which biology lab tasks it would assist them with. Students had to record their commercials on their Chromebooks and then submit them to our Google Classroom page.

Results

Only eight of the students returned their pre and post VNOS(C) surveys because two of the students did not return them back to the cooperating teacher who was collecting them. Also, only four out of the 5 groups completed their projects and commercials because they ran out

of time. All ten students completed the exit tickets and participated in the class discussions. Below the results from each data collection method are discussed.

NCSES Data Group Discussion

After the students took notes of what they noticed in the NCSES data, I had them sit in a circle and they discussed their findings. I took notes in my personal field notebook and here are some of the comments that I heard from students:

- “Females, African American/Black races, and people with disabilities are underrepresented in STEM.”
- “More men work in STEM than women. There are less people of color and people with disabilities.”
- “We need the ideas of people who have lived life differently than us.”
- “No matter their background or disability, everyone has important ideas to bring to the table.”
- “People who are missing limbs might have trouble picking up equipment or moving around a lab.”
- “People who have an illness may not be able to handle long hours working in a lab.”

VNOS(C) Pre-survey/post-survey

The VNOS(C) survey consists of eight different questions, but for this study I have chosen three to analyze. Firstly, I chose a question that was more generalized and asked about their general view of science. I also believed that this view could be changed the most through maker education because it is not what students generally think science looks like. The first question asked, “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)?” The pre-survey and post-survey responses of three different students for this question are shown in Table 1 below.

Table 1. VNOS(C) Survey Question 1 Responses

	Pre-Survey Responses	Post-Survey Responses
Student 1	I think that science is the	Science is an explanation of the

	studying of the way life works. I think science is more about factual information rather than feeling and emotion a lot of the time.	things in the world and how they work/ why they are the way they are. Science is different because it can be tested and you can know whether or not it is true.
Student 2	My view of science is that it's a way people can find out many things.	Science is the study of how the world and everything in it works. Science is different from all the other disciplines because it has all of the different subjects/disciplines in one.
Student 3	Science is something that is physical and can be proven unlike philosophy and religion.	Science is where you study about things that we do not know much about and then we gain knowledge.

The next question I chose because I wanted to see how this activity could impact students' opinion of the importance of creativity in science. The second question asked, "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? If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate. If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate." The pre-survey and post-survey responses of three different students for this question are shown in Table 2 below.

Table 2. VNOS(C) Survey Question 2 Responses

	Pre-Survey Responses	Post-Survey Responses
Student 1	I feel like scientists don't use their creativity because they always go on the facts and not really on what they like or just because they feel like it. I feel like they also don't	I think they do because if they didn't then we wouldn't learn any new things. They use their imagination the most when planning.

	<p>need to use their imagination because they need to go off the facts.</p>	
Student 2	<p>I don't think that scientists use imagination and creativity while doing their investigations. I don't think they do because it's an important field of work and I think that they take it seriously. If you were trying to find a cure to a disease with the use of science, you wouldn't want your scientist to use their creativity to make the cure a pretty color and because of that, give you an infection.</p>	<p>Yes they have to use creativity and their imagination because they have to design elaborate and unique experiments to get the data they want to find.</p>
Student 3	<p>The put creativity into designing the experiment.</p>	<p>Yes, they do use their creativity and imagination for experiments/investigations. They use their imagination and creativity during the planning and design stage because they have to plan out their experiment and what they are going to be experimenting with.</p>

For the last question, I wanted to better understand my students' ideas of how science is connected social and cultural values. I thought this would be especially important for me to look at since we were discussing disability culture. The third question asked, "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 and how. Defend your answer with examples. If you believe that science is universal, explain why and how. Defend your answer with examples.” The pre-survey and post-survey responses of three different students for this question are shown in Table 3 below.

Table 3. VNOS(C) Survey Question 3 Responses

	Pre-Survey Responses	Post-Survey Responses
Student 1	I do think that science does reflect social values because people would get upset if scientists did something a certain group of people didn't like.	I think that science can be influenced by social and cultural values because governments could have agendas that they push on scientists that could affect information being given to the public.
Student 2	I feel like that it's both because sometimes scientists take information from people's opinions and sometimes they base things off facts.	I do believe that science may reflect on social and cultural values. This is because if a study were to come out and it was the complete opposite of a certain religion, it may make the religion or cultural people second guess themselves or just doubt science in general. I also believe that science is universal though as well, Everyone in all places of the world use and look up to science everyday of their lives.
Student 3	I believe that science is universal because things that scientists do and create and prove just isn't pulled out of nowhere or from something they see posted online. Everything a scientist does has a background to it and a good reason.	Science reflects social and cultural values because what you believe could interfere with what you are experimenting with and how you are doing science.

Nature of Science Gallery Walk Responses

As mentioned before, I put seven posters up around my classroom and each one had one of the major concepts of the Nature of Science written boldly at the top. After they read the Bell (2023) article, every group was given a turn to add their thoughts to every poster. Some of the comments from each of the posters are presented below:

- Tentativeness – “science is tentative; science can change with new evidence, new ways of thinking or new scientific laws; the quality of being uncertain”
- Empirical evidence – “information obtained through observation; includes qualitative and quantitative data; gathered from different types of data”
- Observations and inferences – “science is derived from a series of observations and inferences; observations are using your senses and technology to get information, inferences involve developing explanations from observations”
- Scientific laws and theories – “a law is something that is proven and a theory is a something strongly supported; laws and theories are similar but can not be each other”
- Scientific methods – “there are a wide variety of approaches to solve scientific problems; no single universal method; they use many approaches to generate scientific knowledge; there is not a right or wrong scientific method”
- Creativity – “scientists use this throughout their process; imagination and inspiration leads to innovation; creativity fuels science; using your own mind to create something new”
- Objectivity and subjectivity – “scientists have other scientists check their work to make sure they do it correctly; scientists apply self-checking techniques; objectivity is fact, while subjectivity is more feeling and intuition”

Project Sketches and Commercials

Group A

As stated by a member of group A in their commercial, “Our prototype is a microscope but you can feel it instead of seeing it. The light sensors will detect the shapes under the microscope causing the plungers to rise and cause a shape the blind person can feel.” A screenshot of their commercial is shown in Figure 1.



Figure 1. Group A Final Project

Group B

As stated by a member of group B in their commercial, “The prototype is a monitor that tracks the causes of an epileptic seizure to help from preventing them.”. The planning sketches created by group B and a screenshot of their commercial is shown in Figure 2.

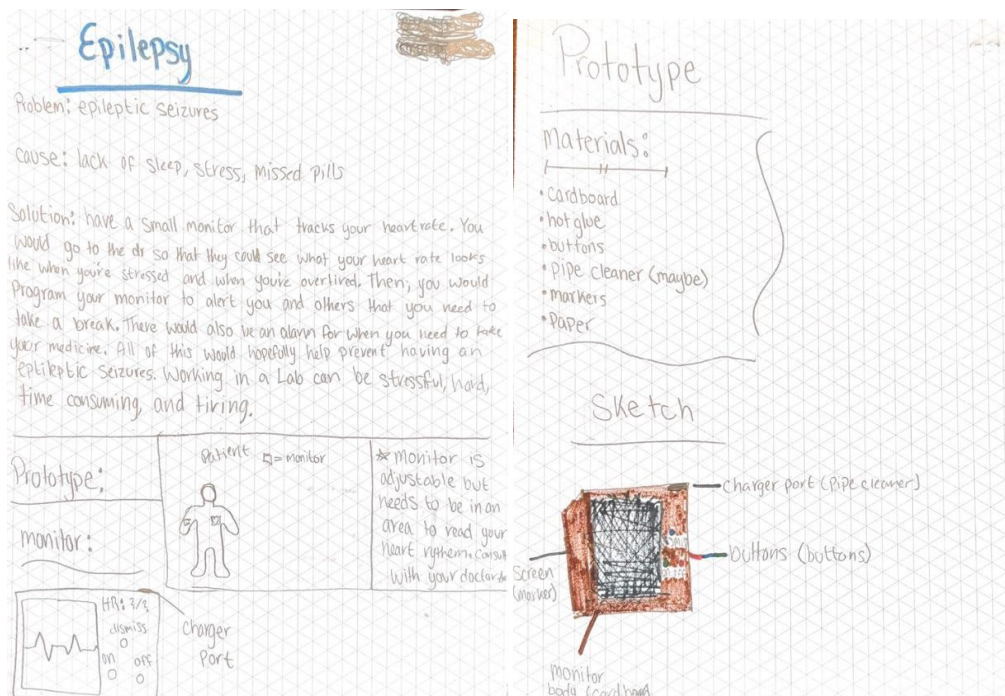


Figure 2. Group B Sketches and Final Project

Group C

As stated by a member of group C in their commercial, “Our prototype is a fidget that help people with ADHD and it is a finger pop tube”. The planning sketches created by group C and a screenshot of their commercial is shown in Figure 3.



Figure 3. Group C sketches and final project

Group D

As stated by a member of group D in their commercial, “This is a device that someone without fingers can wear and it has a lever that helps them pick up things like test tubes in the lab.” A screenshot of their commercial is shown in Figure 4.



Figure 4. Group D final project

Exit Tickets

As outlined before, the students were given an exit ticket question to fill out the last 5 minutes of each class period. The questions and some of the responses for each question are shown below:

How did you come up with your original idea? Did you feel like you had to be creative to come up with a design? Why or why not?

- “I came up with the idea because I am pretty good friends with [another student] and an amputee is the first thing I thought of. I didn’t have to be super creative because it kinda just reminded me of a pirate hook.”
- “I came up with the idea when I thought of how a 3d pin set could be used as a useful display tool for the blind. I had to be creative in how the pins would move to create a feelable 3d object, as well as how scans of microscopic objects could be displayed by pins.”

Do you know of anyone with a disability? Or know of someone on tv or on social media? If yes, did this background knowledge help you when designing your prototype?

- “Yes my little sister is dyslexic and I wanted to do the project on dyslexia but knowing about my sister I would know the device would have to be small and painless.”
- “[A friend] was the inspiration for the product, but the background information made the process a lot faster.”
- “I know a social media guy that is a surfer and is blind. I know that blind people like to feel bumpy things to know what’s going on.”

How did you learn more about disability culture (the different types of disabilities)? How did learning this new information change your ideas/plans?

- “I learned more by doing research and looking up the different types of disabilities that there are.”

- “I learned more by looking them up and reading about them. It changed my ideas and plans because it told me more than what i originally knew.”

Have you changed anything about your original design? Why? Was it because you learned something new along the way?

- “Yes, it is because we didn’t have the resources to fully complete the original goal. I learned that I am overly ambitious with my goals.”
- “We haven't changed anything about our original design because we put a lot of thought into it and we don't need to change anything about it.”
- “I changed the back part of my original design. At first it was a cardboard back for the monitoring part but I changed it to cotton balls to make it more of a comfort for the wearer.”

What did you learn during this “experiment”? How will you apply this new knowledge in the future?

- “I learned that people with disabilities have a harder time in scientific fields. I will apply this by trying to learn more about it.”
- “We learned that not everything can help a disability and it’s hard to create things that haven’t been made. I will apply this by telling people that have kids with a disability about this creation.”
- “I learned during this experiment that by making this invention I could impact somebody's life. I can apply this knowledge in the future by expanding my knowledge on this disease and how to manage it.”
- “I learned that sometimes people need to be assigned tasks when working as a team.”
- “I learned that the smaller solenoids that we have draw significantly more power than the big ones. This is good to know because the power draw directly correlates with the duty cycle of the solenoids as they like to get hot.”

Nature of Science and Project Connections

As previously mentioned, during our recap discussions at the beginning of each period I

asked the students to connect their experiences from the project to the components of the Nature of Science. As I took notes of their conversations, I listed their comments under the topic of Nature of Science that they said it was associated with. I listed some of the comments from groups A, B and D below:

Comments from group A

- Tentativeness – “We changed from small solenoids to large solenoids.”
- Empirical evidence – “We had to gather a lot of information to know how blind people ‘see’.”
- Observations and inferences – “We tested the components before we built the prototype so that we could use the best option. We needed to know what we were working with before we built it.”
- Scientific methods – “One problem we ran into was an overheating issue, the solenoid was drawing too much power for our need. There was another dimensioning problem that I think happened during the CAD step.”
- Creativity – “We had creative freedom to create our design.”

Comments from group B

- Tentativeness – “We had to change how we were going to make our prototype multiple times.”
- Observations and inferences – “We observed other people making their experiment and it gave us ideas.”
- Scientific methods – “We talked about different ideas and then chose the best one at of all of them.”
- Creativity – “We used creativity to think of an idea for our prototype.”
- Objectivity and subjectivity – “We included our own views of disabilities and what they need into our project.”

Comments from group D

- Tentativeness – “We kept thinking of better ideas.”

- Empirical evidence – “We used the internet to research disabilities.”
- Observations and inferences – “By using observations, we knew that it would be harder for a person with no hands to pour a beaker.”
- Scientific laws and theories – “We had to count on the law of gravity for our beaker idea to work.”
- Scientific methods – “We had to use trial and error when we created our prototype.”
- Creativity – “We had to brainstorm to think of a good way to make our idea happen.”
- Objectivity and subjectivity – “We had [another group] review our project.”

Discussion

Maker Education Projects as a Tool to Teach Nature of Science

The creativity component of Nature of Science was highlighted the most in this study. Several students noted in the discussions that they had to use creativity to come up with designs and how to build their prototypes. When looking at the VNOS(C) pre-survey, one student originally stated, “I feel like scientists don't use their creativity because they always go on the facts and not really on what they like or just because they feel like it. I feel like they also don't need to use their imagination because they need to go off the facts.” After the project, their thinking changed to “I think they do because if they didn't then we wouldn't learn any new things. They use their imagination the most when planning.” This project helped students understand that scientists and engineers must use creativity to come up with their experiments and designs. This was most likely the most evident for the students during the planning stage of their prototypes when they needed to be creative to come up with their designs. I drew this conclusion from the recap discussions when I asked them to relate the different components of Nature of Science to their projects and all of the groups said they had to use creativity to brainstorm ideas for prototypes. As stated by Maaia (2019) and mentioned in the theoretical background section of this chapter, one of the major learning outcomes of doing any type of design project is that the students become accustomed to reiterating their design through a “stuck and unstuck” cycle. I believe that working through this project helped students understand the tentativeness of science. For example, in the recap discussions some of the students were able to point out that their ideas changed over time and that they had to change their plans based on the materials they had available. They also indicated that they had to use trial and error and changed their design based on those errors. Through the

group discussions, the students were also able to understand that not everyone's scientific methods are the same.

After completing this project, I believe that my students have a better understanding of how science can be subjective and heavily influenced by the researcher's background. VNOS(C) survey results indicate one student who went from believing that science is universal and does not change to, "Science reflects social and cultural values because what you believe could interfere with what you are experimenting with and how you are doing science." A student was also able to point out in a group discussion that each person has their own prior views on disabilities that affected how they approached the project. As a teacher, I plan to use strategic grouping when doing projects like this to ensure that there is a variety of backgrounds and ideas contributing to the project.

Explicitly Teaching the Components of Nature of Science

In my future courses, I will strive to integrate Nature of Science throughout the course and structure their reflections around the seven aspects of Nature of Science. Earlier studies by Akerson et al. (2000) indicated that the explicit and reflection (ER) approach is the most effective way to teach Nature of Science. Perhaps explicit doesn't mean that I need to teach the seven components of Nature of Science, but rather integrate reflective questions that address the different components. Although, I believe that the gallery walk provided the background knowledge that the students needed to participate in the recap discussions in which they connected experiences from their project with the seven aspects of nature of science. During the group discussions I put the seven components of Nature of Science on the board so that students could refer back to them. They may not have been able to make those references without reading the article by Randy Bell first. Although Lederman and Lederman (2004) state that every aspect of Nature of Science will not and should not be addressed in every science lesson. If I was to continue this study, I would want to see if the post-survey results were similar if I didn't do the poster gallery walk with the students. As Lederman and Lederman (2004) discuss in their article, you can explicitly teach NOS through any science activity with the addition of reflective questioning. As a facilitator, I should be walking around and asking them more questions about their scientific thinking rather than waiting for the exit tickets at the end of the period. It would have been useful to have more field notes about how their thinking changed throughout the making process.

Understanding the Tribulations Within Disability Culture through a Maker Education Project

There is evidence from this study that suggests that by doing the research and planning for their prototype, students had to learn more about various disabilities. One student stated in one of their exit tickets, “we learned that not everything can help a disability and it’s hard to create things that haven’t been made. I will apply this by telling people that have kids with a disability about this creation.” Not only does this indicate that the student realizes that their design can impact on another person’s life, but it also shows that the student is thinking about how to share their design so that it can impact as many people as possible.

Limitations

My biology 2 class was a small class that resulted in only four projects. Also, not all of the students completed their projects or were present for all of the discussions. The students were also limited by time and materials to build their prototypes. As seen with group A, they took their project home to work on it so that they could have more materials to work with. And then there is group C who kept it simple and only utilized a pipe cleaner. This makes me wonder if limited materials lead to less or more creativity in the students.

Conclusion

Maker education projects can bring forward the creative component of the Nature of Science by allowing students to innovate and giving them the opportunity to solve real-world problems in their own way. Projects that require students to design for another culture can also help them build empathy because the students must put themselves in someone else’s shoes. In this study, students became more understanding of the tribulations that members of disability culture may face in a science lab, and they stated that they learned something they create can have a big impact on someone else’s life.

Recommendations

In conclusion of this study, I give the following recommendations to my colleagues:

- *Exit Tickets:* Exit tickets are an excellent opportunity to teach Nature of Science

through reflective questioning.

- *Group Discussions*: This is an opportunity for students to share what they think aloud and also to see that not everyone's scientific methods are the same.
- *Teacher/Facilitator*: While students are working on their projects, act as a facilitator rather than the keeper of all knowledge. Walk around the room and question students about their scientific thinking to lead them to deeper thinking about the process.
- *Creativity*: Give students the opportunity to innovate and use their own ideas to come up with solutions to real-world problems.

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Chapter 12 - Using Puzzles in Ninth Grade Physical Science Curriculum to Improve Understanding of the Social and Cultural Nature of Science

Corey Zickel , Valarie L. Akerson 

Chapter Highlights

- Freshman physical science
- Puzzles and Brainteasers
- NOS intervention
- Rural teaching

Introduction

I have been teaching introduction to physical science classes in a high school setting for about six years now. Every year a new batch of freshmen come into my classroom for the first time, and each year we begin our journey to understand science and scientific thinking. We start the year with an explicit introduction to measurements, experimental design, and data analysis. Throughout this unit we explicitly talk about how tentative science is, about how it is always changing, about how creative scientists need to be to design experiments, and how scientists must use observation and inference to make predictions. The students seem to arrive with a nebulous view on the nature of science (NOS), specifically the social and culturally embedded aspects of NOS. Through the rest of the year, I have embedded these tenets into the curriculum, both explicitly and implicitly, and the students have shown some improvement in their understanding; however, it is imperative that the students have a much firmer grasp.

Purpose Statement

Understanding NOS has long been a targeted goal in science education. In a position statement, the National Association of Science Teachers (NSTA) has identified NOS as a critical component of scientific literacy and reasons that scientifically literate students will be better positioned to make informed and logically sound decisions in the future (NSTA, 2021). This position is echoed throughout research in scientific literacy, showing that understanding of NOS sharpens students' critical thinking and problem-solving skills (Almeida et al., 2022). The rationale for better understanding of NOS is to foster scientific literacy in the population which will lead to a better understanding of the current advancements in science and technology allowing for more informed decision making in the future (McComas, 2017). The current political and social climate is making it more difficult to distinguish fact from fiction, making the understanding of scientific inquiry, critical thinking, and a deep understanding of scientific concepts necessary.

Students entering high school often have limited understanding of NOS, and there are large gaps to fill in their incomplete understanding, in part due to COVID-19 and their interrupted education. The limited contact with peers through the quarantine and the ensuing years of “hybrid-learning” seem to have impacted their understanding of how science fits into the

social environment and how it has its roots in the culture of the time (Colvin et al., 2021). The implications of the social and cultural understandings in NOS are far reaching, but difficult to define. The themes of cultural connectedness in science education are nuanced, but the ability of students to understand the specific cultural and historical perspective of any scientist will help gain a deep understanding of the impact in the humanities (Reiners et al., 2017). Over the past thirty years, reforms to state and federal curriculum have stressed the importance of an understanding of NOS as a major component of overall scientific literacy.

Puzzles and brain teasers have been shown to help the cognitive development of students (Willingham, 2009). To this end I believe that introducing puzzles and brainteasers in freshman physical science classes could help students find better connection to the pillars of NOS by stimulating their cognitive abilities and allowing them a more complete understanding of the social implications of NOS.

Research Questions

1. What impact will embedding puzzles, riddles, and brain teasers as a form of explicit reflective instruction have on ninth grade physical science students' understanding of NOS?
2. Can this intervention help to strengthen their understanding of the social and cultural connectedness of NOS?
3. Will this help sharpen a student's ability to generalize their understanding of NOS?

Background/Theory

NOS is often portrayed in generalities and abstract ideas. As Abd-El-Khalick et al. (1998) explain "NOS has been used to refer to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge," (p. 418). This abstract idea of NOS provides a way to relate NOS across historical, social, and philosophical domains; however, it makes NOS too abstract for the typical high school student. Therefore, for the purpose of this paper, we will focus on NOS being ever changing, based on observations, theory- laden, inferential, imaginative, creative, and socially and culturally embedded. The ministry of education in New Zealand described it

best by saying that science is a “culture in just the same way that we think of the cultural worlds of art and music. We need to understand and talk art or music when we enter these worlds. In the same way, we need to be able to understand and talk science” (NZME, 2023, Describing the nature of science section).

Much of the research in teaching NOS have concluded that the method that garners the best student insight into NOS is through an explicit-reflective presentation (Abd-El-Khalick et al., 1998; Akerson et al., 2000; Almeida, Santos, & Justi, 2022; Hanuscin et al. 2006; Khishfe, 2007; Lederman, 2007; Schwartz et al., 2007). Current research in science education shows gains in NOS understanding when students have used escape games as a vehicle for introduction to scientific reasoning (Yachin & Barak, 2023). When students were exposed to escape games, they achieved gains in real world thinking, problem solving, and self-reflection. The same creativity and critical thinking skills shown in escape rooms are used to solve riddles and brainteasers and a brief exit ticket and debriefing after the puzzle will allow for greater reflection and possible transfer. Puzzles in general have been shown to be great didactic tools (Gorev et al., 2018). The use of puzzles to spark curiosity and open dialog will benefit the students’ cognitive abilities, opening them to better understanding of abstract principles (Willingham, 2009,). The use of puzzles has also been shown to help students with their computational learning, allowing gains in logic abilities including sorting, ranking, comparing, and problem-solving (Liu, 2024). The use of puzzles and games in learning also help the students with self-directed learning, allowing the students to take responsibility for their own learning (Pacheco-Velazquez et al., 2024). Each of these helps students to make connections between the puzzles and how science is carried out. The reflective component of the debriefing will also help to extend the dialogical nature of my classroom, which has been shown to increase the students’ critical and scientific thinking (Iwuanyanwu, 2023).

Method

I used a grounded theory approach to this action research project to track the changes in my students’ views of NOS through this intervention (Merriam & Tisdell, 2016). I collected a variety of artifacts to analyze including student responses, interviews, researcher journals, and discussion notes. The study’s context and my approach to the intervention, data collection, and data analysis are detailed here.

Context

This study was carried out over a three-week period in a small rural school of 750 students. Dover, Ohio is a rural city with a population of about 13,000 people. The community is close-knit and driven by tradition. Like most small midwestern towns, there has been little diversity historically; however, this has been changing over the past decade as an influx of Latinx have settled in the area. The residents of this little hamlet make an average household income slightly below the national average with a significant portion of the population dipping below poverty level. Dover City Schools strives to accommodate the shifting demographics and has recently opened a new high school building to better serve the community.

The study focuses on two physical science classes of first year high school students. One class has twenty- four students and the other has eighteen. There are five English Language Learners (ELL) in these classes, along with six students that have been identified as gifted in one or more domain. More than 35% of the students enrolled in these classes are identified as being economically disadvantaged. These classes reflect the general makeup of the high school and provide a decent cross section of the freshman class. Of the 42 students enrolled in these classes, only three of them were excluded for not receiving more than 50% of the intervention due to attendance issues, bringing the total participation to 39 students.

Intervention

The week prior to the intervention, all students completed the *Views on the Nature of Science form D+* (VNOS-D+) to gauge their understanding of NOS before the intervention. (Appendix A) This will be compared to a VNOS-D+ taken the week following the intervention for comparison. Twice a week during the three-week period of this study, the students were given a puzzle or brainteaser to try to solve for the first 10 minutes of class. The puzzles are collected, and the daily lesson commenced.

In the last five minutes of the class period, all the students are given an exit ticket to gauge their connection between the puzzle and their understanding of how science works. On the days between puzzles, we discuss the previous puzzle, how they solved it, and their understanding of the transfer of knowledge. Students were interviewed throughout this

process to provide context and gain better understanding of their answers (see Table 1, Appendix B).

The classroom is set up for small group discovery with three to four students to a table group. During the first intervention class, I went to each table as the other groups worked on the day’s lessons. I engaged the students in conversation to probe their understanding of NOS using examples from their answers to the VNOS. This allowed me to gain better insight into their answers and gave context for my analysis.

Table 1. Puzzles used in this Intervention

Week	Puzzle	Intervention Target
1	How do doctors target cancer cells? (Puzzle 1)	Group work, creative thinking
1	How to attack a castle (Puzzle 2)	Connections to abstract thinking, group work, creative thinking
2	Numbered parking spaces (Puzzle 3)	Creative thinking, group work, perspective
2	Missing weight (Puzzle 4)	Creative thinking, group work, connections across curriculum
3	Connections (Puzzle 5)	Group work, creative thinking, connection to prior knowledge
3	Wuzzle (Puzzle 6)	Group work, creative thinking

After passing out the first puzzle, I gave very little instruction to the students in order to gauge their connections to the ideas without undue influence. The students began working quietly on their puzzle for a few minutes and slowly began to discuss answers with their groups. This pattern was repeated with less time between the student getting the puzzle and their consultation with their group. By the time the final puzzle was given, the students immediately began talking with not only their own group, but to all the other groups as well. At the end of every intervention period, each student was given an exit ticket that said, “At the beginning of class we completed a brainteaser. How was solving that brainteaser related to science?” This allows me to track the progress in their ability to connect the puzzles to their views of NOS.

Data Collection

I used a variety of data sources to track my students' understanding of NOS. Prior to the intervention, each student completed the VNOS-D+. This form is designed to assess high school students' views on the many pillars of NOS, including the tentative nature of scientific knowledge, the empirical nature of scientific knowledge, the creative nature of science, and the social and cultural nature of science (Ayala-Villamil & García-Martínez, 2021). Students' answers were then augmented through small group discussions to clarify answers.

At the conclusion of the intervention, the students once again completed the VNOS-D+ to track the changes to their understanding and again we discussed their answers in small groups. It would be beneficial to discuss the post intervention results with the students individually, but time did not permit for this approach. I believe it could have some impact on the study and would suggest that this is done in for any future interventions.

To track the changes in understanding throughout the intervention, the student work was collected, the exit tickets were collected, and I kept a teacher/researcher journal with my impressions of the follow up discussions after each puzzle. During these discussions, I tried not to lead the discussions, I simple began with "what do you think about this puzzle," and I let the class discuss the answers and the processes, if I wanted any clarification, I tried to keep a neutral stance and probe by saying something like, "can you give me an example?"

Data Analysis

Using an open coding scheme, I read through all the data and made notes for any clarifications needed and held individual or group interviews to better understand the students' answers. Once the clarifications were complete, each answer was analyzed to find any patterns that emerged. I coded all the answers and made notes of any themes that I discovered. I developed a similar rubric to that used by Akerson and Donnelly (2009), where they coded the VNOS-D to track the views of young students through a six-week summer program. Once all the data had been coded, I organized everything into concepts using Ayala-Villamil and Garcia-Martinez's (2021) categorization of the VNOS- D+ questions as a guide. I then categorized the students' responses as having naïve, emerging,

or informed views of NOS. Any further discrepancies were cleared by holding brief individual interviews with the students for clarification on their answers. For example, I coded the response, “Scientists aren’t sure what happened because they weren’t there,” as a naïve view of the empirical nature of science, and I coded, “They used data to create a model,” as emerging understanding. The response “Through continued experimentation and existing data, this is the most likely model,” would be coded as being an informed understanding of NOS.

Table 2 outlines a few examples of the rubric used for coding the answers along with how each facet of NOS was targeted for each question. I used a similar schema when coding the students’ exit tickets so that I was able to track the students’ evolving views of NOS throughout the intervention. The exit tickets were gathered and coded to show whether the students were connecting the puzzles with the targeted pillar of NOS. The question asked what the puzzle had in common with science and the response, “They’re both hard,” or “I had to think,” were coded as naïve where the response “ I needed to use problem solving and math,” was coded as having emerging views of NOS, and “I needed to work with my group, problem solve, and use prior knowledge,” I considered to be informed. I used my teacher researcher journal, individual, and group discussions to clarify any uncertainties in my data.

Once all the answers had been coded, I gathered all the data together to see any patterns that came forth. Then, each category was combined, and the average score was determined using a simple numeric value for each question, ie Naïve = 1, Emerging = 2, Informed = 3. All the students’ scores for each question in a category of NOS were added together and the average for each domain was found. This allowed me to get a sense of how the students’ views on NOS improved over the course of the intervention.

Table 2. Examples from the Coding Rubric

Dimension of NOS	VNOS-D+ Questions	Selected Coding Rubric
	Questions 3,9:	Naïve: Everything changes
		Emerging: Yes, there could be new technologies to find new things
The Tentative Nature	3: Do you think scientific	

of Scientific Knowledge	knowledge could change in the future?	Informed: Yes, new technologies and reinterpretation of existing data can change them.
	Questions 1,2,4,5,6: 1: What is science?	Naïve: Science is everything, Scientists aren't sure what happened because they weren't there
The Empirical Nature of Scientific Knowledge	6: Does the model of the layers of the Earth exactly match the Earth?	Emerging: Science is studying nature, They used data to create a model Informed: Science is a way of knowing, using experimental data to understand natural phenomena, Through continued experimentation and existing data, this is the most likely model
	Questions 3,9,10:	Naïve: Yes, we do science in a society Emerging: Yes, sometimes we change things because we use science to find a better way.
Social and Culture Influences on Scientific Thought	10: Is there a relationship between science, society, and cultural values?	Informed: Science and society influence each other. Scientists interpret data using the societal influences of the time and can be reinterpreted as we evolve as a society.
	Questions 5,6,7,8:	Naïve: No, they just use facts Emerging: They do when they set up the experiments
The Creative and Imaginative Nature of Science	7: Do you think scientists use their imagination and creativity when they do these investigations?	Informed: They use imagination to design experiments, interpret the data, and explain the phenomena.

Results

Prior to the intervention, the students held mostly naïve views of NOS, with some straying into emerging understanding of certain pillars. The data post-intervention showed gains in all domains of NOS, with the greatest increase in the understanding of the creative and imaginative nature of science. Modest gains were shown in the social and cultural nature, with small gains in the empirical and the tentative domains. Unfortunately, none of the students showed informed understanding in any of the areas; however, after a few interviews it was clear that some students were on the cusp of true understanding. There were certain questions on the VNOS-D+ that some students held informed views on, but the average understanding in any domain remained emergent. For example, question 3 asks the student if they thought that scientific knowledge could change in the future, which fits into the tentative nature of science. They answered with an informed view of, “Yes, it has changed before. When new technology gives more data or when scientists review things that they thought in the past,” but on question 9, “after scientists develop a theory, will it ever change,” they answered, “Yes, because it’s just a guess.” On an individual question, they showed an informed understanding of the tentative and subjective nature of science, but on the next they showed a naïve view. This would average out to mean that this student held an emerging view of this domain. They clearly understood that scientists can get new information or reevaluate old information, but then held that a theory was only a guess showing that they do not understand how scientists gather evidence to form a theory.

Table 3 gives the overview of the students’ views of NOS, pre and post intervention, along with the percentage of increase in each domain. It should be noted that the small sample size will affect the percentages and should be accounted for in any interpretation of the data.

Table 2. Results Pre and Post Intervention. (n=39)

NOS Domain	Preintervention		Postintervention		Percent Increase in Emerging
	Naïve	Emerging	Naïve	Emerging	
Tentative/ Subjective	29	10	25	14	10.2%
Empirical	33	6	29	10	10.2%
Social and Cultural	31	8	24	15	17.9%
Creative	35	4	27	12	20.5%

The data clearly shows an increase in understanding of NOS through the three-week period of the intervention. Throughout the intervention, the exit tickets steadily became more focused on the similarities between the way they solve the puzzles and NOS. For example, one student turned in the first exit ticket explaining that the puzzles were related to science because science is everywhere, and both can find the answers in different ways. Their final exit ticket at the end of the three weeks stated that they need to use creative thinking and work with their group to solve the puzzle, just like scientists work in groups and design experiments. The students' views of NOS showed gradual positive growth throughout the intervention.

Discussion

In response to the first research question, *What impact will embedding puzzles, riddles, and brain teasers as a form of explicit reflective instruction have on ninth grade physical science students' understanding of NOS?* The data from the pre and post VNOS-D+ as well as the students' exit tickets show that embedding puzzles into the daily science curriculum has great potential for improving the students' understanding of NOS. The students' VNOS-D+ postintervention showed modest gains in just a three-week period. The implication being that a longer intervention or integrating puzzles into the daily curriculum for an entire year could vastly improve the students' grasp of NOS.

The second research question, *Can this intervention help to strengthen their understanding of the social and cultural connectedness of NOS?* is also seen in the results of the VNOS-D+. The nearly 18% increase in emerging understanding of the social and cultural aspects of NOS can also be seen in the teacher research journal. In an entry from the first week of the intervention I wrote,

The students are not able to think beyond the obvious problem-solving aspects of science. I saw all the students collaborating and using prior knowledge and creativity to construct explanations, but they don't see that this is the same thing we do as scientists.

When the intervention started, the students had very concrete understanding of science and were not connecting to the idea that science is collaborative or that their views could change the answers, but as the intervention went on the shift in their thinking could be seen. From

my journal during week three of the intervention I wrote:

The students were openly talking with each other about the connections to science rather than the puzzle. One student told her group, ‘I mean, we’re talking about the puzzle and ways to solve it, isn’t that just like doing a lab?’ I heard several students talking about working with their group and using the things they already know to answer it. One student even said that they changed their answers, ‘like we do when we figure out something new.’ I almost cheered.

It was clear that the students were starting to see the social implications of science, even if they weren’t really connecting the cultural significance.

For the final research question, *Will this help sharpen a student’s ability to generalize their understanding of NOS?* we can clearly see the students generalizing the different aspects of NOS from their work on the puzzles in their responses to the exit tickets. Throughout the entirety of the intervention, the students showed measurable, incremental improvement in their knowledge of NOS and how it transferred from the evolution of their exit ticket responses when asked, “how is solving this brain teaser related to science?” Examples can be seen in comparing early responses to late responses as seen in Table 4.

Table 4. Early vs Late Exit Ticket Responses

Early intervention	Late Intervention
We had to use our brains to solve it.	In science you have to brainstorm and work with other people to find the correct answer. You have to look at things in outside the box ways in science.
It helps our ability to problem solve and think.	Science is preformed [sic] by testing out processes and uncovering new things. Science is preformed [sic] with groups or partners [sic]. Science is preformed [sic] by determination and drive.
You solved a problem with the data provided.	Creative thinking, Working with people, Collaborating [sic] your ideas
It made us give an educated guess and using details to show	In science there might be times when you don’t understand something and you have to ask others for help. You also have to use context clues and be creative

something.	to find answers.
Science uses your brain and doing brain teasers helps you think.	It uses problem solving It also makes you communicate with other people and makes you think about ways the problem can be solved.

It is obvious from the length of the responses that the students were getting more comfortable with the process of the intervention, but the reasoning and connection was also apparent. The shift from a general “I had to think,” to the more nuanced “I had to collaborate and use existing data to find a creative solution to a problem,” was refreshing and showed a potential for great gains in NOS understanding from similar interventions.

Conclusions

This study used the introduction of puzzles and brainteasers in a freshman physical science class to improve the students’ understanding of NOS. It was completed over a three-week intervention period in which the students worked in collaborative groups to solve puzzles, reflected on the connection to NOS, and discussed their findings. The data gathered from the VNOS-D+ showed a gain in all aspects of NOS after the intervention period.

The use of the puzzles and the collaborative groupings lead to gains in understanding of NOS in this freshman class. The results of this intervention reinforce those of Yachin and Barak’s (2023) study of escape game designs where the major factors seem to be collaboration and reflection. The students’ sorting and ranking abilities showed gains as seen in their improving V-NOS scores, which echoes current research (Liu, 2024). The intervention also seems to have helped the students take responsibility for their learning, with more in-depth and complete answers to the questions. This also confirms the current research in the effectiveness of puzzles in a learning environment (Pacheco-Velazquez et al., 2024). The students integrated these views through the repeated use of the brainteasers and the reflective components of the exit tickets and class discussions which echoes the current findings which point to explicit reflective learning (Abd-El-Khalick et al., 1998; Akerson et al., 2000; Almeida, B., Santos, M., & Justi, R. 2022; Hanuscin et al. 2006; Khishfe, R. 2007; Lederman, 2007; Schwartz et al., 2007). This study provides a new approach to such teaching. By integrating the teaching of NOS with puzzles and brainteasers, the students can

gain insight into NOS while working through games.

Recommendations

This study shows that the use of intermittent puzzles and brainteasers can have a positive effect on students' understanding of NOS. As outlined above, this can be an activity that is both novel and supported by current literature. I believe that this intervention could be used throughout a school year to help students to better understand NOS and connect their burgeoning understanding to real-world examples. In the future, I would recommend weekly puzzles integrated into the curriculum to spread the intervention out and help extend their understanding and better synthesize the lessons. I further recommend a more robust study be conducted to gain further understanding of the students' gains in understanding.

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Appendix A – VNOS-D+

VIEWS OF NATURE OF SCIENCE

(VNOS D +)

Name: _____

Date: / /

Instructions

Please answer each of the following questions. You can use all the space provided and the backs of the pages to answer a question.

Some questions have more than one part. Please make sure you write answers for each part. This is not a test and will not be graded. There are no “right” or “wrong” answers to the following questions. I am only interested in your ideas relating to the following questions.

1. What is science?

2. What makes science (or a scientific discipline such as physics, biology, etc.) different from other subject/disciplines (art, history, philosophy, etc.)?

3. Scientists produce scientific knowledge. Do you think this knowledge may change in the future? Explain your answer and give an example.

4. (a) How do scientists know that dinosaurs really existed? Explain your answer.

(b) How certain are scientists about the way dinosaurs looked? Explain your answer.

(c) Scientists agree that about 65 millions of years ago the dinosaurs became extinct (all died away). However, scientists disagree about what had caused this to happen.

Why do you think they disagree even though they all have the same information?

(d) If a scientist wants to persuade other scientists of their theory of dinosaur extinction, what do they have to do to convince them? Explain your answer.

5. In order to predict the weather, weather persons collect different types of information. Often they produce computer models of different weather patterns. (a) Do you think weather persons are certain (sure) about the computer models of the weather patterns?

(b) Why or why not?

6. The model of the inside of the Earth shows that the Earth is made up of layers called the crust, upper mantle, mantle, outer core and the inner core. Does the

model of the layers of the Earth *exactly* represent how the inside of the Earth looks? Explain your answer.

7. Scientists try to find answers to their questions by doing investigations / experiments. Do you think that scientists use their imaginations and creativity when they do these investigations / experiments? a. If **NO**, explain why.

b. If **YES**, in what part(s) of their investigations (planning, experimenting, making observations, analysis of data, interpretation, reporting results, etc.) do you think they use their imagination and creativity? Give examples if you can.

8. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

9. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and give an example.

10. Is there a relationship between science, society, and cultural values? If so, how? If not, why not? Explain and provide examples.

Appendix B – Inventory of Puzzles Used in this Intervention

Puzzle 1

Suppose you are a doctor faced with a patient who has a malignant tumor in his stomach. It is impossible to operate on the patient, but unless the tumor is destroyed the patient will die. There is a kind of ray that can be used to destroy the tumor. If the rays reach the tumor all at once at a high intensity, the tumor will be destroyed. Unfortunately, at this intensity the healthy tissue the rays pass through on the way to the tumor will also be destroyed. At lower intensities the rays are harmless to healthy tissue, but they will not affect the tumor either. What type of procedure might be used to destroy the tumor with the rays and at the same time avoid destroying the healthy tissue?

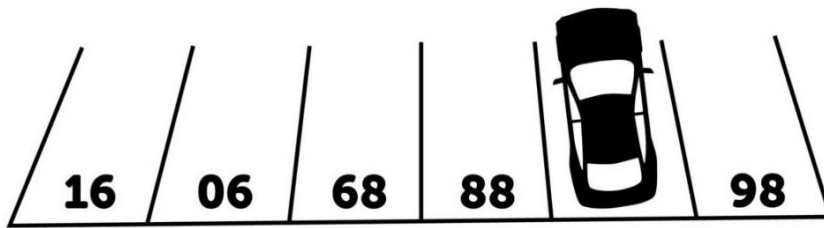
Answer in complete sentences:

Puzzle 2

A dictator ruled a small country from a fortress. The fortress was situated in the middle of the country and many roads radiated from it, like spokes in a wheel. A great general vowed to capture the fortress and free the country from the dictator. The general knew that if his entire army could attack the fortress at once, it could be captured. But a spy reported that the dictator had planted mines on each of the roads. The mines were set so that small groups of men could pass over safely, because the dictator needed to move troops and workers about; however, any larger force would detonate the mines. Not only would this activity blow up the road, but the dictator would destroy many villages in retaliation. How could the general attack the fortress?

Answer in complete sentences:

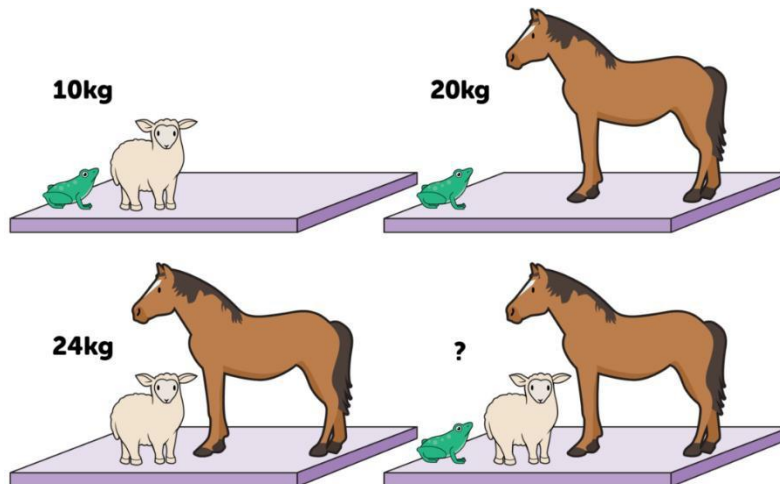
Puzzle 3



What is the number of the parking space containing the car?

Explain how you know in 2-3 complete sentences.

Puzzle 4



What is the final mass of each of the three animals? (Show your work)

Puzzle 5

Word association: find a word that associates with the following sets of words.


1. Cake, swiss, cottage
2. Glasses, screen, day
3. Cream, cube, cap
4. Knife, fly, cup

Puzzle 6

1 history history history	2 R g rose e i n	3 MEREPEAT	4 _____ read _____
5 Arrest You're	6 M Meal M e e a a l Meal l	7 E more more more more	8 wonalicederland
9 me right	10 stefrankin	11 Chimadena	12 settle
13 million	14 d e r d e r e v i e v i d e r d e r e v i e v i	15 land time	16 mini/bethereute
17 R R a a l l l l	18 soar	19 ban ana	20 o_er_t_o_
21 e t a d	22 Meal ^	23 issue issue issue issue issue issue issue issue issue issue	24 XQQQME

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Chapter 13 - Enhanced Student's Understanding of Foreign Exchange Rate Forecasting Leveraging the Cultural and Socially Embeddedness Aspect of the Nature of Science Construct

Ricardo L. Guimarães 

Chapter Highlights

- Examines the impact of social and cultural embeddedness on business students' understanding of foreign exchange rate forecasting in the context of international trading patterns, focusing on how social norms and cultural values shape knowledge in economic sciences.
- Demonstrates the unique intersection of natural and economic sciences, particularly through the social and cultural embeddedness aspects of the nature of science (NOS), enhancing understanding of complex trading patterns.
- Reveals significant shifts in students' naïve perceptions of the NOS, recognizing its social and cultural embeddedness through targeted educational interventions.
- Introduces explicit and reflective teaching methods that effectively bridge theoretical economic models with practical, real-world business management scenarios.
- Utilizes action research to systematically improve teaching strategies in international business, emphasizing the role of social and cultural contexts in shaping economic theories and practices.
- Discusses the strength of the findings from a research design standpoint, including considerations and limitations and the impact of its implementation.

Introduction

As an international business teacher, it is my goal to ensure that my students grasp the idea that trading and businesses are shaped by the decisions and influence of the social structures and cultural elements in any given country. These components are crucial in determining how theories are developed, regulations are implemented, and business plans are executed. To help me in this endeavor, this action research was designed to improve my practice, leveraging the construct developed for the natural sciences that science is socially and culturally embedded, which is to say that societal and cultural contexts influence scientific practices and norms. The social and cultural embeddedness aspect of the nature of science (NOS) refers to the idea that scientific knowledge and practices are influenced by the social and cultural context in which they are developed. This aspect emphasizes that science is not an isolated or purely objective endeavor, but rather, it is shaped by the values, norms, and interests of the society in which it is conducted (Lederman et al., 2002).

On the other hand, trading patterns reflect a strong weight from globalization advocates and detractors' ideas and actions (people from all sorts of backgrounds, such as policymakers, opinion makers, etc.) Stiglitz (2004) explained it in: "...not to walk away from globalization, not to put on blinders to the costs, which are not just potential, but have actually been experienced by many countries. Only if one is aware of the downside can one design policies to mitigate these risks, thus making it more likely that globalization will, in fact, live up to the claims that its ardent advocates have put forward. (p. 522)" Moreover, in prosperous or tempestuous times, researchers, policymakers, and business managers battle daily to develop economic outlooks, including scenarios, guidance, and predictions of several economic indexes, including the estimation of foreign currency (FOREX) estimates (subject in this study), based on scientific knowledge rooted in social and economic thinking and theories.

Acknowledging the parallel relationship between trading (FOREX forecasting in this study) and the NOS aspect, which is that science is socially and culturally embedded, this paper leverages the vast literature on the aspects of NOS to help formulate and plan this action research study. Action research has an applied focus, addresses a specific, practical issue, and seeks to obtain solutions to a problem; its designs are systematic procedures completed by individuals in an educational setting to gather information and subsequently improve how their particular educational setting operates (Creswell & Gutterman, 2019, p. 587). Therefore,

action research is context-based, a work prepared and implemented by the teacher. In this specific study, the design was applied in my International Business Course, aiming to improve the learning outcomes and in-class experience of students enrolled in one section of the spring semester of 2024.

Problem Statement

Undergraduate business students often overlook the significant influence of social norms and cultural values on economic modeling and forecasting, particularly in the realm of international trade. Despite the clear and established impact that market agents—such as researchers, policymakers, and business managers—have on shaping economic outlooks, students frequently fail to recognize how these agents' cultural and social contexts inform scenarios, guidance, and predictive models. This lack of awareness may lead to an incomplete understanding of global trading patterns, resulting in misguided assumptions and analyses in both academic and professional settings. The present study explores this knowledge gap, offering a strategy to improve students' recognition of these influences.

Background

It is no surprise that there is no literature about any suggestion of the intersection between NOS and the field of Economics. However, I am a firm believer that the constructions developed in NOS are conceptually useful in explaining certain aspects of the nature of the economic theories. NOS, with its focus on the epistemological underpinnings allied to scientific inquiry and scientific literacy, shares common ground with economics, particularly in areas such as model-building, hypothesis testing, and the interpretation of empirical data. Both fields are concerned with understanding complex systems, whether they are natural phenomena or social and economic market dynamics, and rely on similar logical and analytical frameworks to do so.

Abd-El-Khalick (cited in Lederman et al. 2014) has emphasized that, in a classroom context, student decision-making regarding socio-scientific issues is analogous to the process that scientists undergo when justifying scientific knowledge. That process is rational, critical, and necessarily involves value judgments. In the context of this same study, Lederman et al. (2014) comment on discussions in the science classroom of genetically modified foods and

the decisions that the globe-wide opinion on the controversial production and consumption of such products require comprehending the interrelationships of students understanding the different angles of the same issue. Its complexity in the context of health and ethics leads to a broader discussion of values and beliefs, marking the embeddedness of social and cultural aspects in scientific knowledge, inquiry, and literacy. Lederman concludes that for the classroom science teacher and because of the complexity of the subject matter involved, the use of these socio-scientific issues arising in the arena of genetics may take the form of engaging students in purposeful ancillary reading activities with a related set of thought-provoking questions around which to frame a classroom discussion.

Lederman et al. (2014) discuss scientific literacy as a concept that comprehends the knowledge of science and the applications of this knowledge to make decisions about personal and societal situations that have science and non-science components. Lederman then points out that for an individual to make informed decisions about scientifically based issues, he/she must be able to weigh the claims and evidence against the characteristics inherent to scientific knowledge and its development through scientific inquiry. These assertions reinforce the importance of preparing students for a holistic view of the theories that includes not just the technical and philosophical parts but also the societal and community aspects.

To better guide the students on the process of incorporating the true sense and fully experiencing the concept of social and cultural embeddedness aspect of science, this study incorporates explicit pedagogical approaches, also inspired by the NOS researchers' works. Abd-El-Khalick and Lederman, in the late 1990s, suggested and supported the explicit approach to incorporating the NOS aspects as a preferred way to enhance the student's learning outcome. Akerson, Abd-El-Khalick, and Lederman (2000) present two pedagogical approaches to teaching NOS: implicit and explicit approaches. The implicit approach assumes that students will naturally develop an understanding of NOS through engagement in inquiry-based activities without a specific focus on NOS. In contrast, the explicit approach involves deliberate instruction on NOS aspects, incorporating clear objectives, instructional attention, and assessments related to NOS. Among the conclusions of the study, the researchers found that prior to the intervention, the majority of participants held naive views of the NOS aspects. During the intervention, the instructor coupled class activities with explicit instruction on the aspects of NOS. This approach opened up the opportunity for the

participants to reflect on their views of the NOS aspects in the context of the scientific inquiry activities. Post-instruction assessments indicated that participants made substantial gains in their views of some of the target NOS aspects. However, and curiously, less substantial gains were evident in the case of the subjective, social, and cultural embeddedness aspects of NOS. This study also invites the reader to think about the implicit and explicit approaches from the cognitive aspect of learning.

Swartz, Lederman, and Crawford (2004) explain that the implicit approach assumes that students will develop an understanding of NOS concepts simply by engaging in inquiry-based activities without specific attention being paid to NOS. This approach relies on the natural integration of NOS principles within the process of scientific inquiry. In contrast, the explicit approach involves deliberate instruction on NOS aspects alongside inquiry-based learning. This method includes clear objectives, instructional focus, and assessments related explicitly to NOS. It emphasizes drawing students' attention to NOS through discussions, guided reflection, and targeted questioning within the context of activities and historical examples. The teacher plays a crucial role in providing learning opportunities, modeling, offering practice, assessing understanding, and giving feedback with necessary reteaching.

Krajewski and Schwartz (2014) explore the experiences of the main author of the study, an in-service teacher, as she integrates NOS into her community college biology course through a participatory action research approach. The research focuses on the challenges and successes the author encounters while implementing an explicit-reflective NOS teaching approach across four units: genetics, molecular biology, evolution, and ecology. Through cycles of planning, implementing, and reflecting, the author identifies key themes that contribute to her successful embedding of NOS within the science content. The study's findings regarding the development of the author's pedagogical content knowledge and pedagogical strategies to enhance student learning were leveraged to further fine-tune the purpose and research questions for the research described herein.

Purpose

Recognizing the complexity of international business environments, this study seeks to help students uncover how deeply ingrained social norms, cultural values, and societal structures shape trading patterns in general. By exploring international business cases, the research

aimed to illuminate the nuanced interplay between culture and commerce, shedding light on how cultural differences and social dynamics can lead to trading variances in practices, policies, and strategies among countries. Through a methodical qualitative investigation, this study intends to provide actionable insights that could guide students in developing a culturally informed understanding of effective international trade policies and practices in international business operations.

Research Questions

1. Does the explicit-reflective approach incorporated into lesson plans and instruction help students connect diverse thinking and social structures (including political and economic systems) to influence scientific knowledge?
2. What are the challenges and facilitating factors affecting the implementation of the research approach?

Procedures

This action research was conducted during normal class days (twice a week). The teaching approach was student-centric pedagogy. Students have a textbook as a reference from which a knowledge test was taken before the first class of the week. In the first class of the week, the concepts related to the week's theme were briefly reviewed for clarification, followed by a group activity and discussion, normally based on a case study posted as handouts before the class. After discussing and addressing prompt questions about the case and the week's theme, students and I normally wrapped up the topic, tying the learning objectives. All materials, assignments, references, and handouts were posted weekly using a web-based learning management system (LMS) platform that provides a comprehensive suite of tools to organize and support the students' learning experiences. In the second class of the week, students were required to come prepared with another but denser case, and therefore, more in-depth analysis was expected.

Intervention

The intervention, defined and to be measured from a learning outcome efficiency standpoint herein, aims to elevate the cultural and social aspects affecting theoretical models, inciting

the necessary discussion among the participant students of the amplitude of the assumptions and robustness of the scenarios in addressing the case studies. The International Business course subject to this action research is an introductory course, so it does not aim to form economists but company managers and, to this matter, professionals with enough awareness to evaluate and mitigate potential risks. The social and cultural aspects in developing such scenarios and mitigating potential risks represent a “wild card” in any business, from the negotiation to the effective transaction standpoint. As it is in natural sciences, here in economic sciences, the cultural and social embeddedness is an intrinsic factor in the formation of scientific knowledge. So, in the weeks that followed the first assessment, I incorporated in the lesson plans the explanation about the social and cultural aspects of scientific knowledge and inquiry in case assignments and the post-case-analysis discussion. A summary of the week’s Lesson Plan is posted in Annex A, and its implementation is explained in the Discussions section herein.

The baseline first assessment (before the intervention) was implemented in the mid-term exam in week ten of the Spring Semester of 2024, to which a short essay question was added to address the student’s understanding of the cultural and social influence on the formation of scientific knowledge. As mentioned before, the intervention lasted for three weeks, and in week fifteen of the semester, the same question was repeated in the final exam, aiming to measure the progress in the understanding of the cultural and social aspects of science.

The question that served as the measurement before and after the intervention was taken from a 2002 study titled Views of Nature of Science Questionnaire (VNOS): Toward Valid and Meaningful Assessment of Learners’ Conceptions of Nature of Science (Lederman et al., 2002). In this study, the authors describe the history of the evolution of questionnaires on the aspects of the nature of science, voicing concerns with the standardized paper and pencil assessments related to the understanding of the NOS aspects. The study reinforced and advocated for qualitative method instruments and an increasing focus on individual classroom interventions to enhance learners’ NOS views. VNOS questionnaires have been extensively used in research, and for this action research item number 9 from VNOS-C (Lederman et al., 2002), used in the mid-term and final exams, reads as follows:

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. Defend your answer with examples.
- If you believe that science is universal, explain why. Defend your answer with examples.

VNOS-C has been administered to college undergraduates and graduates, as well as preservice secondary science teachers (Abd-El-Khalick, 1998). Moreover, Abd-El Khalick (1998, 2001) established the validity of the VNOS-C by systematically comparing and contrasting participants' NOS profiles that were independently generated from separate analyses of the questionnaires and corresponding interview transcripts. Comparisons indicated that interpretations of participants' NOS views, as elucidated in the VNOS-C, were congruent to those expressed by participants during individual interviews (Lederman et al., 2002).

Data Collection and Methodology

To explore the cultural and social aspects of NOS, this study employed a qualitative research approach, leveraging different data sources to enrich the analysis and improve the validity of the findings. Four distinct data sets were collected for this research. The first data set was derived from responses to the mid-term exam, which served as a baseline assessment. This exam included the short essay question mentioned in the previous section that prompted students to reflect on whether they perceived science to be influenced by social and cultural values or if they considered it to be a universal, value-free endeavor. The students' responses provided initial insights into their pre-existing perceptions of NOS.

The second data set consisted of my reflection notes taken after each class. These notes were aimed at capturing my observations on the students' engagement and reactions during the discussions and noting any spontaneous debates that arose. This reflexive practice was critical in adapting and refining the lesson plans to better address student misconceptions and deepen their understanding of science's nature. The third data set encompassed the responses to structured prompt questions following group case studies. These case studies were

designed to challenge the students' thinking and provoke discussions that highlighted the influence of societal and cultural contexts on scientific endeavors. Analyzing these responses allowed for a deeper understanding of how students collaboratively negotiate and construct their views on science. The final data set was collected from the final exam, which revisited the same question posed at the midterm to assess any shifts in students' perceptions following the intervention. Like the baseline assessment, this was a short essay question, and responses were again categorized and thematically analyzed.

In both the baseline and final assessments, students' essays were first categorized into three distinct groups: those viewing science as 'Influenced by Value,' 'Universal,' or 'Both.' Subsequent thematic analysis involved a reiterative process to identify and group common themes across the responses, ensuring comprehensive theme saturation; it entailed repeated readings of the responses to refine themes and confirm that no new distinct themes emerged. This process was vital for capturing the complexity and nuances of students' understanding of science as influenced by cultural and social contexts. The data derived from the assessments were synthesized and summarized in Tables 1 and 2, which serve as the foundation for the discussion presented in the subsequent 'Results' and 'Discussion' sections of this paper.

Results

Initial Assessment

Recognizing that science is not conducted in isolation but is a part of the broader social and cultural fabric, the initial assessment of the students enrolled in the course before the intervention provided insights into their understanding of NOS. Forty-two students took the midterm exam; however, three did not address the NOS assessment question. As shown in Table 1., among the 39 students who addressed the NOS assessment question, 23 (or 59%) adequately indicated the embeddedness of social and cultural aspects in interpreting and generating scientific knowledge. These students showed a clear understanding that scientific endeavors are influenced by the societal and cultural environment in which they occur. They recognized that science is not a purely objective and detached enterprise but is shaped by the values, beliefs, and priorities of the society in which it is practiced. This perspective aligns well with contemporary views on NOS, emphasizing its inherent subjectivity and the impact of external factors on scientific inquiry. In order to more easily identify this category in the

remainder of this paper, I will refer to it as The Endorsers.

Table 1. Initial Assessment – categories and Themes Frequency

Category	Frequency	Themes	Frequency
Students who believe that Science is influenced by cultural and societal values (The Endorsers).	23 (59%)	Priorities and Trends	11
		Human endeavor	8
		Government-driven	4
		Roots	3
Students who believe that science is Universal (The Skeptic).	7 (18%)	Ambiguity	6
		Objective	1
Students who believe that science is Universal but is also influenced by values (The Concurrent)	9 (23%)	Ambiguity	9
Total	39 (100%)		42*

* Students' responses could be classified in more than one theme.

Nine students (23% of the answers) were quite tentative in their responses, stating that science is universal but is also influenced by the social and cultural context in which scientists are educated, work, and live. These students acknowledged the universality of scientific principles and methods but also recognized the contextual influences that shape scientific practice. Their responses reflect an intermediate understanding, highlighting the tension between the objective nature of scientific knowledge and the subjective influences of societal and cultural factors. This category will be identified as The Concurrent.

Seven students (18% of the responses) were straightforward in writing that science is universal. However, interestingly, all of them indicated an awareness that the context does have some influence, suggesting that science may not be completely "value-free." This group of students demonstrated an understanding that, while scientific knowledge aims to be objective and universally applicable, it cannot entirely escape the influence of the social and cultural milieu. Their recognition of this nuance reflects a sophisticated grasp of the

complexities involved in scientific inquiry. From now on, The Skeptic.

The ambiguity observed, particularly among the students who indicated that science is universal yet influenced by societal values, did not come as a surprise, given the business management human behavioral background and the student's distance from the STEM courses. However, the frequency of this ambiguity was surprising. Out of the 16 students in these two categories, 15 exhibited this ambiguous stance, with only one student defending the pure "universal" aspect by arguing that scientific inquiry ensures rigor and consistency, making science "value-free."

In contrast, in the category of students who adequately indicated that science is affected by social and cultural values, The Endorsers presented diverse themes to justify their position. They argued that science is embedded with social and cultural values because (a) science is a human endeavor and is, therefore, subject to human biases; (b) scientific research may be driven by government grants and incentives; (c) societal priorities can shape research agendas, leading scientists to focus on trendy topics; (d) of the bandwagon effect that influences the direction of scientific inquiry; and lastly (e) cultural roots leave an irrefutable mark on scientific practices.

The themes findings reveal the spectrum of understanding among students regarding NOS. Moreover, the recognition of social and cultural embeddedness among a significant portion of students is encouraging, indicating a majority awareness of the contextual nature of scientific knowledge. Notwithstanding the persistent ambiguity, the adherence to a somehow "value-free" view of science among The Skeptic and The Uncommitted categories highlights the need for continued emphasis on teaching the embeddedness of science with society and culture in the intervention activities.

Second Assessment

Following the intervention, the final assessment of the students in the international business course provided additional insights into their evolving understanding of the Nature of Science. Forty students took the final exam, two fewer than the previous assessment. Notably, eight students did not address the NOS assessment question, a substantial increase compared to the earlier assessment. From these ten students, compared to the initial

assessment, five were from The Endorsers category, one from The Concurrent, three from The Skeptic, and one never addressed the question.

Table 2. Final Assessment – categories and Themes Frequency

Category	Frequency	Themes	Frequency
Students who believe that Science is influenced by cultural and societal values (The Endorsers).	26 (81%)	Priorities and Trends	15
		Human endeavor	8
		Bias	6
		Funding	3
		Roots	2
Students who believe that science is Universal (The Skeptic).	4 (13%)	Ambiguity	2
		Objective	2
Students who believe that science is Universal but is also influenced by values (The Concurrent)	2 (6%)	Ambiguity	2
Total	32 (100%)		40*

* Students' responses could be classified in more than one theme.

Of the 32 students who addressed the NOS assessment question, 26 adequately indicated the embeddedness of social and cultural aspects in interpreting and generating scientific knowledge. Interestingly, only two students were still tentative in their responses, stating that science is universal but also influenced by the social and cultural context in which scientists are educated, work, and live, substantially decreasing the number of students in The Concurrent category. Four students answered that they believe science is universal, which is also a substantial decrease in the number of students in The Skeptic category. However, this time, only two exhibited the ambiguity seen in the previous assessment, while the other two were inadequately convinced that science is entirely value-free.

Discussion

In the initial assessment, before implementing any planned interventions, the student

responses portrayed quite well their pre-existing knowledge regarding the social and cultural embeddedness of science. These responses were categorized into three groups: The Endorsers, The Skeptic, and The Concurrent. Six themes across the three categories were identified, each illustrating different perspectives on NOS.

Most students, categorized as The Endorser, were clustered in the Priorities and Trends theme based on the way they explained the social and cultural embeddedness of science. This prevalent theme demonstrated the student's awareness of the direct correlation between societal priorities and resource allocation in scientific research in their responses, with students like Luca noting, "If we look at the things our society views as important, there is a direct correlation between what/how much resources are being put towards that. Cancer affects almost everyone. Much money, time, and resources are researched to find a cure. (Moreover), each culture views the world differently, focusing on what they believe is more important." Luca pointed out that prevalent issues like cancer, which touch almost every community, receive substantial attention and funding. This observation supports the notion that scientific research does not occur in a vacuum but is deeply influenced by the cultural and societal context. Leonor further expanded on this by suggesting that the questions scientists ask, and the research priorities they set are heavily inspired by current social issues, reflecting the dynamic nature of science as it responds to societal needs; she wrote, "The questions we ask and the thoughts in our heads are motivated and inspired by our surroundings, which consist of our culture and society. Topic priorities can easily be changed based on current social issues; therefore, I do believe that science reflects that."

Another significant theme among The Endorsers was "Human Endeavor," which highlighted the personal aspects of scientific work. This theme underscores the idea that scientists, as individuals, are products of their environments, which shape their interests and the interpretation of their findings. Responses from students like Alvaro and Isabella emphasized that personal and cultural backgrounds profoundly influence how scientists perceive and process scientific data. Alvaro stated, "... individuals are embedded in particular society or culture, (which) affect the way they interpret scientific information," also supported by Isabella, "...scientists decide to study and how they interpret their findings." Leonor's insight that scientists are fundamentally human, with their unique biases and perspectives, further solidified this point, illustrating the subjective elements that inevitably permeate scientific endeavors; as she described, "Ultimately, scientists—those making discoveries, asking

questions, and conducting research—are all humans."

The theme of "Government-driven" influences revealed another layer of complexity, highlighting how government policies and funding priorities steer scientific research. Mario's response was particularly revealing; he compared the influence of different political systems (a topic previously studied in the semester in the context of trading systems and barriers) shaping scientific priorities and practices in these countries; he wrote, "The government uses the information it has for the good of the people. Policies are constantly made to affect people, businesses, and consumers. The USA has a capitalist view, so it will make decisions based on those social and cultural values. China, on the other hand, is a communist country, so it will make decisions based on that ideology."

Lastly, the theme of "Cultural Roots" was explored through responses like that of Beatriz, who discussed how cultural values toward advances and types of medical treatment influence scientific research and practice. Her example of a partner who favors holistic approaches over Western medicine due to cultural beliefs underscored the profound impact of cultural upbringing on scientific practice, "A culture that values material progress will invest more resources and money in scientific research. Scientists and their discoveries are heavily influenced by the culture they practice and were raised in. As an example, my partner (an Asian descendant) who believes in a holistic approach to health (he) invests more in alternative therapies rather than in Western medicine."

These themes collectively illustrate that the initial understanding among students acknowledged the complex interplay between science and the social, cultural, and political environment. However, I was pleased to see the connection some of the students made to economic sciences in a more specific way. Pablo wrote, "In the case of business science, external factors can affect it, such as politics, religion, and cultural norms. For example, a country may have an independent business philosophy in which importing products is a bad thing because it hurts domestic businesses, so policies are towards protectionism. If circumstances change, though, the same country can reverse policies towards free trading (no tariffs) and prioritize consumers." This is a clear connection from previous classes where the society (in this case, the government) creates policies that produce economic shocks or substantial changes that interfere with the trading patterns, debunking theoretical economic prognostics. Another good example came from Florent, who stated, "...economics may help

us understand monetary (and financial) implications; however, in its basic sense, economics is (a social science) the study of human behavior and (and in this case) how humans react to changes in prices, changing preferences, etc. As we all know, human behavior is often affected by our surroundings and the environment we grew up in. Thus, economics is influenced by social and cultural values that affect how humans make monetary decisions.” It was particularly interesting (and rewarding) to see the student’s effort to connect the natural and social sciences in their arguments.

This recognition of the complexities inherent in scientific knowledge informed by social and cultural contexts set the stage for subsequent interventions, which were designed to deepen and refine students’ understanding through explicit and reflective teaching approaches. In the week following the initial assessment, our focus shifted to the study of foreign exchange rates and market fundamentals—a topic that has long presented challenges in economic research. Despite decades of sophisticated econometric modeling aimed at forecasting future exchange rate values and movements, empirical results have often been inconsistent. It is important to note that the prevalent notion of expectation dispersion among market participants contradicts traditional exchange rate analyses, which presuppose rational and homogeneous expectations (Taylor, 1995). Furthermore, macroeconomic fundamentals alone are insufficient for predicting short-term market movements, as psychological factors significantly influence traders' expectations of future exchange rates (Hill, 2023, p.311). This realization led to an exploration of the bandwagon effect, where market agents collectively move in a specific direction, often driven by speculative motives. As this effect intensifies, it becomes a self-fulfilling prophecy, with the market moving as anticipated by investors. This phenomenon, among other concepts discussed during the week, was explicitly tied to the cultural and social aspects of NOS, as outlined in the lesson plan provided in Annex A (Lesson Plan: Foreign Exchange Rate and Markets).

In the first intervention, three classes were adapted to address the knowledge gaps informed by the initial assessment, as detailed in Annex A. During this period, two case study activities were implemented, incorporating question prompts designed to guide student discussions on how societal influences affect empirical work and theoretical application in economics. These discussions particularly focused on the bandwagon effect and other psychological factors that impact the prediction of future foreign exchange rate movements and, consequently, business risk management. One case study examined how the American conglomerate 3M managed its

foreign exchange risks. A critical question posed to the students was, “Can foreign exchange rate bets go wrong?” This question aimed to connect the discussion to scientific knowledge’s societal and cultural embeddedness, encouraging students to recognize and articulate the role of these influences. All ten groups engaged with the question affirmed the potential for errors in foreign exchange forecasting, with six groups explicitly citing the bandwagon effect in their analyses. For example, Group A (Angela and Caterina) noted, “Forecasting future exchange rates is extremely difficult and can mislead currency bets due to psychological factors and the bandwagon effect, leading to financial issues. Similarly, government policies can lead to forecasting errors.” Another group, Group D (Bianca, Julius, Mateo, and Ruben), elaborated further, stating, “Interest rate forecasting, modeling issues, monetary policies, and the bandwagon effect—all examples of social and cultural embeddedness in science—can affect currency bets.”

The second case study in the intervention examined the impacts of quantitative easing, inflation, and the fluctuating value of the U.S. dollar. This scenario provided students with a practical example of how market dynamics are influenced by collective behaviors, such as the bandwagon effect, which can drive spot rates and affect short- to medium-term spot forex in unpredictable directions. Similar to the initial case, this study was designed to encourage students to recognize and articulate the influence of societal and cultural factors—specifically, the prevailing mood towards risk—on economic theories and models. Eight of the eleven groups successfully connected these economic phenomena to the broader cultural and social embeddedness of scientific knowledge, meeting the expectations set for this exercise. This discussion was particularly illustrative of the intersection between natural and economic sciences, as both disciplines often deal with the interpretation of complex and dynamic systems where human behavior and societal influences play critical roles. By examining how economic agents’ expectations and behaviors can shape market outcomes in ways similar to how scientific inquiry is guided by cultural and societal contexts, students could appreciate the pervasive nature of these influences across scientific disciplines. This provided a valuable opportunity to explicitly connect and reinforce the themes of cultural and social embeddedness of NOS and trading, thereby enriching our understanding of how these factors influence natural and economic sciences.

Following the intervention explained above, the semester continued for another three weeks when the final exam was implemented. With the final exam, I repeated the question on social

and cultural aspects of NOS to measure progress as reported in the Results section above as the final assessment. It is important to note that the NOS question was implemented as an optional bonus-point question in both the initial and final assessments. I believe this was a better approach in order to have a more spontaneous response. It is also important to note that in the initial assessment, the question was graded, but I offered little to no explanation to avoid skewing the answers in the final assessment.

The final assessment came with changes in the themes for The Endorsers. The Government-driven theme disappeared, and overall, a new Funding theme emerged as mentioned by José: “Scientists and researchers need funding to live, provide for their families, and conduct their research. This funding does not come from non-biased sources. This funding comes from governments and the richest people in the world who have an interest in having more power and influence on the lives of the rest of us.” Along the same lines, Duarte wrote, “Scientific research often depends on funding from governments, private institutions, or corporations. The allocation of funding reflects societal priorities, which can be influenced by political, economic, and cultural factors. For example, research into medical treatments may receive more funding in countries with aging populations, reflecting societal concerns about healthcare. The questions scientists choose to investigate are influenced by societal needs and interests. For instance, research into renewable energy technologies may receive more attention in regions facing environmental challenges or seeking energy independence.”

Bias was another theme emerging in The Endorsers category. An interesting pattern was observed in this theme, with almost all students departing from the previously reflected Human Endeavor theme. Leonor (mentioned before in the initial assessment) wrote, “I do believe that science is infused with social and cultural values. Although some take it as fact, which certainly has aspects of it, it can have a tendency to be biased. For example, women could not get an education until a few decades ago, so much of what is known to science is through a male lens, especially in psychology. For example, there are studies that show ADHD in men, but ADHD in women is actually quite different, so women are diagnosed much later than men.” Isabella (also cited previously) stated, “Furthermore, the underrepresentation of both women and minorities in scientific studies has led to a bias in the understanding of both health and diseases, which highlights the influence of societal values on scientific investigation. Additionally, ethical standards in research, which vary across and depending on cultures, shape the conduct and application of science, as seen in the debates

around stem cell research and/or genetic engineering.”

In the case of the other categories, The Skeptic and The Concurrent, there were no changes in themes but in the frequency with which they appeared. Analyzing the themes across all three categories, a new theme labeled “Objective” emerged with two students, both from The Skeptic category. This suggests that despite efforts to emphasize the embeddedness of science in social and cultural contexts, a small subset of students remains convinced of the universal and objective nature of scientific knowledge, an ongoing challenge in addressing deeply ingrained perceptions about the nature of scientific inquiry. The Ambiguity theme persisted but was reduced to only four instances from The Skeptic and The Concurrent, which is progress in the right direction.

Talking about progress, despite a small apparent increase of only three students in The Endorsers category, it is worth noting that the three students are a net number. Let me explain it. In the initial assessment, there were 23 students who responded that science is influenced by social and cultural values. However, in the final exam, out of the 23 initial assessment respondents, one did not take the exam, four did not answer the question, three converted from The Skeptic category, another 3 converted from The Concurrent category, and finally, two addressed the question for the first time. We will never know what the five missing responses would be, and we must not speculate, but it is remarkable that six students, or 37% of The Skeptic and The Concurrent categories, got converted to The Endorsers category. This is also progressing in the right direction, incontestably.

An observation, and not with some disappointment, though, was the absence of reference in the Endorsement category responses of the economic sciences examples. At least, it might be fair to say that the references were not as obvious as they were in the initial assessment. This is intriguing because, within the explicit approach to teaching society and cultural influence in science, it was always in the context of economic science narrowed to trading and risk management. A reflection on that point led me to think that the question was consciously focused on natural sciences, and the students, more thoughtful about NOS, responded to it accordingly, referring to culture and societal influence at large. The decision to conveniently adopt a well-validated question, as discussed in the background section of this paper, had the assumption that I could establish the bridge from natural to social sciences easily. I may still have done it; I just did not ask for it in the final assessment.

The validity of the inquiry instrument—central to addressing the first research question—merits attention, particularly given the intention of bridging theoretical constructs from natural science to economic science. Validity, in this context, refers to the degree to which an instrument accurately measures what it is intended to measure (Creswell & Gutterman, 2019, p. 159). For our purposes, this involves assessing whether the responses to our instrument genuinely reflect students' understanding of the social and cultural embeddedness in science knowledge and inquiry. The validity of an assessment is extensively defined in quantitative designs, but the principles equally apply to qualitative designs (Leedy & Ormrod, 2018, p. 104). However, it is recommended that qualitative researchers engage in procedures such as triangulating among different data sources (assuming that the investigator collects more than one) and writing detailed and thick descriptions as effective strategies to enhance validity in qualitative designs (Creswell & Poth, 2016). In the context of this action research, there is another layer of complexity that is the bridging of distinct academic disciplines—each with its own conceptual frameworks and terminologies. Other procedures, such as peer audits and external audits, could have helped to improve the instrument (the question validity in this case), but they are more time-consuming.

Adding to the challenge above and addressing research question number two, coordinating peer collaboration can be logistically challenging, especially in academic settings where faculty schedules and commitments vary significantly. This research could benefit from longitudinal studies that provide more robust data but also complicate the logistics of data collection, analysis, and interpretation across multiple semesters. Something to be considered in the future is triangulation not only between assessments and the instructor's reflection notes but also extending it to peers, structured one-to-one interviews with facilitators other than the instructor, and focus groups with students.

Bridging concepts from natural and economic science involves aligning different paradigms and vocabularies, with the potential to create confusion among students, which requires additional time for explanation and discussion to ensure that students accurately understand and correctly apply the principles from one field to another. Tailoring instruction was also needed to accommodate the differences among students' cognitive processes without slowing down the progress of the class or overwhelming less prepared students. Lastly, implementing explicit and reflective teaching methods that effectively convey the study's concepts required to adapt or overhaul my usual teaching strategies. It required commitment and discipline to

reflect and document the circumstances and implementation of each class, a best practice anyway, but a formality that adds pressure to an already exiguous time.

Conclusion and Recommendations

This action research study examined the influence of social and cultural embeddedness on business students' understanding of international trading patterns. By employing a qualitative approach within an educational setting, the study aimed to enhance student comprehension of how deeply ingrained social norms and cultural values shape natural and economic scientific knowledge. The interventions, which included explicit and reflective teaching practices, were designed to address key economic concepts around foreign exchange rates and their market dynamics, emphasizing the role of societal conditions such as psychological effects (market mood) and the bandwagon effect in determining short- and medium-term exchange rate forecasting.

The results of this study indicate a positive shift in students' perceptions of the nature of science (NOS), moving from a naïve to a more accurate view of NOS that acknowledges its social and cultural dimensions. This shift was particularly evident in the changes in the frequency of the expected adequate responses and the more focused themes revealed in the answers between the initial and final assessments. The study's findings underscore the importance of integrating explicit discussions of the social and cultural aspects of science into the curriculum to enhance students' overall scientific literacy and economic understanding. Forming students with improved awareness of what influences scientific inquiry and the impact on scientific knowledge aids in bridging the gap between theoretical knowledge and practical application. Hopefully, it also prepares students to navigate and manage the complexities of international business environments more effectively.

The final assessment after the intervention revealed a notable shift in students' understanding of the social and cultural influence of scientific knowledge. The increased recognition of social and cultural embeddedness, coupled with the emergence of new (more specific) themes, underscores the positive impact of the intervention. However, the persistence of certain views, such as the value-free perspective of science, indicates areas that require continued emphasis and exploration in future educational efforts.

Ensuring the validity of the inquiry instrument and the data collection is at the core of the research process, adding to the overall quality and strength of the findings. Instructor-researchers should consider extending the research timeline eventually across multiple consecutive semesters, allowing more time for the iterative development, testing, and refinement of data collection and analysis. Furthermore, it facilitates gathering longitudinal data, enhancing the robustness of the conclusions drawn from the research and significantly improving the instructor learning curve to find what works best in this specific interdisciplinary context.

In conclusion, the research highlights the need for ongoing emphasis on the embeddedness of science within society and culture, particularly in educational strategies aimed at developing a scientifically literate and culturally competent workforce. Future educational efforts should continue to explore and expand upon the strategies tested in this study, potentially incorporating more diverse case studies and comparative analyses across different cultural contexts to further enrich student learning and engagement. This research contributes valuable insights into the pedagogical approaches that can enhance the learning outcomes of business students by deeply integrating the cultural and social aspects of scientific understanding into the teaching of international business and economics.

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Appendix A – Lesson Plan: Foreign Exchange Rate and Markets

Course: International Business Environment

Term: Spring 2024. All Sections. The section meets twice a week.

Week/Module: 11. Foreign Exchange Market, Theories, and Forecast Influencers. March 26 & 28

Learning Objectives

1. Foreign Exchange (Forex) rate definitions and markets
2. Forex components, theories, and forecasting limitations
3. Business management and Forex risk (transaction, translation and economic)

Requirements

- Read the textbook chapter 11.
- Complete the Smart Book assignment.

Class 1. Duration: 75’.

Activity	Notes/Reminders:
<p>Concepts review. (20-30’)</p> <p>Work with the students to fill in the blanks on the whiteboard schema.</p> <p>Exercise (individually) on questions 1 and 2 (page 319) to help consolidate the forecasting concepts.</p>	<p>Review typical misconceptions and ensure clarification.</p>
<p>Class Activity (15’)</p> <p>Breakdown in the predefined task force teams. Address textbook question 4 (maybe 5 if time allows).</p> <p>Class Activity (15’)</p> <p>Country Focus case (page 309) – Quantitative Easing Inflation and the Value of the U.S.</p>	<p>Focus: Question 4 on Transactional risk and question 5: Economic/translation risks.</p> <p>The case focuses on government official monetary policy decisions. Critics'</p>

<p>Dollar.</p> <p>Class prompt on forecast influencers, emphasizing economic and Social/cultural embedded aspects (bandwagon and psychological factors).</p>	<p>expectations from a non-orthodox decision and the impact of the decision are observed later, reflecting the psychological aspect of the market agents in the policy's outcome.</p>
<p>Class Discussion (15 minutes)</p> <p>Open up for class discussion on the findings from the case.</p> <p>Closing on Forex Markets influencers.</p>	<p>Introduce and explain the cultural and social embeddedness aspect of the NOS concept, leveraging the construct to create a parallel that can explain the societal influence on FOREX forecasting.</p> <p>In my observation, this is a common oversight among students who view FOREX as a mathematical modeling exercise.</p>
<p>Individual Homework Assignment</p> <p>Review class notes and check for concept understanding.</p> <p>Read the Case on page 650 in preparation for class 2.</p> <p>Research on G20 group.</p>	

Class 2. Duration: 75'.

Activity	Notes/Reminders:
<p>Concepts review. (5')</p> <p>Project “whiteboard schema” as a reminder.</p>	
<p>Research Presentation (15')</p> <p>G20 research and presentation by the task</p>	<p>Connect the institution's mission and goals to globalization and trading, its influence in</p>

force designated in the syllabus/schedule.	geopolitics and economic development, and its position on trading barriers.
<p>Case Debrief (30')</p> <p>Groups to debrief on the integrative case (page 650) – How does 3M manage currency worldwide?</p> <p>Question Prompts for group discussion:</p> <ol style="list-style-type: none"> 1. What type of forex risks is 3M exposed to? 2. What will be the impact on the Income Statement if the U.S. Dollar keeps appreciating against the other currencies? What can be done to minimize the impact? 3. What happens if the currency bets go wrong? Explain. 	<p>Introduce the company profile. Debrief on the problem/situation presented in the case.</p> <p>Connect with the class #1 topics.</p>
<p>Class Activity (25')</p> <p>Teams report on the findings and reactions to the prompt question. Wrap up week activities and learning objectives.</p>	<p>Forex risk management and influencers.</p> <p>Influence of the social and cultural aspects embeddedness determining and managing Forex risk.</p>

Post Class Reflection – Class 1 (Tuesday, March 26)

At the beginning of the class, I faced challenges getting students to engage in developing the main concepts summary (schema) on the whiteboard. It was a slow start, as students struggled to actively participate in this foundational activity.

However, as the class progressed, engagement improved significantly during the inquiry process. Students began to grasp the intuitive aspects of appreciation, depreciation, purchasing power parity, interest rates, and inflation components in exchange rate estimation. The class dynamic shifted when we transitioned to bringing formulas to the whiteboard, reflecting a noticeable change in mood. We delved into short-term and long-term estimations

and discussed the implications of the “bandwagon” effect and how the market agents, such as the government, investors, and traders, affect the determination of foreign currency value (and forecasting) While students showed a good grasp of the intuitive concepts, frustration surfaced when they realized these theories often get debunked in the short term—welcome to the complexities of real-world economics!

Given the situation, I decided to allocate more class time to thoroughly work through the conceptual/mathematical exercises at the sacrifice of the Country Focus case analysis. The case was introduced and moved to an off-class activity to be reviewed the following Tuesday. A 15-question test was prepared to further train on the concept-to-math themes, which were to be revisited the following Tuesday as well.

Post Class Reflection – Class 2 (Thursday, March 28)

The group presentation on the G20 went well, as expected. However, I must continue emphasizing the importance of focusing less on background information and more on current news related to course topics such as free trade agreements and tariffs.

The 3M case study was an excellent example of exploring FOREX risks, including transaction, translation, and economic risks. It proved to be very effective, and I plan to keep it for the next semester with a more focused question on the different types of risks.

The connection between culture and the social embeddedness in scientific knowledge was then addressed. Students explored this with an emphasis on the bandwagon effect, highlighting the complex interplay between cultural factors and economic behaviors.

Post Class Reflection – (Extra) Class 3 (Tuesday, April 2nd)

In this extra class, a decision made on the prior Tuesday aimed to wrap the forex concepts, revisiting the 15-question test prepared to further train on the concept-to-math themes and the remaining case Country Focus: Quantitative easing, Inflation, and the U.S. Dollar value.

Overall, it was a good investment of time, allowing students to focus on the main missing points from the test. The class discussion on the case was also productive, and after the

discussion, I published a solution I had prepared emphasizing the main points, especially the one regarding market agents' expectations and the influence of the cultural and social aspects in determining FOREX.

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Chapter 14 - The Effect of Inquiry-based Learning on Content Mastery and Understanding of NOS Concepts in a Secondary Chemistry Classroom

Daniel Evans 

Chapter Highlights

- Traditional instructional methods were found to correlate with higher levels of student understanding.
- Instructional method was not found to have a statistically significant impact on student confidence scores.
- On qualitative surveys students displayed a conceptual understanding of various NOS concepts.
- Inquiry-based instruction was associated with many essential behaviors associated with NOS education. Student behaviors include critical thinking, problem solving, collaboration, and communication with peers.

Introduction

In today's classrooms, educators are constantly searching for methods to engage students in learning to deepen their understanding of the material. Traditionally, lecture-based instructional methods have been used in classrooms to pass along knowledge to students (Areepattamannil et al., 2020). However, recent trends in education have suggested that student-centered lessons show increased content proficiency and engagement from the student's point of view (Buchanan et al., 2016). One such method is known as inquiry-based learning (IBL). This instructional strategy is designed to engage students in lessons that replicate authentic science experiences. Inquiry-based learning is a key component of nature of science (NOS) education. By participating in NOS education, students will develop their scientific literacy through collaboration, peer learning, and group discussions (Widowati et al., 2017). These skills are essential for participating in the global science community.

The purpose of this research is to explore the role of inquiry-based learning in a secondary science classroom, specifically examining its relationship with student understanding of content. Within the secondary classroom, the instructor utilized inquiry-based instructional methods and lecture-based instructional methods to compare mastery of science concepts based on which instructional methods were used. Additionally, students will be assessed on their confidence in answering questions relating to the material to see if alternative methods of instruction affect their confidence in their answering ability. The following research questions were explored: *How does integrating IBL lessons affect student confidence and mastery of scientific concepts compared to lecture-based instruction? How does implementing IBL lessons affect student understanding of nature of science (NOS) education?*

Literature Review

Traditionally, science classrooms have focused on content-based instruction rather than inquiry-based instruction (Bybee, 2018). The content-based approach emphasizes the importance of understanding well-established facts and figures. The traditional approach treats science as a fixed body of knowledge, when in reality it is a constantly revising body of principles. With this traditional approach, educators guide the learning experiences based on their own interests, desires, and understandings. This teacher-focus method of instruction leads to a very passive learning environment where some students may struggle to succeed. It

served a singular purpose: to act as a method of delivering information from an expert to the inexperienced. However, it was not long before the norm of this traditional classroom was challenged. John Dewey was a prominent educational reformer during his time. His writings established the constructivist point of view for educational reform. Dewey thought that education should focus on building experiential learning opportunities that mimic real life applications of the content (Ord, 2012). This approach is to be guided by the students' context and interests. Although some educators at this time did not share the same point of view as Dewey, others began to experiment by implementing these practices in their own classrooms. It was not long before researchers had evidence supporting Dewey's claims of education reform.

This shift towards a student-centered learning environment aligned with the ideals behind inquiry-based learning. IBL creates learning experiences that are designed to replicate real world scientific inquiry. These learning experiences allow students to explore the scientific concepts at a deeper level (Areepattamannil et al., 2020). This is due to students being able to develop their understanding from their own experiences. Integrating these strategies allows students to gain vital skills such as problem solving, critical thinking, collaboration, and resilience (Öztürk et al., 2022). These skills are essential tools to be successful in the 21st century workplace. Bybee (2020) outlines how these skills are naturally developed through the nature of science (NOS) education. Fortunately, the principles outlined through NOS education are prioritized by IBL. Widowati et al. (2017) found that when integrating IBL into NOS education, students were able to develop their scientific literacy more effectively than with either method independently.

Researchers have found that despite its many benefits to student outcomes, many educators struggle to incorporate IBL lessons into their classrooms. IBL requires training to proficiently incorporate these strategies into a classroom. Many educators have shown hesitation to implementing these types of lessons due to the lack of familiarity from their prior training (Wahbeh & Abd-El-Khalick, 2014). Additionally, researchers have found that even when educators do receive training (pre-service or in-service), unless they are attending training throughout their career, their effectiveness tends to wane as time goes on (Wahbeh & Abd-El-Khalick, 2014). Some school districts prefer traditional instructional methods as inquiry-based lessons tend to have larger time requirements. School districts receive funding based on standardized test scores. Due to the wide breadth of topics on these exams, many educators

are encouraged to implement traditional instruction to cover more topics before the exam.

Through IBL, learners are given a more engaging role in their education. The students' creativity and point of view will be expressed through their approach while they are working through their lessons (Öztürk et al., 2022). This approach emphasizes student-centered learning, which can be applied in STEM education to foster essential skills while allowing students to take an active role in directing the learning process. With a more active role, students develop a sense of autonomy and increased engagement in their own learning (Beck & Blumer, 2012). Many students engaging in IBL have a deeper understanding of the material and are more accurately able to describe their strengths and weaknesses (Güven, 2014). Students can use this information to participate in peer feedback/constructive criticism, as well as conference with their instructor about how to direct their learning experiences. Researchers have found that when students have this sense of autonomy, they have an increased confidence level regarding their knowledge and abilities (Wang et al., 2021).

By increasing the opportunities of IBL in the classroom, educators will notice trends of increasing engagement and self-confidence from year to year (Safitri & Widjajanti, 2019). Beck and Blumer (2012) found that the confidence level of students increased more when they were engaged in IBL for multiple years in a row. Students were also more likely to favor this method of instruction when their learning experiences had incorporated inquiry-based lessons in their prior classes. This should lead instructors to design opportunities of integrating this strategy into their curriculum.

When designing learning experiences, the educator must be mindful of their audience within the classroom. Gormally et al. (2009) found that the receptiveness to IBL depends partially on student interest in science as well as the number of science courses they have taken. These researchers incorporated an “all or nothing” approach where students were enrolled in a course where all lab-based activities were inquiry-based or none of the activities were inquiry based. The researchers found that students exposed to no inquiry-based activities rated the courses much higher than the students with inquiry-based lab activities. However, students that completed the course with the inquiry-based lab activities showed higher levels of appreciation for their own achievements in the course. These findings would suggest that the ideal learning situation would weave together these two methods to maximize the benefits of

each method while simultaneously minimizing their drawbacks.

Methods

Intervention

Student participants were selected from those enrolled in the author's chemistry classes. A total of 47 students were used to collect data for this study. For each of those classes, all data was collected within two units of instruction. Content within that unit was broken down into relevant standards. Each standard was categorized based on method of instruction. The methods of instruction that were included were inquiry-based instruction, traditional lecture-based instruction, or a mixture of instructional methods.

Data Collection

Data was collected from unit assessments throughout the units of instruction. On the relevant unit assessments, each question was linked to a particular standard. For example, the student would select their answer for the content question. After selecting this choice, the student would then select their confidence level in their answer choice for the content question. Student confidence was assessed on a five choice Likert scale ranging from "Confident", "Partially Confident", "Neither Confident or Unconfident", "Partially Unconfident", and "Unconfident". A teacher log was utilized by the instructor to document the instructional lessons and the student perceptions and performance during those lessons. Students were given select questions from the views on the nature of science (VNOS) questionnaire after instruction had taken place to gauge understanding of NOS principles. Only select questions were utilized from VNOS questionnaire due to relevance to the course being taught. Some questions felt that they were not adequately addressed in the chemistry course. To minimize the influence from external instruction or alternate classes, only the most relevant questions were asked and analyzed in this study. The following questions from the VNOS questionnaire were given to students on the survey. The survey questions were answered by students independently.

1. What is an experiment?
2. Does the development of scientific knowledge require experiments? Why or why not?
3. What is a theory?
4. After scientists have developed a scientific theory, does the theory ever change?

5. Scientists perform experiments and investigations when trying to find answers to the questions they put forth. Do scientists use creativity and imagination during their investigations? Why or why not? If yes, at which stages of the investigation?

Data Analysis

Results from the unit assessments were broken down by standard and instructional method, with this coding being done prior to data collection. After students have completed unit assessments, data was organized by correct and incorrect responses. Once those items were separated, they were linked with that individual student's confidence assessment for that particular question (i.e. the question was answered correctly and the student was unconfident in that answer choice). When all assessment items were separated and categorized, the researcher identified patterns and trends for each instructional method (inquiry-based instruction, traditional instruction, or mixed method). These data were analyzed to determine the type of correlation between instructional strategy and student achievement on the assessment, as well as the type of correlation between instructional strategy and student confidence in the material. The student results from the VNOS questionnaire were analyzed to determine the extent of student viewpoints developing due to the instruction taking place. The teacher's log was analyzed to determine how perceptive students were to certain instructional strategies and correlated with their understanding of the content.

Results

Results from two different summative assessments were collected and analyzed. First, each assessment question was coded based on the content assessed in each question. Based on the instructional strategies, each question was placed into one of the following coding categories: only traditional instruction, only inquiry-based instruction, or mixed methods instruction consisting of both traditional and inquiry-based instruction. Once separated by instructional method, student confidence scores were then linked to whether or not the individual question was answered correctly. This created six sub-groups of data, one for each instructional method divided into correct or incorrect answers.

Analyzing general descriptive statistics produced clear distinctions between the six groups. Each group will be referred to by their group number in subsequent descriptions.

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<i>Groups</i>	<i>Group Number</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Correct (Traditional)	1	963	3925	4.075804777	1.070131238
Incorrect (Traditional)	2	293	818	2.791808874	1.555823087
Correct (Mixed Method)	3	481	1956	4.066528067	0.8455647956
Incorrect (Mixed Method)	4	150	453	3.02	1.335167785
Correct (Inquiry)	5	120	474	3.95	0.8378151261
Incorrect (Inquiry)	6	59	180	3.050847458	1.4628872

Figure 1. Qualitative Analysis by Instructional Method and Correctness

First, a two-sample t-test was performed to determine if the difference found between correct-incorrect subgroups was significant for each instructional method. With an established alpha value (α) 0.05, each instructional method was found to have significantly different confidence values between correct-incorrect groups. This warranted further exploration to determine if the instructional methods produced a significant enough difference. To ensure fair comparison between groups, all correctly answered data was separated from the incorrectly answered data since correctness had already shown an influence on confidence scores.

With the correct answers sub-group (Groups 1, 3, and 5), a Shapiro-Wilk test was completed to determine if the sample of data followed a normal distribution. The results of this analysis indicate that all three sub-groups display normally distributed data. After completing the Shapiro-Wilk test, it was determined that Levene's test would be conducted. Levene's test is performed to determine if these samples of data had equal variances.. Levene's test indicated that for the correct answer sub-group, variances were not equal between groups. Based on these results, a Kruskal-Wallis test was performed to determine if the differences between groups were great enough to be considered statistically different from one another.

After performing the Kruskal-Wallis test, a p value of 0.0964 was calculated, indicating there was not significant evidence supporting the differences between these three sub-groups. With the incorrect answers sub-group (Groups 2, 4, and 6), an identical procedure was performed. The results of the Shapiro-Wilk test indicated that the traditional instructional sub-group was normally distributed, but the inquiry-based instruction and mixed methods instruction sub-group were not normally distributed. Levene's test indicated that the variances between the three groups were not equal. With the incorrect answer sub-group, the Kruskal-Wallis test indicated that there was not a significant difference between the instructional methods with a p value of 0.08407.

As the p value indicates, both the correct answer and incorrect answer sub-groups were approaching significance. It was hypothesized that combining these two sub-groups (correct answer and incorrect answer) may have a compounding impact on the differences between instructional methods. For this analysis, the only method of separation was based on instructional methods, regardless of correctness of answer. When the data is combined, the following descriptive statistics were produced.

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Traditional	1256	4743	3.776273885	1.477396782
Mixed Method	631	2409	3.817749604	1.158795563
Inquiry	179	654	3.653631285	1.216433369

Figure 2. Qualitative Analysis separated by Instructional Method

These groups were analyzed with the same procedure as the correctness sub-groups. A Shapiro-Wilk test indicates that the instructional method groups have normally distributed data. Additionally, Levene’s test indicated that these groups do not have equal variance. After performing the Kruskal-Wallis test, a p value of 0.1477 was obtained indicating that combining the sub-groups did not improve the significance of the data. This suggests that regardless of instructional type and correctness separation, that the data collected in this study did not indicate that it had a statistically significant impact on student mastery of the content standards.

While unable to establish the relationship between instruction method and student confidence, the data can be analyzed to determine if there is a correlation between instructional method and the likelihood of answering the question correctly. The data in Figure 3 indicates the number of occurrences of a correct or incorrect answer for each instructional method.

<i>Observed</i>	<i>Correct</i>	<i>Incorrect</i>	<i>Total</i>
Traditional	963	293	1256
Mixed-Method	481	150	631
Inquiry	121	59	180
Total	1565	502	2067

Figure 3. Chi-squared Analysis of Instructional Method

A Chi squared analysis was performed to determine if the observed frequencies were significantly different than the expected frequencies of occurrences. Upon completing the Chi squared test, a p value of 0.0204 was obtained indicating that the observed data was statistically different from the expected data. A set of odds ratios were calculated to quantify the differences between the instructional method as a follow-up to the Chi squared test. The odds ratios indicated that the traditional instructional method and mixed methods instructional method were nearly identical to one another. Traditional instructional methods were slightly favored over mixed methods instruction. Both of these methods also performed very similarly when compared to only inquiry-based instruction. Both traditional instructional methods and mixed methods instruction were more likely to produce correct answers when compared to only inquiry-based instruction, by a factor of 1.60 and 1.56 respectively. This suggests that the presence of traditional instructional methods provides an increase in content mastery. This is likely due to the exposure to traditional instructional methods in many previous science courses.

Student responses from the VNOS survey were collected via Canvas. An ungraded survey assignment was opened, which allowed students to craft whatever response they saw fit for the question. Surveys were completed in class independently. Once survey responses were submitted on Canvas, the results were exported into a Microsoft Excel spreadsheet. The spreadsheet was organized to remove extraneous information not relevant to this study. Finally, the content of the responses was analyzed and coded. These codes focused on core principles of NOS education such as advancement of knowledge being data driven, scientific actions and theories being flexible, and science is not completely objective in nature. Below is a table containing the themes identified from the survey questions. These themes were obtained by manually analyzing and coding the responses from the students. After each theme, the number of responses that correlated were identified with that theme is marked as the value in the parentheses. Each response may have been identified as matching more than one theme.

Survey Question	Thematic Analysis
#1	<ul style="list-style-type: none">• An experiment is a method to test a hypothesis (26)• It is focused on data collection (21)

	<ul style="list-style-type: none"> • Many responses integrated specific example from this course (11)
#2	<ul style="list-style-type: none"> • An experiment is crucial for validating knowledge (33) • It is a practical application of understanding scientific concepts (23)
#3	<ul style="list-style-type: none"> • A theory is an explanation of the natural world based on data (20) • It is subject to change as more data is collected (9) • A theory is a guess that scientists make (8)
#4	<ul style="list-style-type: none"> • A change in a theory represents advancement of scientific knowledge (26) • Adaptable to change with new information being collected (19)
#5	<ul style="list-style-type: none"> • Creativity is essential for the scientific process (31) • Creativity allows for scientists to attempt new procedures to gather new data (18)

Figure 4. Thematic Analysis of Survey Questions

Discussion

How does integrating IBL lessons affect student confidence and mastery of scientific concepts compared to lecture-based instruction? This research question was attempting to draw a correlation between increased mastery of content standards and inquiry-based instruction. Although the Chi squared test indicated that there was a difference in question accuracy between differing instructional methods, the methods that correlated with the highest level of accuracy included traditional instructional methods (only traditional instruction and mixed methods instruction) based on the odds ratios produced. The instructional methods that included inquiry-based instruction (mixed methods instruction and inquiry-based instruction) had the two lowest levels of accuracy indicating that inquiry-based instruction does not increase student mastery according to the data collected in this study. This may be due to the students' familiarity with the instructional strategy. Inquiry-based

instruction may not be an instructional method that all students have experienced in their previous science courses. Students in a high school setting are transitioning between the structure of elementary and middle school instruction and the flexibility of post-secondary instruction. Due to this, some students may not have built up the stamina to be successful in a less structured and directed learning environment.

Additionally, this research question searched for a correlation between instructional method and student confidence. The researcher was unable to establish a significant correlation between instructional method and student confidence level. Unsurprisingly, student confidence was significantly higher when the student correctly answered the questions. However, when analyzing the groups with and without separating the data based on correctness, the data did not display a significant difference from each other, only traditional instruction and mixed methods instruction received higher confidence scores. This may indicate that the presence of inquiry-based instruction may decrease student confidence as well as accuracy. This trend may be present due to the lack of exposure to a more extensive application of inquiry-based learning. Beck and Blumer (2012) found that when students were exposed to similar instructional methods across multiple semesters, it allowed student confidence to grow by larger margins. It would be expected that similar findings would be present when high school students are exposed to inquiry-based learning in science courses over multiple years in their academic career.

How does implementing IBL lessons affect student understanding of nature of science (NOS) education? This research question focused on the qualitative data collected from the survey results. It was aimed to determine what kind of understanding was present regarding the nature of science. For the questions included on the survey, many students exhibited a strong grasp on many concepts emphasized by NOS education. These responses emphasized the students' understanding of the dynamic nature of science. Additional themes identified focused on the data driven aspect of science, and the importance of experimentation for advancing the general body of scientific knowledge. This indicates that many of the students had a grasp on the essential concepts of NOS education. The most concerning theme developed from the third survey question, "What is a theory?". When analyzing the responses for this question, some students stated that they believed that a theory was just a hunch or an idea that a scientist had at that point in time. Some of the other responses for other survey questions indicated similar feelings, mostly from the same set of students. This indicates a

disconnect from how scientific knowledge is advanced, and that advancements do not need scientifically collected data for support.

This research question is designed to obtain the types of behavior associated with inquiry-based instruction. The data collected on student behavior during inquiry-based activities were favorable towards the kinds of actions associated with NOS education. The inquiry-based activities incorporated into the lessons were typically lab or experiment-based activities. The instructor provided a general overview of the activity prior to beginning the activity, but after that overview, students worked through the activity on their own. During these activities, students would frequently collaborate with one another, engage in discussion relating to critical thinking, and report their findings with appropriate tables and graphs. All of these skills are essential for the development of a deeper understanding of the nature of science. With traditional instruction, the activities utilized usually focused on problem solving relating to the topic being discussed with worksheets and articles to read. During work time for these activities, many students became disengaged from their work. Even with topics that were covered with a mixed methods approach, students seemed to struggle more with applying their knowledge, when compared to inquiry-based activities.

Conclusion

While inquiry-based instructional methods were not found to show a statistically significant correlation between its presence and student confidence or content mastery, it does not mean that there is no merit to the inclusion of inquiry-based instruction. With student responses, students will be more likely to feel confident in scenarios they are familiar with. In this course, the majority of the content standards taught were at least partially taught using traditional instructional methods. This familiarity would likely create a testing environment where students are more at ease, which may increase their accuracy and confidence (Ogundokun, 2011). The opposition may create a conflicting testing environment. Inquiry-based instruction is naturally more abstract and independent than traditional instruction. If students are less familiar with this kind of learning environment, it may create some dissonance in their test responses.

The qualitative data gathered during this investigation show that it had a positive impact on student understanding of various NOS concepts. While this data was collected near the end of

instruction in a high school chemistry class, the researcher cannot be completely sure that it was solely the instructional method that influenced the development of the students' views on NOS education. Ideally, the researcher would provide growth assessments periodically throughout the course. This would allow the researcher to determine how students' views on NOS education changed throughout the course. However, there is confidence that many of the students that participated in this study displayed behaviors and understanding that correlated with individuals developing their mastery of concepts related to NOS education. One could conclude that expanding upon these instructional strategies in future science courses would continue to show a positive impact on students' understanding of various NOS concepts.

Flaws with experimental design likely contributed to the confounding quantitative data collected. This study focused on data collection within a small sample of an entire course. The data analyzed was collected from a two-month time period over two distinct units within a high school chemistry course. Within that data collection window, there were no typical control groups to serve as a fair comparison. Future studies should explore this topic while remedying some of these flaws. Studies could focus on expanding the time frame of the research. Studying how these instructional methods affect student confidence over an entire school year would likely gather more significant data. Additionally, to properly gauge the impact of certain instructional strategies, the instructor should teach that specific course with only one specific type of instructional method covering all the same topics. This study allowed the teacher to teach each content in a manner that was most fit for that specific content. This means the researcher was unable to determine if the difference is due to the content rather than instructional method. Teaching all content under the same instructional method would be able to eliminate some of the bias associated with this analysis. If the same teacher was able to teach three sections of the same course (one using only traditional instructional methods, one using only inquiry-based instructional methods, and one using a mixed methods approach of instruction), the researcher would be able to draw a stronger correlation by minimizing confounding teaching biases. While there were limitations present in this study, it was still able to expand on the existing body of literature. The approach taken was designed to mimic the instructional strategies integrated in a typical classroom. Most educators will incorporate a variety of instructional strategies which allows the instructor to reach a more diverse audience. Utilizing only a single method of instruction would limit the potential growth of the students.

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Chapter 15 - Perceptions of Nature of Science, Including Social and Cultural Aspects of NOS, in At Risk High School Populations

David M. Gardner 

Chapter Highlights

- Nature of Science
- Special Needs Students
- At Risk Students
- Science Classroom
- High School Students
- Action Research.

Introduction

NOS is a critical component of scientific literacy. NOS enhances students' understandings of science concepts and enables them to make informed decisions about scientifically-based personal and societal issues. (*Nature of Science*, n.d.) Part of classroom culture means having central values, beliefs, and norms that guide scientific knowledge production. (Magnusson et al., 2007) The teacher in this research provides these ideas to the students through sharing of his own life experiences with science, interconnecting student life with science, and keeping a general atmosphere of trust and respect when it comes to behavior in the classroom and community. By providing the students with relatable, real-world examples, the teacher hopes to spark student interest in science.

The students included in the research for this paper provides a window into how diverse the challenges facing students in a suburban setting can be. Despite their classroom success, most of these students underperform on standardized testing of any kind. They also struggle to articulate their thoughts in essay and short answer questions. The VNOS-B form used for this research survey requires written answers to be effective in measuring the participants' understanding. One question that comes up is, "How do students without these struggles perform on the VNOS-B survey"?

So, what is at-risk and why do students are identified as at-risk struggle in science and math? The Organization for Economic Co-operation and Development (OECD) identified at risk as the major deprivation measures such as lower socio-economic status, ethnic minority status, speaking English as an additional language, immigrant status all having some common features which lead to (a) lack of positive attitudes towards school and learning and (b) less supportive environment (individual, family, neighborhood, or school) (OECD, 2016). OECD research examined the results of students, age 15, on science, math, and reading PISA. None of the participating countries achieved 100% proficiency on the PISA. Every student who struggled on the exam met at least one of the criteria for being at-risk for academic success. The concern of OECD is that these students will become underperformers in STEM related jobs which will ultimately harm the economic growth of their country (OECD, 2016).

The role of NOS should be to prepare underperforming students for STEM jobs by equipping them with better critical thinking and analytical skills. The result should be better preparation

for most career paths in the 21st century. Most jobs require technical skills of some kind, analytical skills, and the ability to think through a process logically and sequentially. This is the role NOS plays in science education. Improved and more explicit teaching of NOS should empower at-risk students to be more independent and successful with any college and career path.

The purpose of this study is to ask several questions about how teachers might better prepare students for STEM careers through NOS. 1) How do students traditionally considered to be at risk for graduating with the readiness for college or career paths interpret NOS? 2) Can a high school teacher effectively influence a student's NOS in a short time-frame through indirect instruction? 3) What factors might influence a student's NOS from their socio-cultural background?

What is nature of science? NOS includes some of the following aspects, (A) scientific knowledge is tentative, (B) science is empirically-based (derived from observation of the natural world), (C) subject to change based on new evidence, (D) partly based on human inference driven by imagination and creativity, (E) socially and culturally embedded, (F) distinguishes between theory and law, (G) distinguishes between observation and inference (McComas, 1998) (Lederman et al., 2002) (Council, 2012).

All eleven high school students surveyed have an English Language Learner (ELL), Individualized Learning Plan (IEP/504), considered an ethnic minority, or are free and reduced lunch qualified which is a socio-economic status (SES) indicator. Nearly all of these students are impacted by two or more of these factors. The results warrant further study and a need to improve NOS related instruction as a means of improving metacognition in all students. The survey data presented below does not show any significant improvement in student NOS. The growth versus diminished response changes from the pre to the post intervention survey are nearly equal for all seven of the VNOS-B questions presented. Yes, the teacher/researcher's approach could be improved. Time seems to have been a large factor. Only two weeks was allotted for the instructional time. The teacher used Socratic Method and laboratory experiences effectively but expecting these high school students to shift from a fixed to a growth mindset involving NOS in five or six hours appears to have been too much to ask of the students.

High school students appear to struggle more since the pandemic with NOS upon entering high school in the United States. Previous research suggests that critical thinking and metacognition skills are very low in many middle school through college level students because of monotonous learning processes causing student boredom and loss of focus when concentration is required (Dari & Ahmad, 2020). Essentially, rote memorization for the purpose of testing could be a key problem since it does not translate to an intellectually deeper, long-term skill. To break this routine teachers also need to acquire adequate NOS understanding if we are to achieve the goal of promoting scientific literacy. Such understanding will enable teachers to be able to help students develop fact based ideas about what science is (Herman et al., 2015).

Students who struggle during their K-12 career because of factors like IEP/ELL/SES are far more likely to fall behind economically as adults. Better NOS instruction from the start of education can prepare students to have the critical thinking and problem-solving skills they need to achieve better college and career readiness as they progress through high school. Improved employability skills improves an individual's socio-economic status. The factors in this research are only a few of multiple factors influencing student point-of-view on social-cultural issues. Improved understanding of NOS does not directly affect individuals' decisions. We should consider students' moral development, cognitive inference development, emotional beliefs, and other factors to integrate the teaching of social-cultural scientific issues (Bell & Lederman, 2003).

The population is described as at risk throughout the paper. The term at risk includes not only traditional SPED students but ELL, minorities, and SES challenged students. Few people with disabilities tend to pursue STEM degrees, and have a low rate of employment in STEM fields (Bonaccio et al., 2020). Research data shows gaps in the learning achievements between 4th and 8th grade White students and students of color - particularly Black and Hispanic - in science (Hussar et al., 2020). Therefore, all possible student populations present in the classroom were given the chance to participate regardless of being considered at risk by the school system or not. The eleven who choose to participate fall under one of the above at-risk identifiers. Special education research generally focuses on issues like students' socio-cultural background, race, ethnicity, national origin, language background and gender (Villanueva et al., 2012). This research endeavors to examine students of these backgrounds NOS understanding and critical thinking about NOS. Understanding the relationship between

student learning in at risk populations versus their personal background should allow teachers to be more effective with instruction. The goal is to provide better preparedness for these students for future college and career opportunities.

Context

The large, suburban high school used in this survey has a total population of nearly 1600 students with roughly 40% free or reduced lunch. The researcher is also the students science content instructor and new to the community, one that has a different SES makeup than the teachers previous community. The class surveyed is part of the integrated chemistry and physics course most sophomores, who are not prepared for chemistry, take. Only part of one of the three sections taught could be surveyed based on time constraints. The entire classroom benefited from the support of a dedicated special education instructor who helped ensure struggling students were getting additional support and testing support as needed.

Social Cultural Influence on Students by the Numbers				
IEP/504	Yes	No		
	8	3		
ELL	Hispanic	Hindi Dialect		
	2	1		
Socio-Economic Status	Free and Reduced - Yes	Free and Reduced - No		
	6	5		
Race	Hispanic American	Caucasian	African American	Indian American
	2	7	1	1
Sex	Male	Female		
	4	7		
Autism Spectrum Disorder	Male	Female		
	1	1		
Writing Sample Grade Level	Below 5th Grade	5th - 6th Grade	7th - 8th Grade	9th - 10th Grade
	1	2	4	4

The eleven students in this research are part of a larger classroom of twenty one. The eleven surveyed are the ones who obtained permission to participate from their parents and also agreed to have their data used. The class makeup is split twelve boys and nine girls. The free/reduced lunch status, (SES) identifier, is 52.4%. The IEP/504 percentage is 42.9%. The ELL/ENL percentage is 23.8%. This includes two different dialects of Spanish and one Sindhi native speaker, a sub dialect of Hindi. The measure of developing English language World-class Instructional Design and Assessment (WIDA score) for these students ranges from two to four. These scores are included with the analysis of responses for the corresponding student. Research on how students from other language cultures in English dominant classrooms learn science provides useful insight into the critical role that language proficiency, both in native and secondary languages, plays with respect to learning scientific discourse (Buxton & Lee, 2014).

Method

Intervention and Strategy

Students were given the following VNOS-Form B to write short answer responses to. They were instructed to write in complete sentences. Using as many sentences as necessary to express their thoughts and ideas. They were reminded to be thorough and detailed so the reader could understand their thoughts completely. They were also informed this would be the only opportunity they would get to share their personal knowledge and understanding as there would not be time for one-on-one interviews before the end of the semester.

Most of the 14 and 15-year-old students in the NOS survey presented below demonstrate a lack of science skills or the maturity to engage in meaningful discourse in science. Their only focus is always on getting the answer right. They have not been taught how to explore the how and why of a given issue. Why teach these skills through science? One reason is teachers not only enable students to learn scientific content but also *train students' basic skills and methods of thinking* through the process of scientific knowledge generation. (Wang et al., 2017)

Metacognition is the ability to think, which is related to the process of thinking about oneself. Empowering metacognition abilities not only makes students more reflective, but students can understand each individual's learning strategies (Jaleel & P, 2016). Many students seem

poorly prepared for using metacognition skills upon entering high school in the United States. The students in this research struggle to use critical thinking and problem-solving skills when answering word problems with three variables. Even when given a template to follow. It does not appear to be a content issue, but rather a lack of training during earlier education levels.

The students in this action research are a small subset of a larger group of sixty-seven students with similar problems that the teacher/researcher worked with. They are stuck in a concrete thinking mode. They learn the answer that gets them the grade. They avoid any work that requires actual thought processing effort.

VNOS–Form B

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?

(Lederman, 2002)

A pre-instruction survey was administered to allow the students to begin thinking about their own NOS conceptions. Students were given one hour to read, reflect, and answer the seven questions. The surveys were then sealed away so the teacher/researcher would conduct the instruction for the next two weeks blinded from the strengths and weaknesses in student knowledge.

The next two weeks involved roughly six and a half hours of contact time with the students. During this time the teacher/researcher engaged the students directly with a Socratic seminar

targeting two of the seven questions each day. Twenty minutes were allotted to the classroom being surveyed. The course content being taught was over forces and energy in physics. There are a total of six classes and two content teachers covering the material so there was little room for instructional deviation during this time.

Two hands-on projects were also conducted. This allowed students to work in pairs to apply critical thinking skills for problem solving to practical problems. The two projects were an egg basket drop and an oscillating car. During this time the teacher/research attempted to reinforce each student's understanding of NOS in small groups of two to four students. Direct questioning of NOS and subsequent relation to the project being completed were used during this time. This was done because some studies observe the traditional method of teaching interventions render students inactive and unmotivated towards engaging with the lesson which reduces academic achievement (Akkus et al., 2007).

The implicit approach to teaching the content was requested by the special education instructor in order to keep the students more active and likely to engage with the content. The implicit approach is one common way of teaching NOS. It is based on the idea that direct student engagement with science will help them understand NOS better. According to this approach, the process considers research-based activities and scientific process skills considered sufficient to teach the NOS concepts. (Kaya, 2011)

Mulvey also points out that reflective NOS instruction would be a class discussion about how scientific knowledge can change, with students providing examples of how their conclusions changed within an inquiry lesson and/or unit based on having more information or change in perspective (Mulvey et al., 2016). This approach is favored by the SPED instructor that supported the teacher/researcher in the classroom that was studied. Please note that research studying direct NOS instruction of this kind in at risk student populations is very limited.

Data Collection

At the end of the two weeks the students were given the VNOS-B tool again as a post intervention survey. The results were processed using a standard inadequate, adequate, or informed determinate. (Lederman, 2002). One area of concern is the post intervention survey which occurred at the end of the semester/school year. Were students interested and engaged

during the final survey? A question to measure the students level of interest was not asked. A post interview was not able to be conducted for this study because of time constraints and student access.

Data Analysis

Data analysis summed the results of inadequate, adequate, and informed for each question. This information was then compared to the respective tenet of each question for analysis. Percentage difference calculations ((part/whole) x 100) then (final minus initial percentages) were used to determine if there was any change between the pre and post intervention numbers and what that percentage might be.

Results

154 total questions were analyzed, 77 questions in the pre-intervention survey and 77 questions in the post intervention survey. Only 147 questions were successfully completed. 7 were left blank by one participant. Nearly every question yielded mixed results. No question yielded only positive growth and two questions produced only negative results. Performance was mostly consistent by tenant. This is suggestive of reading or vocabulary knowledge issues for some of the students instead of science comprehension.

Data by Tenet VNOS-B Response			
Changes Between Pre-Intervention and Post Intervention Surveys	Raw Value*	Raw Value*	Percentage Change*
	Pre- Intervention	Post Intervention	
Empirical Nature of Science			
- Inadequate	9	12	14.2%
- Adequate	9	8	-5.8%
- Informed	2	1	-33.3%
Inference and Theoretical Entities in Science			
- Inadequate	13	13	0.0%

Perceptions of Nature of Science, Including Social and Cultural Aspects of NOS, in At Risk High School Populations

- Adequate	8	8	0.0%
- Informed	1	1	0.0%
Nature of Scientific Theories			
- Inadequate	13	14	3.8%
- Adequate	5	5	0.0%
- Informed	1	1	0.0%
Scientific Theories vs. Laws			
- Inadequate	10	10	0.0%
- Adequate	11	10	-4.8%
- Informed	1	2	33.3%
Creativity in Science			
- Inadequate	12	14	7.6%
- Adequate	7	6	-7.6%
- Informed	1	1	0.0%
Subjectivity in Science			
- Inadequate	14	12	-7.6%
- Adequate	5	8	23.0%
- Informed	1	1	0.0%
Social and Cultural Influences in Science			
- Inadequate	12	13	4.0%
- Adequate	4	7	27.2%
- Informed	3	1	-66.7%
*Data mismatch. One student could not consistently answer all intervention questions, leaving some blank. Those questions are not in the calculations.			

Questions about Empirical NOS yielded a decline in the final results. Performance on one question in this data set yielded consistently weaker results. This is suggestive of reading comprehension struggles by the students. The students demonstrated sound oral comprehension during Socratic seminar and lab discussions. Yet, they struggled to demonstrate the same understanding in writing based on the survey responses.

Questions about Inferences and Theoretical Entities of Science yielded zero change between pre and post intervention understanding. There were changes in responses by question. But,

as a whole, student understanding did not appear to change.

Questions about Empirical NOS yielded very consistent responses overall. The only change being the absence of a pre-intervention response by the one student who was inconsistent in answering questions. This also reflects the idea that student understanding did not change overall.

Questions about Scientific Theories versus Laws stayed mostly consistent throughout. One student showed improvement in their response. This is suggestive that the content provided was proper but not provided in a way that was accessible to all students.

Questions about Creativity in Science provided a decline in understanding. This could be a content delivery issue where some students became confused about the idea. This would lead to inconsistent responses between the pre and post survey.

Questions about Subjectivity in Science yielded the most positive improvement by the students. This suggests the content delivery was proper and accessible to most of the students. Responses also suggest a cultural component may be involved if students do not see science as consistent.

Questions about Social and Cultural Influences in Science provided mixed results. These questions had the weakest post intervention responses. Multiple students responded stronger on the pre-intervention survey than on the post intervention survey.

Discussion

The following section covers student data performance and interpretations by the researcher. Grammar mistakes are retained in each student response for the reader's benefit of understanding the students in this classroom setting. Spelling has been corrected. Some comments about the students' situation are provided for context where it is helpful.

Student A01 yielded a decline on Scientific Theories versus Laws.

- Pre-intervention response, "A scientific theory may change as the go's by and a scientific may have many theory on one simple subject. A scientific law doesn't

change, it stay the same."

- Post intervention response, "A scientific theory may change over time, a scientific law stays the same."

This student is also an English Language Learner (ELL). They demonstrate a basic understanding of the function of scientific law versus theory. But the response on the post intervention survey fell to inadequate because they did not provide any context to their basic statements.

Student B01 yielded a decline on Scientific Theories versus Laws from adequate to inadequate.

- Pre-intervention response, "Scientific theory its an experiment that is in experimentation and can change depend on the results of the experiments and scientific law was a theory that has been tested many times and has an strong statement about the results."
- Post intervention response, "The scientific theory is supported by a lot of data and the scientific law can't change no matter what."

This student is another ELL. They clearly have a limited understanding about the nature of scientific versus law based on the pre-intervention survey. The post intervention survey response is very basic and contains potential errors.

Student D01 has an IEP/504 for slow thought processing and gets extra time on task. The student was provided two hours to finish the survey instead of one on both attempts. Inference and Theoretical Entities in Science was adequate on the pre-intervention survey and inadequate on the post intervention survey.

- Pre-intervention response, "An atom is a ball of protons and neutrons with electrons surrounding the ball. Scientists have been using electro-magnetic microscopes to view the atom. Along with theories on how it works scientists are certain about the structure of the atom."
- Post intervention response, "A cluster of protons and neutrons surrounded by a cloud of electrons. Tons of theory crafting about the structure of the atom."

This student struggles with Autism Spectrum Disorder (ASD). They did a fantastic job expressing their understanding during the pre-intervention survey. It is clear from the post intervention survey the student was struggling to express their thinking. It is clear they have a

basic understanding of how scientists arrived at the atomic model but lack the ability to express it in writing repeatedly.

Student E01 yielded inadequate responses for every question on both surveys except for Empirical Nature of Scientific Knowledge.

- Pre-intervention response, "The theory does change. We have to teach scientific theories because so we learn about more things for scientific theories."
- Post intervention response, "We teach scientific theories so students can learn better and more about scientific theories."

This student is an ELL. What they express both times is a basic understanding that theories are important for foundational scientific teaching. They acknowledge that theories can change. This was an idea that was discussed multiple times throughout the school year.

Student F01 improved every response between the pre and post intervention survey except Subjectivity in Science. The student also did not display a decline on any tenet.

- Pre-intervention response, "Yes because your opinion could be that the earth is flat. Scientifically that is wrong."
- Post intervention response, "Yes because some people believe the earth is flat but that is not true according to science."

This student basically said the same thing both times. But improved the response by switching from a confrontational, flat answer to one where reasoning as to why is suggested. Phrasing is critical when trying to specifically convey thoughts and ideas.

Student G01 yielded a variety of results. Creativity in Science showed improvement between the two surveys.

- Pre-intervention response, "Science and art are similar by how you mix paints, or how you use chemicals. Science and art are different by how you use the mixture in different ways."
- Post intervention response, "Science can be in a form of art. When you make explosion with color, or mixing paint. Everything is made with science, but science is also different by how you have to think on what to do. When art you can let your heart guide you."

This student starts off with a vague idea of what the differences are. It is clear that after

discussion the student takes more away about the similarities and differences. In the Socratic seminars the teacher used more emotional words for describing art and more unemotional words for science. The student in question benefits because of a strong interest in art and learned they can do science work this year.

Student H01 yielded improved responses on Scientific Theories versus Laws. All other answers remained unchanged between surveys.

- Pre-intervention response, "An atom is a circular object that I was taught goes to other atoms and groups up or sometimes is singular. They are not very much sure that it's circular but of course I don't know that. I also don't know what they use to determine atoms features."
- Post intervention response, "An atom is a circular object that is called an atom. They are certain that it is a circle. Research."

These responses demonstrate an absolute basic conceptual understanding with a lot of room for correction and growth. At least the student tried to answer all three parts of the related question. This particular question was discussed at length, several times throughout the year before being presented in this survey.

Student J01 yielded mostly adequate or informed responses. Subjectivity in Science declined from informed to adequate between the two surveys.

- Pre-intervention response, "The only answer I can come to is that the data is incomplete and because of that the experiments are not entirely correct and that causes debate in the community."
- Post intervention response, "It's possible because there isn't enough evidence to completely prove one and disprove the other."

The pre-intervention survey response is strong. It shows a nuanced understanding that disagreements occur because of how data is interpreted from various experiments. The post intervention survey response falls from informed to adequate because it demonstrates the importance of evidence driven knowledge but fails to discuss interpretation.

Student K01 yielded only inadequate responses on both surveys.

- Pre-intervention response, "I believe theories change based on what you are

experimenting."

- Post intervention Response, "The theory may change based on different experiments that you do."

All of these students' responses are similar. cursory understanding only. No attempt to go deeper or explain their thinking. They demonstrate a basic lack of understanding about the role experiments play in developing theories or laws.

Student M01 yielded mostly inadequate responses. Creativity in Science was rated at adequate on the pre-intervention survey and fell to inadequate on the post intervention survey.

- Pre-intervention response, "I think they do, it's important for scientists to be able to think outside the box to solve problems."
- Post intervention response, "I think scientists do use creativity in different ways."

This student has straightforward and simple responses. The pre-intervention response demonstrates some understanding that science requires creativity to find solutions to problems. The post intervention survey just agrees with one of the related questions.

Student N01 yielded responses that were mostly unchanging. One of the Creativity in Science questions showed a decline in the response from adequate to inadequate.

- Pre-intervention response, "Both are and science take heavy amount of experimentation, you not guaranteed to get it right the first time. However they are still different, science deals with math and numbers while art deals with how humans see the world."
- Post intervention response, "Both take time, you can sit and watch them as well as art and science change. At the same time however art will give you a product you can see, hold, feel (paintings), but you won't get a product like that in science (atomic theory)."

The student has mild grammatical struggles. But thought and effort are displayed in the responses. The pre-intervention survey response demonstrates an understanding that science is tentative and subject to change. The post intervention survey response switches to another idea and suggests science does not produce anything tangible. Hence the scoring change.

Conclusion

Based on this research it would benefit the students for the teacher to be more explicit when teaching NOS. The lab experiences did not explicitly distinguish between observation of phenomena and inference of what forces might directly influence the behavior of the object in each activity. The distinction between observations and inferences is important to a desirable understanding of the nature of science as well as the correlations that exist between scientific laws and theories (Akerson et al. 2000).

Students demonstrated better success with improving answers on the questions that had been discussed multiple times. While this was not always the case, the data is suggestive that repeated contact and reflection on a subject instills a better understanding. Building NOS into all education levels as a part of the critical thinking process could benefit all students in all subjects as they advance through the grade levels. It would also be helpful to extend the duration of the concept teaching as well. Considering the social-cultural makeup of the students in this research it may be wise to provide a word bank for the students to use while writing their responses. ELL education plans often call for word banks to be provided based on the students current WIDA score.

By understanding the problems and successes from the perspective of content area teachers and SPED teachers, the science education community could strengthen the preparation of both content area teachers and SPED teachers to engage, support, and challenge each student in a given content area (Mulvey et al., 2016). The idea here is to not only improve science content instruction between two groups of teachers, but to improve critical thinking and metacognition skills activities for students in all content areas. Expanding on the role that science teachers play in supporting other teachers through improved NOS instruction could help restore a lot of the skills current students, especially those in at-risk populations, have not developed.

There are several socio-cultural factors potentially influencing student performance. The students in this survey only represent about one half of the total classroom population. They were eager to engage in the survey's and participated readily in the discussions. The lack of improvement in these students' NOS could be attributed to multiple external factors despite being successful as students in the classroom.

How do students traditionally considered to be at risk for graduating with the readiness for college or career paths interpret NOS? Articulation in writing alone of thought and idea seemed to be a struggle for nearly half. With the most not writing at grade level based on survey answers. Can a high school teacher effectively influence a student's NOS in a short time-frame through indirect instruction? While some students showed gains, there were too many losses to deem the time-frame alone long enough considering all of the social-cultural struggles these students face.

What other factors may influence a student's NOS from their socio-cultural background? The first influence is SES. Parents' behavior at home directly influences their children. Parent choices may be based on financial stability. Another is the perception of education at home. If education, science in particular, is not valued at home then students may tend to take their high school education less seriously. Three of the eleven do not speak English at home. This limits the students chances for success in the classroom if they are not confident in the common language being used at school.

One area of concern is the notable lack of NOS education for students in K-8 education in the U.S. Developing an understanding about the nature of science, how science works, and how scientists have come to know what they declare as truth is one of the most valuable aspects of scientific literacy that will allow students to make informed decisions and act responsibly as adults when faced with science-based social dilemmas in their future (Zeidler et al. 2009). Students should come into the high school level with the broad knowledge and critical thinking skills necessary to begin to successfully specialize in high school level content. Students who have critical thinking skills are able to ask better questions, provide effective information, produce creative reasons, solve problems, make decisions, and have consistent conclusions (Bustami et al., 2018). These are commonly desired skills for any student who graduates from high school to have to be college and career ready.

Recommendations

It is clear from the research that more study is needed to identify exactly where the K-8 educational process in the U.S. is failing to properly prepare all students, regardless of factors like SES and ELL, for the metacognition and critical thinking that high school science

requires. If students are to be truly college and career ready upon graduation from high school, they need to have developed critical thinking skills and better metacognition. Better NOS instruction is one gateway to achieving that goal.

Research of NOS and its value in promoting critical thinking and metacognition skills in students could benefit from further research in several ways. There is very little research concerning high school level NOS. Studies that measure the impact of lengthier inquiry based methodologies incorporating explicit NOS instruction, especially in at-risk student populations, are needed to determine if NOS can provide improvement to the targeted skills at this education level. Another area for study to consider is the impact of NOS on critical thinking and metacognition skills in subjects other than science. More research is also needed to determine the impact of NOS instruction between traditional and inquiry-based, or PBL, models. The last suggestion offered here is to improve NOS instruction in teacher training programs, K-12, to determine the long-term impact of improved NOS related skills for instructors.

The students in this survey need a lot more intervention over a more extended period of time to achieve the desired critical thinking skills based on the fundamental understanding of NOS. To achieve this for all students it is proposed that better training and education of NOS is provided to all educators, both current and future. This will allow educators to improve the problem solving and critical thinking skills of all students.

For current students it means high school teachers should engage students in higher order thinking in all classes in order to compensate for the lack of earlier education in critical thinking skills. This is a vital concern to address as employers continue to voice concern about the lack of prepared employees coming out of high school.

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başarılarına etkisi [The effect of a direct reflective approach associated with science concepts on primary school students' views on the nature of science and their academic success.]

https://www.researchgate.net/publication/305495217_Fen_kavramlariyla_iliskilendiren_lmis_dogrudan_yansitici_yaklasimin_ilkogretim_ogrencilerinin_bilimin_dogasi_hakk_indeki_goruslerine_ve_akademik_basarilarina_etkisi4

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Exploring Social and Cultural Context of the Nature of Science through Action Research

This book focuses on one of the tenets of the Nature of Science (NOS) that needs further exploration in current teaching practice: the social and cultural aspects of NOS. This tenet recognizes that science is a human endeavor and is thus inevitably influenced by social and cultural contexts. While scientists employ procedures to validate the applicability of their work to others and engage in robust investigations, they cannot fully remove their context from their work. This correlates to the Crosscutting Concepts (CCCs), as “a careful analysis of the crosscutting concepts included in the Framework shows that they are more than organizational schemas that interrelate knowledge from different scientific fields. They also encapsulate overarching ways of thinking that we should help our students to develop” (Talanquer, 2019, p.18). The CCCs capture the complexity of the nature of scientific knowledge and recognize that rich contextual factors that impact the science practices. This book includes exploration some of these contexts through educators’ action research in their career setting.

The chapters in this book explore various ways to embed the social and cultural context of NOS into science instruction. They build on other works that explore NOS instruction across contexts through action research (Akerson & Carter, 2022). We hope that works within this book offer ideas to shape your practice. Some tenets of NOS are more concrete, such as that scientific knowledge is developed by collecting empirical data. Focusing on the empirical nature of science may be conducive to a variety of contexts and concepts within science because of the concrete nature of collecting data. Other NOS tenets connecting to the CCCs are more complex and abstract, presumably because they cross disciplines and focus on a dimension of science with which educators may be less familiar. The science content, or what NGSS call Disciplinary Core Ideas, and inquiry/process skills, or Science and Engineering Practices, have had a place in science education discourse for many years. The CCCs offer a level of depth to science teaching and learning, offering a new dimension to the work of scientists. Researchers have found that CCCs can be challenging for teachers (e.g., see Arias, 2024), thus action research is logical approach to systematic investigation of classroom approaches to this work.



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