THE EFFECTS OF CASE-BASED INSTRUCTION ON UNDERGRADUATE BIOLOGY STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE

by

Amy Lucinda Burniston

Liberty University

A Dissertation Presented in Partial Fulfillment

Of the Requirements for the Degree

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ABSTRACT

Undergraduate science education is currently seeing a dramatic pedagogical push towards teaching the philosophies underpinning science as well as an increase in strategies that employ active learning. Many active learning strategies stem from constructivist ideals and have been shown to affect a student's understanding of how science operates and its impact on society- commonly referred to as the nature of science (NOS). One particular constructivist teaching strategy, case-based instruction (CBI), has been recommended by researchers and science education reformists as an effective instructional strategy for teaching NOS. Furthermore, when coupled with explicit-reflective instruction, CBI has been found to significantly increasing understanding of NOS in elementary and secondary students. However, few studies aimed their research on CBI and NOS towards higher education. Thus, this study uses a quasi-experimental, nonequivalent group design to study the effects of CBI on undergraduate science students understandings of NOS. Undergraduate biology student's understanding of NOS were assessed using the Views of Science Education (VOSE) instrument pre and post CBI intervention in Cellular and Molecular Biology and Human Anatomy and Physiology II. Data analysis indicated statistically significant differences between students NOS scores in experimental versus control sections for both courses, with experimental groups obtaining higher posttest scores. The results of this study indicate that undergraduate male and female students have similarly poor understandings of NOS and the use of historical case based instruction can be used as a means to increase undergraduate understanding of NOS.

Keywords: nature of science, historical case-based instruction, explicit-reflective instruction, undergraduate education

Copyright Page

Dedication

This work is dedicated to my beloved husband, Ryan, and my three beautiful children, William, Samuel, and Lucinda. Thank you for coming along on this journey with me.

It has always been for you.

Acknowledgments

I would like to thank my dissertation chair, Dr. Scott Watson, for his enduring patience and guidance throughout this process, my committee members, Dr. Sara Turner and Dr. Joseph Fontanella, for their advice and support when I needed it the most, and my family for always believing in me and my dreams. I would also like to extend a heartfelt thank you to my mother, Jann, who was always there to lend a helping hand with the kids, a listening ear when I needed to get my thoughts out, a home cooked meal to rejuvenate my mind, and a pat on the back to keep me moving forward. I love you, Mom!

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List of Abbreviations

Analysis of Covariance (ANCOVA)

Analysis of Variance (ANOVA)

American Association for the Advancement of Science (AAAS)

Case-based Instruction (CBI)

Human Anatomy and Physiology (HAP) II

Institutional Review Board (IRB)

Nature of Science (NOS)

National Science Foundation (NSF)

National Science Teacher Association (NSTA)

Pedagogical Content Knowledge (PCK)

Science, Technology, Engineering, and Math (STEM)

Views of Nature of Science (VNOS)

Views of Science Education (VOSE) instrument

CHAPTER 1: INTRODUCTION

Background

Since the launching of Sputnik in October of 1957, scientific literacy has been at the forefront of educational goals and curriculum outcomes in the United States (Duschl & Grandy, 2013). Scientific literacy has been defined by the Organization for Economic Cooperation and Development (2003) as "the capacity to use scientific knowledge to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity" (p. 133). The increased awareness of a need for scientific literacy would later give rise to a host of educational reform initiatives and the eventual strong and deliberate push for STEM education. Thus, Sputnik resulted in a dramatic pedagogical shift and emphasis on science to increase the number of scientists and engineers needed to combat the supposed threat of communism. However, it has been suggested that science initiatives put forth failed to impart the underlying processes of science and it's interplay with society, ultimately resulting in a decrease in interest and understanding in students and the general population (Blades, 2016).

Fast forward over half a century later, scientific literacy within the American population is far below comparable nations (Anastasia & Henry, 2015). In fact, surveys conducted by the National Science Foundation (NSF, 2014) reported approximately 70% of Americans lacked a clear understanding of the scientific process. This is particularly alarming considering that a population's level of scientific literacy has been considered a measure of cultural health and competency for participation in a democracy (Anastasia & Henry, 2015). According to Rensberger (2000),

> Without a grasp of scientific ways of thinking, the average person cannot tell the difference between science based on real data and something that resembles science at least in their eyes—but is based on uncontrolled experiments, anecdotal evidence, and passionate assertions. What makes science special is that evidence has to meet certain standards. (p. 61)

For several decades educational reform documents from organizations such as the American Association for the Advancement of Science (AAAS, 2011) have expressed concerned about the declining of science literacy and the reiteration of misconceptions surrounding science due to the rote teaching on the laws, concepts, and theories of science. To counter this, many reform documents have called for paradigm shift in education towards one that explicitly emphasizes the nature of science. Although lacking a universal definition, the nature of science is essentially the epistemological and philosophical underpinnings of how science operates and influences society (Clough, 2011). Agreed upon characteristics of the nature of science include science knowledge and processes as tentative, unified, empirical, creative, socially and culturally linked (Eshach, Hwang, Wu, and Hsu, 2013). Commenting on the foundation of NOS to scientific literacy, McComas (1998) wrote,

> Science has a pervasive, but often subtle, impact on virtually every aspect of modern life-both from the technology that flows from it and the profound philosophical implications arising from its ideas. However, despite this enormous effect, few individuals even have an elementary understanding how the scientific enterprise operates. This lack of understanding is potentially harmful, particularly in societies where citizens have a voice in science funding decisions, evaluating policy matters and weighing scientific evidence

> provided in legal proceedings. At the foundation of many illogical decisions and unreasonable positions are misunderstandings to the character of science. (p. 28)

The interplay of nature of science (NOS) and scientific literacy was further emphasized during the *Vision and Change in Undergraduate Education, A Call to Action* (AAAS, 2011), which denoted four main competencies needed for student scientific literacy. The conference report denotes four main competencies needed for scientific literacy, including: (a) understand the process of science, the interdisciplinary nature of the new biology and how science is closely integrated within society; (b) be competent in communication and collaboration; (c) have quantitative competency and a basic ability to interpret data; and (d) have some experience with modeling, simulation and computational and systems level approaches as well as with using large databases. This report reflects the current pedagogical push in the sciences to deploy best practices that emphasize NOS through active, student-centered learning (Woodin, Carter, and Fletcher, 2010).

While NOS has been extensively studied for over half a century, there has yet to be a connection formed between the pedagogical theories surrounding NOS and the instructional techniques found to be effective (Lederman, 2007). Additionally, many of the recent and past science education initiatives and reform documents include descriptions of pedagogical techniques recommended for use in increasing NOS understanding, of which most are grounded in constructivism (AAAS, 2011). While different forms of constructivism exist, as related to this study, constructivism emphasizes the processes of taking new knowledge and constructing new understandings around existing knowledge structures often through active, inquiry based processes (Hartle, Baviskar, & Smith, 2012). One constructivist approach, case-based instruction has been shown to increase critical thinking, student achievement, and ethical decision making in students and has also shown promise in developing adequate understandings of NOS in student (Deslauriers, Schelew, & Wieman, 2011; Hartfield, 2010; Herreid, 2005). CBI is an instructional strategy that uses case studies as an active learning tool. Many forms exist, but commonly, a case study is composed of an engaging dilemma that requires a basic understanding of underlying scientific principles (Herreid, 2005). Research on CBI suggests students taught with CBI strategies showed improved concept comprehension, retained content longer, and achieved critical thinking and problem solving skills (Hartfield, 2010; Popil, 2011).

Furthermore, recent published articles have advocated for the use of CBI that highlights the history of science to effectively teach NOS in undergraduate courses (Allchin, 2011; Clough, 2011; Höttecke, Henke, & Riess, 2012). In fact, historical case studies have been found to increase NOS understanding in secondary students and pre-service teachers (Allchin, 2012, Eshach et al., 2013; Höttecke, Henke, & Riess, 2012; Lin & Chen, 2002; Paraskevopoulou & Koliopoulos, 2011). Moreover, projects such as *The Story Behind the Science* and *The Minnesota Case Collection* have been created as resources for teachers aiming to implement historical case study teaching in their science education pedagogy (Allchin, 2012; Clough 2011). Given the enormity of students NOS understanding, further investigation into CBI utilizing historical stories is warranted to fully understand how CBI implementation could effect undergraduate students understanding of NOS.

Problem Statement

Despite extensive research and educational reform initiatives calling for inclusion of nature of science, students at all levels of education are still lacking adequate understanding of NOS and subsequent scientific literacy. Without an adequate level of scientific literacy, students are ill equipped to make educated scientific decisions and judgments, skills needed to be active citizens in a democratic society. The overall lack of NOS understanding is in part due to the ambiguity of NOS, teachers' inaccurate understanding of NOS, and overall reluctance to adopt instructional techniques and content covering NOS (Lederman, 2007; Lin & Chen, 2002). While ambiguity of NOS and lack of understanding of NOS certainly contribute to the lack of understanding of NOS in students, this research serves to examine the impact of instructional techniques on student understanding of NOS.

The instructional techniques instructors adopt in their classrooms are chosen based on two main factors, time and content. Due to the age of accountability and high stakes testing that does not include information related to NOS, teachers often fail to see the need to set aside valuable time to explicitly teach NOS (Abd-El-Khalick, Bell, & Lederman, 1998; Lederman, 1998). Similar notions of insignificance of NOS have also been documented in student populations (McComas, 2015). Often times, NOS is presented in a classroom as an add-on item, often in a different manner than other content. With little extra time available to cover NOS concepts, teacher buy-in to teach NOS is relatively low despite NOS's emergence in state standards and reform documents. Consequently, it has been recommended that to increase student and teacher buy-in, NOS instructional strategies must be easily implemented and must be integrated into the original course content (Clough, 2006; Monk & Osborn, 1997).

While many studies have documented the effectiveness of case-based instruction in regard to critical thinking, student achievement, and ethical decision making, very few studies have looked at the applicability of CBI as related to NOS instruction. Even fewer studies have examined the use of explicit and reflective case-based instruction at the secondary level, with no known studies quantitatively examining the impacts of CBI on undergraduate major and non-major biology students understanding of NOS. Thus, the overarching problem for this study is the overall lack of quantitative research regarding the effects of case-based instruction (CBI) on undergraduate science major's understandings of NOS.

Purpose Statement

The purpose of this study was to quantitatively assess the effects of case-based instruction on the understanding of NOS for undergraduate science students. Students at a small, liberal arts college enrolled in lower-level undergraduate biology courses were chosen for participation in this study. Biology majors and non-majors courses were selected for this study. Using a quasi-experimental, non-equivalent group design, the independent variable was case-based instruction and the dependent variable was students understanding of NOS. Case-based instruction as defined by Herreid (2005) is an instructional strategy that uses case studies as an active learning tool. Many forms exist, but commonly, a case study is composed of an engaging dilemma that requires a basic understanding of underlying scientific principles (Herreid, 2005). Student understanding of NOS was assessed through the *Views of Science Education* (Chen, 2006) questionnaire which was given out as a pretest and posttest.

Experimental course sections received case-based instruction using historical case studies. The historical case studies not only included questions explicitly referencing NOS concepts, but also incorporated mainstream science content such as structure of DNA, sickle cell anemia, etc. Finally, a group discussion surrounding each case study allows students to reflect on the knowledge. Thus, this study builds upon and unites the ideas formed by previous studies and holds true to the recommendations of researchers to utilize instruction that is content-laden, explicit, and reflective. By focusing on undergraduate biology majors and non-majors, this study examined the effect of CBI strategies on a population that has yet to be researched.

Significance of the Study

According to several science education reform documents, the overall purpose for science education is to develop scientifically literate individuals (AAAS, 2011; Miles & Thompson, 2015; NSF, 2014). However, American students have consistently ranked much lower than other nations on assessments measuring scientific literacy (National Science Teachers Association [NSTA], 2008, 2009; Miles & Thompson, 2015). Since the foundation of scientific literacy is tied to the nature of science, this study's significance lies in its potential contribution to effective strategies to increase NOS understanding and subsequent scientific literacy. Additionally, for undergraduate students (particularly non-science majors), a core science class could potentially be the final opportunity to develop sound NOS conceptions.

Furthermore, while curriculum standards for K-12 education are replete with content related to NOS instruction, post-secondary education is devoid of any such documentation or curriculum alignment. Thus, future deductions and inferences drawn from this research can aid in reforming undergraduate science curriculum to reflect best practices in teaching NOS; ultimately leading to improvement of scientific literacy in both future scientists as well as the general college student community.

Research Questions

Given the significance of the nature of science within the broader context of scientific literacy, this seeks to address the following questions:

RQ1: Does case-based instruction enhance undergraduate biology students' understanding of the nature of science?

RQ2: Do male and female undergraduate biology students differ in their understanding of the nature of science?

RQ3: What are student perceptions of the use of historical case studies in an undergraduate biology classroom?

Null Hypotheses

The subsequent null hypotheses for this study include:

$H_0$1: There is no statistically significant difference in the mean nature of science posttest scores between Cellular and Molecular biology students who received case-based instruction and those that did not.

$H_0$2: There is no statistically significant difference in the mean nature of science posttest scores between Human Anatomy and Physiology II students who received case-based instruction and those that did not.

$H_0$3: There is no statistically significant difference between the understanding of nature of science of undergraduate biology major male and female students.

Definitions

1. *Case-Based Instruction* - Instructional strategies that use case studies presenting contextualized dilemmas that require students to actively reflect on their learning (Allchin, 2011).
2. *Nature of Science* - The processes and outputs of science along with it's epistemological and philosophical assumptions and it's interactions with society (Clough, 2006).
3. *Scientific Literacy* - Understanding the foundation concepts of science and its processes to be able to make informed conclusions and decisions (NSF, 2014).
4. *Science, Technology, Engineering, and Mathematics (STEM)* - Acronym for education focusing on science, technology, engineering, and math (Duschl & Grandy, 2013).

CHAPTER TWO: REVIEW OF LITERATURE

Overview

A recurring top priority for science curriculum objectives on national reform documents is student understanding of the NOS (AAAS, 2011; National Research Council, 2014). This prioritization is highlighted in science education reformists call for a movement away from rote memorization of disconnected facts and scientific knowledge to a connection of the bigger ideas related to the processes of science, usually referred to as the nature of science. In fact, Peters-Burton and Baynard (2013) indicated that all of national and internal science curriculum reforms over the past twenty years have called for an increased focus on NOS education. In the United States, reform initiatives such as Project 2061 and the Next Generation Science Standards both place a significant emphasis on NOS concept (Iqbal, Azam, & Rama, 2009; NGSS Lead States, 2013).

Several justifications have been put forth for the inclusion of pedagogical strategies aimed at developing students' understandings of NOS, including the development of

(a) the ability to be educated users of technology and societal advances
(b) informed decision making about democratic issues
(c) overall appreciation of impacts of science, and vice versa, on society and culture
(d) ethical and moral conduct related to science and society
(e) the ability to acquire and retain scientific material. (Bloom, Binns, & Koehler, 2015)

All the aforementioned justifications could be grouped into one larger, more central justification of forming scientific literacy in students, or the ability to investigate and analyze information to draw sound conclusions or pose new questions (Lopatto, 2010). Scientific literacy is needed for informed decision making. As indicated by Impey, Buxner, Antonellis, Johnson, & King (2011), "To make informed decisions, Americans need to have assimilated enough from their education to use evidence-based reasoning to separate substance from spin and cull corroborated fact from unsubstantiated assertion" (p. 34).

This interplay of NOS and scientific literacy was emphasized during the *Vision and Change in Undergraduate Education, A Call to Action* (AAAS, 2011), which denoted four main competencies needed for student scientific literacy. The conference report denotes four main competencies needed for scientific literacy, including: (a) understand the process of science, the interdisciplinary nature of the new biology and how science is closely integrated within society; (b) be competent in communication and collaboration; (c) have quantitative competency and a basic ability to interpret data; and (d) have some experience with modeling, simulation and computational and systems level approaches as well as with using large databases. This report reflects the current pedagogical push in the sciences to deploy best practices that emphasize NOS through active, student-centered learning (Woodin et al., 2010). Regardless of its necessity, researchers have identified a lack of scientific literacy found in undergraduate students, and even more so, for non-science students who may only be required to take one science course. For some non-science majors, an undergraduate science course is often times the final opportunity to develop sound NOS conceptions. For this population, specific content is less applicable and necessary to their future lives than becoming scientific literate. Although one might expect understanding of NOS to be higher in undergraduate, science majors, research has shown that the majority of undergraduate students held naïve or incorrect perspectives on NOS and the perspectives did not differ between science majors and non-majors (Miller, Montplaisir, Offerdahl, Cheng, and Ketterling, 2010).

Emerging research in the field of CBI has provided evidence to suggest that employing CBI strategies may aid in the development of more informed understandings of NOS (Höttecke et al., 2010). CBI is an instructional strategy that uses case studies as an active learning tool. Many forms exist, but commonly, a case study is composed of an engaging dilemma that requires a basic understanding of underlying scientific principles (Herreid, 2005). Research on CBI suggests students taught with CBI strategies showed improved concept comprehension, retained content longer, and achieved critical thinking and problem solving skills (Hartfield, 2010; Popil, 2011). CBI including historical accounts and reflective, explicit NOS inferences have been reported to enhance middle school students, high school students,' and pre-service teachers understanding of NOS. However, literature is devoid of any research on the impact of historical, reflective, and explicit CBI on science majors and non-major students understanding of NOS, particularly in the biological sciences. The subsequent literature review will begin with descriptions of the underlying theories supporting this research, including; constructivism, schema theory, and cone of learning. Nature of science and its importance will be defined, with additional attention paid to its complexity associated with teacher understanding and student understanding. Related research on students understanding of NOS and implementation of CBI to increase student understanding of NOS will follow.

Theoretical Framework

Constructivism and NOS

As indicated by documents produced by the AAAS (2011) *Vision and Change in Undergraduate Biology Education: A Call to Action*, students perceptions and understandings of the nature of science can be enhanced through active, inquiry based pedagogies. The foundation of all activity, inquiry based pedagogies is the theory of constructivism (Hartle et al., 2012).

Similar to the nature of science in its lack of a formal definition, common characteristics of constructivism have arisen and include social interface, authentic and dynamic learning settings, realistic tasks, variety perspectives and representations of content, and acceptance of the process underlying knowledge construction (Rolloff, 2010). Hartle et al. (2012) define constructivism as:

> a theory that describes learning as taking new ideas or experiences and fitting them into a complex system that includes the learner's entire prior learning. In other words, students arrive with pre-existing 'constructs,' and in order to learn, must modify these existing structures by removing, replacing, adding, or shifting information in them. (p. 31)

At its core, constructivism emphasizes students' existing knowledge structures, beliefs, and skills that impact their acquisition of new material. Combining Piaget and Vygotsky, constructivism promotes social interaction as well as individual active participation in learning to construct knowledge (Garbett, 2011). Knowledge is thought of in both individual and social frames. Consequently, constructivism is more than a theory of teaching but a theory that has equal educational and epistemological foundations. While a single constructivism tenant is nonexistent, common themes among constructivists can be found. These agreed upon aspects include social interaction, complex and realistic learning environments, authentic tasks, multiple perspectives and representations of content, and acceptance of the process underlying knowledge construction (Rolloff, 2010). Narrowing down the common aspects, Von Glasersfeld (1989) indicated two key aspects of constructivism: (a) knowledge foundations are not passively acquired, but rather are actively constructed by the learner, and (b) cognitive processes assimilate to form organizational structure of knowledge rather than discover ontological reality (p. 114). Thus, similar to the tentative and subjective aspects of NOS, constructivism relies on learner's ability to reframe knowledge and form new conclusions through authentic activities. Research grounded in constructivism, using reflective, active learning as the strategy, has shown increases with student achievement and success (Slavich & Zimbardo, 2012, p. 2).

Schema theory. The notion of actively constructing knowledge, also lends itself to the theoretical underpinnings of schema theory. Schema theory as proposed by Bartlet (1932) is "an active organization of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response" (p. 201). Schemata are abstract knowledge structures of memory that function in the course of deciphering incoming and new content (Anderson & Pearson, 1988). The student's existing schema allows the student to assimilate the new knowledge and add it to the already established warehouse of information. Comprehending information can be likened to finding to a new mental home for the information or modifying an existing home to accommodate the incoming content. It is an interaction of old information stored with the new incoming information that allows assimilation. Research has shown that students who actively wrestle with changes in their understanding of NOS through reflective exercises, overall demonstrate deeper and more adequate understandings of NOS (Clough, 2006).

Cone of learning. Through its support of the use of active, inquiry-based learning strategies, the Cone of Learning theory supports the aforementioned tenets of constructivism. Proposed by Edgar Dale, the Cone of Learning is a theoretical model that illustrates pedagogical strategies and their effects on information retention. The model depicts learning from verbal information as least effective and hands-on learning to be most effective, with the individual actively participating in the acquisition of their knowledge (Duru, 2010). Related to this study, research has shown that students are less likely to be interested and engaged in content presented in a lecture or reading material in a text (Höttecke et al., 2010). Thus, deductions can be made that when constructivist strategies are employed, overall learning is enhanced.

Case-based instruction. Within the constructivist-learning umbrella there are many caveats or similar seeming processes that all employ active learning; discovery-based, problem-based, case-based, etc. All aforementioned strategies advance that knowledge is generated from individual experiences and use of problem solving situations allows students to "actively draw on their past experiences and knowledge to discover new facts and effectively develop deep conceptual understanding" (Hartfield, 2010, p. 22). While, both case-based and problem-based learning have been extensively studied, meta-analyses lump together anything called by those names; not considering their underlying presentations. For example, one would expect significant differences in a classroom that solely teaches from a case-based pedagogy than a classroom that only incorporates certain aspects of constructivism (Herreid, 2005).

Research has shown similar results occurring from all constructivist strategies, but this study aims to focus on the impacts of case-based instruction solely. Heavily used in law and medical education, case study implementation in science education is quickly rising. Case-based learning solidifies knowledge structures and promotes active learning to promote acquisition of knowledge, skills, and perceptions via dilemmas often presented in a traditional story format (Allchin, 2011). Simply put, case studies put learning into a context that is memorable by relating knowledge obtained to real-world dilemmas. As stated by Höttecke et al. (2010), case studies used in CBI, portray science as a "human and social endeavor [that] includes perspectives on motivations of scientists, on conflicts, controversies, and blind alleys" (p. 1235).

Across science disciplines, case-based instruction has been shown to positively impact student learning, achievement, and higher order thinking skill formation (Deslauriers et al., 2011;

Hartfield, 2010; Herreid, 2005; Popil, 2010). Case-based instruction has also been credited with skills related to characteristics of NOS including, higher knowledge acquisition, execution of sense-making processes, and promotion of ethical deicision making (Bagdasarov et al., 2012). Furthermore, case studies are listed as an instructional tool for improving understanding of nature of science in undergraduate biology students in the AAAS (2011) *Vision and Change in Undergraduate Biology Education: A Call to Action* report.

Nature of Science: What It is and Why It is Needed

While the NOS lacks a universal definition, it has been commonly described by Clough (2006) as "what science is, how science works, the epistemological and ontological foundations underlying science, the culture of science, and how society both influences and reacts to scientific activities" (p. 463). Furthermore, widely accepted characteristics have been repeated throughout science standard documents and primary literature. As indicated by Eshach et al. (2013), these common characteristics of nature of science include:

(a) Science knowledge is empirical and is precluded from supernatural elements to form knowledge.

(b) A distinction is present between observations and inferences. Inferences are formed through observations.

(c) A distinction is present between laws and theories which represent distinctly and functionally different types of scientific knowledge.

(d) Scientific knowledge is reliable but never absolute.

(e) The process of science is partly due to human inference, imagination, and creativity.

(f) Scientific knowledge is socially and culturally linked.

(g) Scientific knowledge is subjective in nature and theory laden.

The aforementioned characteristics were also supported by Lederman (2007) who has explained the process of scientific knowledge as tentative, empirically based, theory-laden, creative and imaginative, and socially imbedded. Understanding the nature of science is important due to its necessity for scientific literacy, which benefits individuals and society as a whole. As stated by McFarlane (2013), "Scientific literacy is an integral part of our individual and collective search for purpose" (p. 37).

Despite the need for scientific literacy and the need for adequate perceptions of NOS, Lederman (2007) suggests that the majority of students do not hold adequate perceptions of NOS. Lederman's suggestions have been supported by research done through the International Association for the Evaluation of Educational Achievement, which indicated that U.S. students had lower scientific literacy scores as compared to similar nations (Molé, 2006). Research has also shown that individuals that hold naïve perceptions of the nature of science are more likely to treat scientific knowledge as absolute and more inclined to ignore the role of scientific data, imagination, and creativity (Allchin, 2011). Furthermore, studies have shown that students with informed views of the nature of science are associated with increased motivation, critical-thinking, and conceptual problem solving (Chai, Deng, Wong, & Qian, 2010). While there is a rise in STEM majors across the nation, students who are not in the sciences are being less exposed to courses allowing them to build their scientific literacy and understandings of the nature of science (Whalen & Shelley, 2010). In a survey of the top 50 institutions ranked by the *U.S. News and World Report,* the rigor of science requirements at surveyed institutions went from 90% to 34% in a near 20-year period (Impey et al., 2011).

Complexities associated with NOS instruction. While the literature base strongly suggests that American students are lacking in their knowledge related to NOS concepts, several complexities related to effective NOS instruction stand in the way. First, the ambiguity related to defining NOS impedes developing effective pedagogical strategies to teach it. How does an educator effectively teach material that they cannot truly define? The lack of a universal NOS definition has led to the development of plethora of NOS assessment instruments, pedagogical approaches, and even some wholesome controversy (Allchin, Andersen, & Nielsen, 2014). While a consensus of shared features of NOS has been formed, it can be argued many knowledge-acquiring enterprises can differ greatly in their degree of characteristics and commonalities, leading to a family resemblance of scientific enterprise rather than a direct list of declarative statements about NOS. By limiting NOS to a set list of characteristics and epistemological foundations, Matthews (2012) argues that several pitfalls have resulted in both education and philosophical understanding of NOS, including:

(a) The formation of a single list of NOS tenets that jumbles together statements related to ethics, sociology, psychology, epistemology, commerce, and philosophy, ultimately impeding effective measurement of said tenets.
(b) The promotion of one side of controversial arguments surrounding NOS.
(c) The assumption of agreed upon solutions to controversial arguments.
(d) The assumption that NOS learning can be adequately measured by student's ability to identify certain declarative statements surrounding NOS. (p. 4)

Effective measurement of NOS. Confounding the lack of a universal definition of NOS is the complexity associated with how to adequately measure it. Over the past half century, much attention has been paid to the development of an instrument to effectively assess an individuals understanding of NOS. Table 1 includes a historical list of the major, validated instruments used to assess NOS.

Research measuring the understanding of NOS began as a quantitative endeavor, with the first instrument, Science Attitude Questionnaire, developed in 1954 (Lederman, Wade, & Bell, 1998). For decades to follow similar instruments would be produced, all including some quantifiable measure such a Likert-type scale, multiple choice, or agree/disagree items. However, much criticism of these early empirically based measures arose due to questions concerning their validity, item construction, and feasibility to form adequate conclusions on an individual's understanding of NOS (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Researcher's felt that the forced option measurements were biased in their wording, constructed from the researcher's presumptions, and failed to account for individuals with views outside of the forced choice options (Chen, 2006; Lederman et al., 2002). Additionally, many of the early instruments were criticized for their oversimplification, overgeneralization, and emphasis on internal consistency over authenticity (Liang et al., 2008).

As a result of the aforementioned criticisms, qualitative instruments began to appear in the literature body starting in the 1980s (Chen, 2006). One of the most popular qualitative instruments, the Views of Nature of Science Questionnaire (VNOS) was developed to ascertain meaningful assessment of learners' NOS views through open-ended items and individual interviews (Lederman et al., 2002). Research using VNOS has greatly increased the literature body concerning NOS understanding among students and teachers. However, similar to other qualitative instruments, the VNOS takes on average 40-60 minutes for individuals to complete, additional time demands for interviews and interpretation, and requires a depth of knowledge to fully answer the open-ended questions (Chen, 2006; Liang et al., 2008).

Table 1

Instruments for Assessing NOS (adapted from Lederman & Abell, 2014)

Instrument	Author(s)	Year	Type
Science Attitude Questionnaire (SAQ)	Wilson	1954	Quantitative
Images of Science, Scientists, & Science Careers (ISSSC)	Mead & Métraux	1957	Quantitative
Facts About Science Test (FAS)	Stice	1958	Quantitative
Test on Understanding Science (TOUS)	Cooley & Klopfer	1961	Quantitative
Science Process Inventory (SPI)	Welch	1966	Quantitative
Wisconsin Inventory of Science Process (WSPI)	SLRC	1967	Quantitative
Nature of Science Scale (NOSS)	Kimball	1967	Quantitative
Nature of Science Test (NOST)	Billeh & Hasan	1975	Quantitative
Views of Science Test (VOS)	Hillis	1975	Quantitative
Nature of Scientific Knowledge Scale (NSKS)	Rubba	1976	Quantitative
Conception of Scientific Theories Test (COST)	Cotham & Smith	1981	Quantitative
Views on Science-Technology-Society (VOSTS)	Aikenhead et al.	1987	Quantitative
Views about Philosophy of Science (VaPS)	Koulaidis et al.	1989	Quantitative
Views of Nature of Science A (VNOS-A)	Lederman et al.	1990	Qualitative
Modified Nature of Scientific Knowledge Scale (MNSKS)	Meichtry	1992	Quantitative
Critical Incidents (CI)	Nott & Wellington	1995	Qualitative
Beliefs about Science and School Science Questionnaire (BASSSQ)	Aldridge et al.	1997	Quantitative

Views of Nature of Science B (VNOS-B)	Abd-El-Khalick et al.	1998	Qualitative
Views of Nature of Science C (VNOS-C)	Abd-El-Khalick & Lederman	2000	Qualitative
Perspectives on Scientific Epistemology (POSE)	Abd-El-Khalick	2002	Qualitative
Views of Nature of Science D (VNOS-D)	Lederman & Khishfe	2002	Qualitative
Views of Nature of Science E (VNOS-E)	Lederman & Ko	2004	Qualitative
Scientific Epistemological Views (SEVs)	Tsai & Lu	2005	Quantitative
Views on Science and Education Questionnaire (VOSE)	Chen	2006	Quantitative
Student Understanding of Science & Scientific Inquiry (SUSSI)	Liang et al.	2006	Mixed
Myths of Science Questionnaire (MQSQ)	Buaraphan	2009	Quantitative
Nature of Science Instrument (NOSI)	Hacieminoglu et al.	2012	Quantitative

Furthermore, while the qualitative instruments dealt with the aforementioned ambiguity seen with early quantitative instruments, overall consistency among the instruments and researchers interpretations was questionable with different methodologies related to measurement often resulted in inconsistent findings across researchers (Chen, 2006). For example, in the 1990s both positive and negative results were reported related to teachers' understandings and ideas related to NOS (Abd-El-Khalick et al., 1998; Aguirre, Haggerty, & Linder, 1990; Discenna & Howse, 1998).

Additional criticisms of qualitative NOS instruments related to the limitations of sample sizes and in turn, the ability to assess large number of individuals to be able to extrapolate significant findings has resulted in a resurgence of newly renovated quantitative measures (Liang et al, 2008). With the incessant call for science education reform to emphasize NOS and the inclusion of NOS into science education standards, large-scale, quantifiable instruments have become necessary and warranted. Furthermore, in the era of standardized testing and assessment, quantitative instruments allow educators and researchers to perform large-scale assessment of student understanding of NOS. Newly formed quantitative instruments have addressed the concerns related to validity by assuming student centered positions to reduce ambiguity (Chen, 2006).

One of the newly constructed quantitative instruments, the Views on Science and Education Questionnaire (VOSE), dealt with earlier criticisms of quantitative instruments by constructing the instrument from a qualitative mindset by emphasizing trustworthiness and authenticity over high internal consistency. Framed for undergraduate and adult individuals, the VOSE was developed through interpretation of multiple sources of information including primary literature, student interviews, and widely used NOS instruments such as the VNOS and Views on Science Technology Society (VOSTS) questionnaires. The fifteen-item questionnaire making up the VOSE allows timely scoring of the instrument while diminishing ambiguity through its construction framed by the learner's perspective (Chen, 2006).

Teacher's understanding and willingness to teach NOS. Other complexities related to students understanding of NOS, lie within science educators. Research has indicated that teacher perceptions, preparations, and personal backgrounds significantly impact NOS instruction. As eloquently framed by Russell and Aydeniz (2013),

> Standing on the shore of a sea of disjointed scientific facts and activities is a group of American high school science students, frantically note-taking from typically didactic lectures designed by well-meaning teachers determined to prepare those students for

> high-stakes end of course exams. Far across that turbulent sea is a distant shore outlined by science education reform initiatives such as National Science Education Standards…which insist that those students [need to] become scientifically literate with the ability to think and act as scientists do, developing working knowledge of scientific epistemologies. Science educators must make a personal commitment to help their students transverse that sea if science education reform initiatives are to be fulfilled. (p. 529)

Nevertheless, despite the incessant calls for science curricula reform to include NOS, numerous studies have indicated that teachers largely fail to see the necessity of NOS instruction (Clough, 2006, Monk & Osborn, 1997). Reasons for the reluctance to include NOS concepts into science curricula include lack of adequate NOS materials, lack of NOS concepts on standardized testing, and inadequate knowledge related to NOS and how to properly teach NOS (Abd-El-Khalick, Waters, & Lee, 2008; Cough, 2006, Lederman, 1998). Many teachers rely heavily on already produced teaching materials and the overall lack of NOS materials has resulted in teachers reporting NOS as problematic to teach (Viana & Porto, 2013). Additionally, the reliance on science textbooks for instruction and curriculum planning and the overall lack and misrepresentation of NOS throughout texts, confounds the lack of materials issue (Abd-El-Khalick et al., 2008).

Misconceptions and undervaluing of NOS by educators has been well documented in the primary literature for several decades (Abd-El-Khalick et al., 1998; Lederman, 1992; Abd-El-Khalik & Lederman, 2000). In a recent study examining both student and teacher understanding and interest of NOS, Sahin & Köksal (2010) found teachers held incorrect views on the majority of NOS aspects and demonstrated lack of motivation to teach NOS aspects. However, research has also shown that even when teachers do have adequate understandings of NOS, transferring of NOS understanding is ineffective, largely due to lack of knowledge related to NOS instruction (Abd-El-Khalick et al., 1998). Abd-El-Khalick and Lederman (2000) indicate three main aspects to teacher's effectively teaching NOS, including: (a) Teachers must have the knowledge base and resources for teaching NOS; (b) Teachers must have the intention to teach and the belief that they are able to teach NOS; and (c) Teachers must believe that their students can and need to learn NOS. Examining the first aspect related to an overall lack of knowledge and resources, Wang (2001) studied the intervention of in-service training of NOS for elementary teachers and found that teachers failed to relate the in-service knowledge of NOS into their teaching due to lack of examples translating NOS characteristics into explicit instructional practice. Abd-El-Khalick et al. (2016) indicated that effective NOS instruction warrants teachers to have adequate knowledge of NOS, content area knowledge, and instructional knowledge. The three aforementioned knowledge areas represent the formation of pedagogical content knowledge (PCK). First introduced by Shulman (1987), PCK, as related to NOS instruction, relies on teacher's knowledge areas to transform notions into accessible and attainable learning objectives for students (Abd-El-Khalick, 2016).

Examining the second aspect related to teachers' beliefs surrounding their ability to teach NOS, research has also indicated that a teacher's reluctance and/or ability to effectively teach NOS may be context dependent. Abd-El-Khalick (2001) has shown that teacher's beliefs on NOS, ability to teach NOS, and need for students to learn NOS can vary depending on the science content being covered. Further research has indicated that pre-service teachers having adequate knowledge of NOS revert back to traditional, didactic pedagogies focusing on one way communication when teaching a specific content area that they feel they are not as knowledgeable in (Kang, 2008).

Furthermore, a large majority of science teachers have not themselves participated in authentic scientific processes such as forming a testable question of their own and carrying out methodologies to perform a scientific investigation and consequently, struggle to create meaningful, authentic scientific activities for their students (Russell & Aydeniz, 2013). A large body of evidence has highlighted the lack of science methods courses in teacher preparation programs to effectively prepare teachers for the lofty NOS goals emphasized by many science education reform documents (Abd-El-Khalick, 2001; Abd-El-Khalick & Lederman, 2000; Aguirre et al., 1990; Lederman, 1999).

Finally, the third aspect regarding the necessity of NOS instruction was highlighted by Lederman (1999), who argued that teachers need to truly believe that NOS instruction is truly warranted. However, the majority of science teachers prioritize their curriculum goals based on standardized testing and textbook materials, both of which are largely void of NOS material. Furthermore, the rise of high stakes, standardized testing has resulted in a move away from inquiry based lessons towards more didactic instruction in secondary science classrooms to encourage rote memorization and regurgitation of science facts (Russell et al., 2013). Thus, science reform initiatives must also begin to address and emphasize the inclusion of NOS content into standardized testing.

Studies have indicated that without the push from high stakes testing, teachers must hold a personal commitment to developing “scientific habits of mind” in their students to effectively include NOS instruction into their curricula (Lederman, 1999; Russell et al., 2013). Research focusing on pre-service teachers has indicated that only when teachers have internalized the importance of NOS as a necessary instructional objective, does their overall willingness to teach the subject increase (Abd-El-Khalick & Lederman, 2000; Lederman, 1999). Similarly to teachers, research has shown that students also undervalue NOS instruction and feel that it is less important than traditional science content (Sahin & Köksal, 2010). Studies have also indicated that the most viable solution to deal with teacher and students underlying perceptions of the necessity of NOS is linking NOS concepts into science content already being taught (Clough, 2006; Monk & Osborne, 1997). Research has suggested that historical case studies effectively intertwine science content and NOS, allowing an educator to seamlessly teach both within the same lesson (McComas, 2006; Slezak, 1994).

Related Research

Students' Understanding of NOS

While the incorporation of the nature of science is forefront in science education reform documents; student's perceptions of NOS remain sub-par across age groups, including higher education. Research has also indicated that college students are still graduating with little gains in their understandings of nature of science and overall scientific literacy (Impey et al., 2011). In a 20-year survey on student scientific literacy conducted by Impey et al. (2011) on nearly 10,000 undergraduate astronomy students, no detectable improvement in undergraduate scientific literacy was found from 1988-2008. Additionally, freshmen students were found to only perform slightly higher than the general public. Furthermore, only a 10-15% increase in literacy was observed after having taken three or four science courses. In a recent study examining cultural differences related to NOS instruction, Arino de la Rubia, Lin, and Tsai (2014) found significant differences in NOS perceptions among undergraduate students from different ethnicities. The researchers suggested that pedagogical techniques concerning NOS must take into account students from other ethnicities and cultural backgrounds (Arino de la Rubia et al., 2014).

Specifically looking at student ideas about NOS, Parker, Krockover, Lasher-Trapp, & Eichinger (2008), utilized a qualitative design to administer the VNOS-C questionnaire to 17 undergraduate atmospheric students; of which three were later interviewed. The researchers found undergraduate atmospheric students to hold mostly inaccurate views of science. The researchers did note that students had the most accurate views related to NOS aspects of creativity, experimentation, and testing of ideas.

Despite taking additional science courses, research has suggested that science major students hold inadequate understandings of NOS similar to their non-science major peers. In a study examining 265 undergraduate biology majors and 86 non-biology majors understandings of NOS, Miller et al. (2010) found both sets of students to have similar views ranging on average from naïve to somewhat informed. The authors also noted discrepancies in scores across aspects of NOS. For example, both student populations indicated relatively informed views related to scientific theories. However, the non-biology majors had more informed views related to differences between theories and laws when compared to their biology major counterparts. Miller et al. (2010) offer a possible explanation to this finding by indicating that the heavy portrayal of science as universal and objective may be negatively impacting science students' understandings of NOS. The authors further advocated for more similar studies to be conducted throughout the various disciplines of science to identify possible nuances within the disciplines.

NOS Instruction

Research related to the aforementioned complexities of NOS indicate that the factor most associated with student understanding of NOS is instruction in the classroom. Several instructional strategies have been put forth, one of them including case studies. However, outside of the instructional techniques, three main pedagogical approaches have dominated the primary literature to include; the implicit approach, the explicit-reflective approach, and the historical contextualized approach (Smith, 2010).

The literature base on NOS instruction has been divided on whether students should learn NOS implicitly through engaging in science activities such as student-led research or through activities and lessons that specifically spells out and emphasizes which tenets of NOS are being taught. According to Çibik (2016), implicit instruction of NOS assumes that students are able to form adequate NOS understandings through active participation in science activities. With implicit instruction, students are assumed to naturally develop NOS understanding through authentic science practices that require inquiry and scientific process skills (Çibik, 2016).

Typically, implicit NOS education is associated with a holistic approach to science where the subject matter and NOS at interwoven (Clough, 2011). While explicit NOS education, sometimes referred to as VNOS, sets aside NOS into discrete units of teaching apart from other science content knowledge (Allchin, 2011). Although many researchers have advocated for implicit NOS strategies, current research has shown greater understanding of NOS concepts when pedagogical strategies explicitly addressed NOS (McDonald, 2010). Advocates of explicitly teaching NOS argue that NOS warrants extensive planning for knowledge transfer to actually occur, rather than waiting for it to be picked up as a byproduct of instruction (Clough, 2006, 2010; Lederman, 2007). In fact, research conducted by Meichtry (1992) indicated that without explicit references to NOS characteristics, students were unlikely to make the implicit, inferential connections on their own and the NOS characteristics were lost in translation.

Furthermore, research has shown that when paired with reflection, the explicit approach greatly enhances student understanding of NOS (Khishfe & Abd-El-Khalick, 2002; McComas, 2006; Lederman, 2007). The combination of the two approaches is often termed explicit-reflective in the literature and will now be characterized as such in this study. As related to constructivism tenets, the explicit- reflective approach allows students to identify and actively address misconceptions of NOS and construct new, more adequate views (Clough, 2011).

In a study examining explicit-reflective versus implicit inquiry oriented instruction on 6th grade student's understanding of NOS, Khishfe and Abd-El-Khalick (2002) reported a significant increase (34-52%) in the understanding of NOS among students who received the explicit-reflective instruction. Similar results were also seen when the researchers examined secondary students, with high school students taught with explicit-reflective instruction developing more informed views of NOS constructs as indicated by the score of the VNOS instrument. The researchers also indicated that by utilizing the explicit-reflective instructional approach, the need for full integration of NOS concepts into course content was not needed or impactful on secondary science student's development of adequate NOS views (Khishefe & Lederman, 2006).

Conversely, Brooks (2011) also investigated explicit-reflective instruction on secondary students understanding of NOS and indicated significant increases in students understanding of NOS with both explicit and implicit reflective instruction. The explicit-reflective approach has also shown promise in regard to improving understanding of NOS among teachers. In a NSF funded project, Lederman, Lederman, Khishfe, Druger, Gnoffo, and Tantoco (2003) examined the use of explicit-reflective NOS instruction via monthly workshops and summer classes on teacher's understandings of NOS. Examining the teachers for a full year, the researchers were able to conclude that 80% of the participating teachers experienced significant improvement in their understanding of NOS and a subsequent increase in the teacher's students' understanding of NOS (Lederman et al., 2003).

According to Clough (2006), in order to effectively teach NOS the instruction has to be directly tied to actual science content. Essentially, the NOS instruction must be relevant or students will fail to see the necessity of NOS. Clough states,

> Explicit and reflective highly contextualized NOS instruction plays a crucial role in NOS instruction by overtly drawing students' attention to important NOS issues entangled in science content and its development… highly contextualizing the NOS means integrating historical and contemporary science examples that are tied to the fundamental ideas taught in particular science subjects. (p. 474)

The final approach, historical, aims to contextualize the material within science content. Using history as an instructional tool is certainly not a new pedagogical approach to teach science. Dating back to the 1950s past efforts such as *Harvard Case Histories in Experimental Science* (Conant, 1957) and *History of Science Cases* (Klopfer & Cooley, 1963) have sought to teach science through a historical and humanistic perspective. As indicated by Clough (2011),

> An historical approach that faithfully reflects the work of scientists illustrates the humanity of science, the enjoyment and frustrations in conducting research, and the complexities and challenges individual scientists illustrates the humanity of science, the enjoyment and frustrations in conducting research, and the complexities and challenges individual scientists and the scientific community experience in developing and justifying science ideas. In addition to potentially enhancing understanding of science content, these examples can exemplify important epistemological and ontological lessons that are

> bound up in that content and central to understanding the NOS, and place the science content in a human context. (p. 703)

Clough, along with several other researchers have spent many years investigating the role of the historical approach as related to NOS. However, differing from historical implementation advocates of the past, Clough has argued for contextualizing the historical approach by incorporating the history into the content already being taught in the classroom. By emphasizing historically contextualized content, educators and students alike are more likely to react more positive to the historically laden activities (Clough, 2010).

In some of his most noted work, Clough (2006) along with Olson, Stanley, Colbert, and Cervato, created and implemented thirty historically contextualized stories for use in undergraduate science courses as part of a project funded by a NSF grant. The authors designed the stories to explicitly teach NOS, meanwhile teaching specific science content. In a later study conducted by Clough, Herman, Smith, Kruse, & Wilcox (2010), five of the thirty previously created stories were implemented in an undergraduate majors biology course to explicitly teach NOS. The researchers concluded that the historical stories significantly positively impacted students understanding of NOS, with all students (N=85) indicated an increase in the interest in the content being taught in their course after implementation of the stories (Clough et al., 2010).

Furthermore, research has suggested that incorporation of a historical frame could increase student interest in non-science major students who are more naturally inclined towards content that focuses on human endeavors and emphasizes history, sociology, and philosophy (Tobias, 1990). Supporting this notion, Seymour and Hewitt (1997) explored the reasons for students choosing or not choosing science fields and found that the lack of humanity in sciences to be a negative factor when deciding on a major of study. As indicated by one student in the study, "I think my four years would have been terrible if I only focused on science classes, because everything would have been facts, and regurgitation of facts – no real conversation, no studies of civilization or culture."

While an historical approach could be a viable approach to increasing student understanding and interest in NOS, Clough (2006) argues that teachers must pay attention to several demands when using historical stories used in classrooms, including:

(a) Science stories should incorporate content already being taught in the course to increase their likeliness of being used, since teachers are reluctant to take any significant amount of time away from teaching science content.

(b) Science stories should be written to be flexible to allow for variation in implementation.

(c) Science stories should include both historical and contemporary elements to avoid dismissal of NOS ideas as elements of a bygone era.

(d) Science stories should use verbiage of actual scientists to indicate the humanistic side of science and increase authenticity to the NOS ideas being emphasized.

(e) Science stories should be explicit in their emphasis of NOS ideas and allow students to actively reflect on their understandings of NOS.

(f) Science stories should be contextualized with science content inside and outside the classroom.

Constructivist approaches. Studies examining constructivism in the classroom have shown positive, significant gains in student performance and success. In a metaanalysis of 225 studies examining the efficiency of constructivist instructions versus traditional, didactic instruction in STEM courses, Freeman et al. (2014) found overall increases in student achievement, decreases in course failures, and lower course withdrawal instances.

Utilizing a non-equivalent group design, Sridevi (2013) studied the effects of constructivist approaches on eighth grade Indian students' understanding of NOS. Using the 4E Model of Exploration, Explanation, Expansion, and Evaluation as the constructivist experimental intervention, the researcher found significant increases in students' perceptions of NOS as measured by the Perception of Nature of Science test for both male and female students.

Case-based instruction. In a quasi-experimental study examining the impacts of CBI on biology courses, Derting and Ebert-May (2010) found long-term improvements in student knowledge acquisition. Increases in student achievement were also reported by Hartfield (2010) who used a multipartite strategy to examine case-based instruction in an undergraduate biochemistry course. Dori, Tal, & Tsaushu (2003) examined the impact on case-based instruction on non-science major students enrolled in a biotechnology course. The researchers found significant improvements in their science & technological literacy and higher order thinking skills. Additionally, The researchers also found the gap between high achieving and low achieving students to be narrowed.

Research dating back to the 1960's has suggested that case-based learning incorporating the history of science can improve NOS understanding. In a study of 2,808 students, Klopfer and Cooley (1961), found significant increases in student understandings of NOS as measured by the TOUS questionnaire. In addition, the researchers concluded that the understanding of NOS held by the teacher was not a factor related to student understanding of NOS. Due to its findings and strong sample size, Klopfer and Cooley's research ultimately gave rise to the increase in emphasis on NOS education, inquiry related pedagogies, and science skills (Lederman, 1992).

The existing literature base indicates strong support for utilizing case studies that incorporate history with an explicit and reflective approach. Examining the efficacy of historical CBI on middle school student perceptions of NOS, Rudge and Howe (2009), incorporated a historical case study about the research process behind the discovery of sickle cell anemia in an eighth grade course. The historical case study explicitly addressed science content being currently covered in the class as well as explicitly indicated specific NOS elements. The researchers examined changes on the VNOS questionnaire before and after instruction using historical case studies and overall reported a mark change in students' understandings of four NOS aspects. The researchers concluded that the reflective and explicit approach imbedded within the historical case study activity help to deepen student NOS understanding.

Also focusing on secondary education students, Paraskevopoulou and Koliopoulos (2011) examined the impacts of historical case study implementation on high school student NOS understanding. Through a quasi-experimental design, the researchers implemented a case study on the Millikan-Ehrenhaft dispute that contained several elements of NOS, including; the distinction between observation and inference, need for empirical data, role of imagination and creativity, and subjective nature of theory formation. Using non-parametrical data analysis, the researchers concluded that the historical case study improved students understanding of NOS.

The aforementioned positive effects of historical case studies on understanding of NOS have also been indicated in pre-service teachers. Lin and Chen (2002) completed a quasi-experimental study comparing the understanding of the nature of science between pre-service chemistry teachers instructed on ways to teach using the history of science. The researchers found that the experimental group held stronger and more consistent NOS beliefs and were able to support those beliefs with scientific evidence and hypotheses formed by past scientists. In a similar study, Höttecke et al. (2012) qualitatively examined student and teacher perspectives of the nature of science after the implementation of historical case studies within science education. The researchers found that pre-implementation both teachers and students held negative perceptions related to the teaching of the nature of science.

Looking at higher education, Kruse, Clough, Olson, & Colbert (2009) used a mixed methods methodology to investigate the influence of historical case short stories in a post-secondary introductory biology course. In their study, five historical stories from the NSF CCLI grant (Clough et al., 2006) were implemented throughout majors biology course, with the students given a week to complete and discuss the questions related to each short story. The researchers reported significant increases in student interest in science careers and knowledge related to NOS. Furthermore, the researchers indicated a positive experience as reported by the instructor and an intention for continued use of the short stories in their course.

Most recently, Eshach, Hwang, Wu, and Hsu (2013) examined the impact of implementation of historical case studies detailing Nobel Prize stories on undergraduate students understanding of nature of science. Following the recommendations of previous studies, the researchers explicitly emphasized important aspects of NOS within the Nobel Prize stories and required students to actively reflect on the stories through questions and discussions. Students were also required to synthesize their own Nobel Prize case study and present it to their class while identifying the NOS aspects highlighted in their case. The researchers assessed student understanding of NOS through qualitative instrumentation and methodologies and ultimately concluded that the students exposed to the historical case studies had enhanced views of NOS.

Decades of research on NOS have led to an evidence base surrounding pedagogical approaches that are explicit, reflective, and historical framed. In combination with the constructivist instructional tool of case-based instruction, several studies have reported significant increases in students understanding of NOS, as well as teacher high levels of teacher buy-in due to ease of use and integration of science content (Clough, 2010; Eshach et al., 2014). Figure 1 indicates the combination of approaches and strategies to increase student understanding of NOS as deployed and emphasized in this study.

Summary

Common themes throughout the research on NOS education point to active, inquiry based learning strategies to promote NOS understanding. Grounded in constructivism, CBI is an active, inquiry based strategy that has been studied and used extensively. If CBI has been shown to have significant impacts on student performance, engagement, and perspectives, then it is not too far fetched to hypothesize similar effects on student understandings of NOS. Research on historical CBI has revealed promising results in relation to secondary students and pre-service teachers understandings of NOS. A review of the literature suggests that case based instruction can be an effective pedagogical technique to increase student understanding of NOS as long as the case studies are embedded contain reflective and explicit prompts related to NOS, contain course content other than NOS, and have some level of authenticity, often achieved through a historical lens.

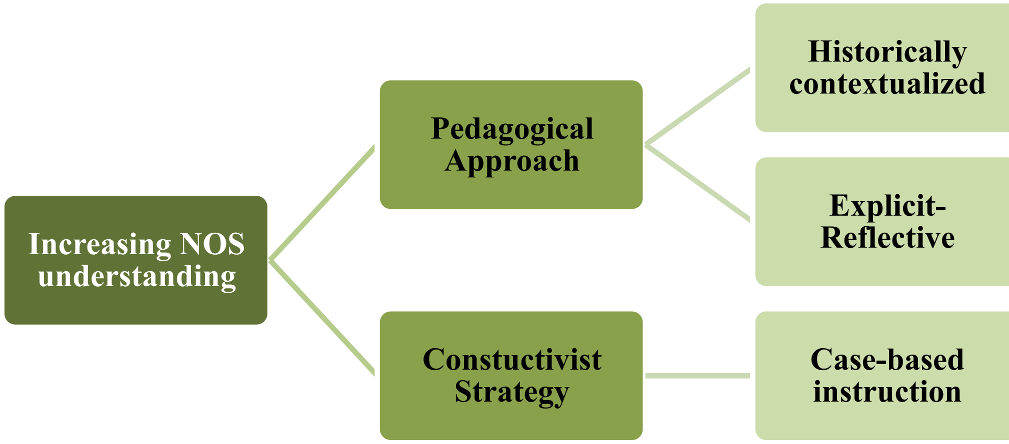


Figure 1. Graphical representation of the pedagogical approaches and constructivist strategy utilized to increase student understanding of NOS.

There is currently a large void in empirical studies examining the effects of CBI on the teaching of NOS, with very few studies aimed at undergraduate biology students. Studies examining understanding of NOS in undergraduate education are sparse, particularly in the biological sciences. Even fewer studies have looked at the employment of constructivist strategies to teach NOS, particularly examining the relationship of explicit-reflective and historically contextualized case-based instruction to the understanding of nature of science. The lack of evidence-based research alone makes this research valid and necessary, but future deductions and inferences drawn from this research can aid in reforming undergraduate science curriculum to reflect best practices in teaching NOS; ultimately leading to improvement of scientific literacy in both future scientists as well as the general college student community.

CHAPTER THREE: METHODS

Design

Due to preexisting student enrollment in selected courses, this study was quasi-experimental and followed a non-equivalent control group design. Students enrolled in experimental sections received historical case-based instruction utilizing three separate historical case studies throughout one unit within the semester long course. Students enrolled in control sections received traditional, didactic lectures. Due to lack of ability for random assignment of students, whole course sections were randomly assigned to either experimental or treatment groups. Lab components for all course sections were unchanged. A pretest and posttest in the form of the Views of Science and Education (VOSE) questionnaire was administered to both experimental and control sections to measure students' understanding of the nature of science.

Research Questions

The research questions for this study was:

RQ1: Does case-based instruction enhance undergraduate biology students' understanding of the nature of science?

RQ2: Do male and female undergraduate biology students differ in their understanding of the nature of science?

RQ3: What are student perceptions of the use of historical case studies in an undergraduate biology classroom?

Null Hypotheses

The subsequent null hypotheses for this study include:

$H_0$1: There is no statistically significant difference in the mean nature of science posttest scores between Cellular and Molecular biology students who received case-based instruction and those that did not.

$H_0$2: There is no statistically significant difference in the mean nature of science posttest scores between Human Anatomy and Physiology II students who received case-based instruction and those that did not.

$H_0$3: There is no statistically significant difference between the understanding of nature of science of undergraduate biology major male and female students.

Participants and Setting

The target population for this study included undergraduate biology majors and non-majors students from a small, liberal arts university located on 75 suburban acres near Lake Erie and its sister campus located 16 miles away in North East. The university has a current enrollment of 2,573 students, of which 56% are female and 43% come from out of state. The school's ethnic diversity is below national average with 77.5% Caucasian students, 4.5% African American, 2.1% Hispanic, 1.2% Asian, and 7.7% ethnicity unknown. Class sizes vary from 6-45 students and range in time from fifty minutes for classes meeting three times a week to an hour and a half for classes meeting twice a week.

The university offers a wide array of programs ranging from certificate to doctoral. Offering rolling admission, this university has an acceptance rate of 80.3% and a tuition rate of $33,314 per year. Large amounts of scholarship and grant money, coupled with a variety of NCAA Division I & II sports teams, brings students to the university from across the country as well as abroad. Being one of four colleges located in the surrounding area of an economically declining city, enrollment has been declining for the university. As a result, reinvention and creation of programs is occurring across both campuses, including in the biological sciences.

Participants selected for the research were chosen based on their enrollment in courses meeting the selection criteria. Such criteria include meeting over the traditional 15-week semester, offering at least two sections taught, lower-level course, and belonging within the biology department. Two biology courses meeting the aforementioned criteria were chosen for this study. Cellular and Molecular Biology is a biology majors course offered on the university's main campus. The course was mostly composed of traditional science major students, a few non-majors students, and a few non-traditional students. All students in this course were seeking a four-year degree. It's two sections, experimental and control, produced a total sample size of 52.

Human Anatomy and Physiology II is a non-majors course offered at both the main and sister campus. For this study, course sections at the sister campus were utilized due to having four sections aligned with their content and taught by two separate instructors, each having a control and treatment section. The student population in this course was made up of half traditional students, mostly in health related majors, and half non-traditional students with varying life experiences. The student sample also consisted of students seeking a certificate, associate degree, or bachelor's degree. The four course sections of HAPII, with two experimental and two control sections, produced a sample size of 97 students. Thus, the selection of course sections generate a total sample size of 149 biology undergraduate students. The sample size number exceeds the minimum size as recommended by Gall et al. (2006, p. 145) for a medium effect size with statistical power of .7 at a significance level of 0.05.

Based on their enrollment in selected courses, all students were asked to participate and consent in the study by allowing procurement of their documents and access to their scores on the VOSE assessment. Prior to the procurement of the student consent, approval to conduct research from Institutional Review Board (IRB) for both Liberty University and Mercyhurst University was obtained. On the first day of the instructional unit, the course instructor debriefed the class on the study, emphasized that questionnaire was voluntary and anonymous, and administered the student consent form and VOSE questionnaire (see Appendix B). It was emphasized that by completing the VOSE questionnaire, students were consenting to take part in this study and any students not wishing to participate, should have left the questionnaire blank. After the instructional unit had passed, the course instructors once again administered the VOSE questionnaire, again emphasizing that the questionnaire is voluntary and anonymous.

Instrumentation

To assess student understanding of the nature of science, the VOSE questionnaire was utilized. Developed by Chen (2006), the VOSE is a quantifiable, empirically based questionnaire designed specifically for college students and pre-service teachers. Having been validated by a panel of experts and administered to a 302 college students with a Cronbach's alpha of 0.82, the VOSE is an appropriate and valid instrument for this study. The use of VOSE in the literature is increasing with the shift in NOS research towards quantitative design and will be utilized similar to studies conducted by Callahan, Zeidler, and Orasky (2011) and Burton (2013). Permission to use this instrument was granted by the author, Chen (2006), on August 17th, 2016.

The VOSE consists of 15 multiple-choice questions aimed at students and science teachers. Of the 15 questions, 10 items are specifically aimed to address students' understanding of the nature of science, including; socio-cultural influence, use of imagination, tentativeness, theory epistemology, law epistemology, theory-law relationship, subjectivity of observations, and scientific methods and will be included in this study. The VOSE employs a five point Likert scale, ranging from strongly agree to strongly disagree. A scoring guide for the instrument has been provided by the developer and will be utilized by the researcher to form a mean score for each the items/NOS constructs. The average across all items was calculated for a total mean score for each student and then averaged together for course section mean NOS scores as a measure of student understanding of NOS. Additional demographic information related to sex and level will also be collected on the VOSE questionnaire as well as two perceptions of case study affects on understanding of NOS and understanding of content will be included on the posttest VOSE questionnaire. See Appendix B for the student consent form.

Procedures

A total of six biology course sections were selected for this study, two Cell and Molecular Biology sections and four Human Anatomy and Physiology II sections. Each course was chosen due to meeting selection criteria, including; a 15-week format, multiple sections, content formatted into units, and lower level course number. A unit of study within a semester is roughly three to four weeks and is highlighted by an exam given at the end of the unit. Prior to beginning the study, IRB approval was sought and granted. Instructors were trained on implementation of the historical case studies, including the making an explicit connection of the case study and course content to nature of science. All materials associated with the case study were provided to instructors during training. All instructors were given copies of the VOSE questionnaire and student consent form to view.

Content during the experimental phase for both sections was aligned for both experimental and control sections. Course instructors teaching control sections were instructed to administer traditional pedagogies through a lecture given by PowerPoint. For the Cellular and

Molecular Biology course, the case studies were assigned in class with students reading through the narrative, breaking the students into small groups to answer related questions, facilitating a classroom discussion related to the questions and corresponding content, and explicitly stating which areas of NOS the case study highlights. For the Human Anatomy and Physiology II courses, the case studies were assigned as homework, with students reading through the narrative and completing the questions individually and then, participating in a discussion explicitly addressing constructs of NOS.

At the beginning of the instructional unit, a student consent waiver was dispersed and the VOSE questionnaire was administered by the course instructors in all course sections at the beginning of the unit of study as a pretest. The VOSE pretest was collected, placed in a sealed envelope, and given to the researcher. A total of three historical case studies were utilized in the experimental course sections during the duration of one semester unit. The historical case studies were selected due to their emphasis of NOS and their connections to course content. As such, as the case studies used in Cellular and Molecular Biology differed from those used in Human Anatomy and Physiology II. The experimental instructors employed traditional PowerPoint lectures aside from integrating the historical case studies.

After the instructional unit was completed, the VOSE was administered again as a posttest in all course sections at the end of the first unit, prior to the unit exam. The VOSE was administered by the course instructor, placed in a sealed envelope, and given to the researcher for analysis. The VOSE was scored using a scoring guide provided by Chen (2006). Additional demographic questions including college standing (e.g., freshman) and sex were included on the questionnaire. Data were entered into Excel and organized into course number and course section. Sex was entered with 1 being male and 2 being female. College standing was entered as 1-4, 1 being freshman, 4 being senior.

Data Analysis

For the first and second hypotheses examining significant differences of understanding of NOS between biology students who received case-based instruction and those who did not, an analysis of covariance (ANCOVA) was most appropriate. The appropriateness of the ANCOVA was due to the pretest acting as a covariant in the analysis. Similar to the analysis of variance (ANOVA), the ANCOVA requires homogeneity of variances and normally distributed data. However, additional assumptions of linearity and homogeneity-of-slopes underlie the ANCOVA's validity (Warner, 2013, p. 694). Thus, prior to rejecting or failing to reject the null hypothesis, data screening and assumption testing needs to be completed. To assess whether the data is normally distributed and lacking outliers, preliminary data screening is required (p. 193-194). If outliers exist, they must be removed for the validity of the ANCOVA to remain. Scatterplots were used to detect outliers in the two-student population's NOS scores before and after the pedagogical treatment, case-based instruction or traditional.

For the ANCOVA to be valid, assumptions of normality and homogeneity of variances must be met with significances greater than 0.05. Normality was examined using a Kolmogorov-Smimov due to the sample size being greater than 50. The assumption of homoscedasticity was examined using the Levene's test, which examines whether sample variances differ significantly (Warner, 2013, p. 197). To assess whether posttest and pretest NOS scores were linearly related, scatterplots and bivariate correlations were constructed (p. 705).

To analyze the third hypothesis looking at differences of understanding of NOS related to sex of students, an independent samples t-test was most appropriate. The appropriateness of the independent t-test was due to the presence of two independent variables, male and female. The t-test was administered to analyze sex differences in the course section employing case-based instruction and the course section employing traditional pedagogies. Similar to the ANCOVA, the validity of the t-test centers on the assumption of normality and equal variances met with significant *p*-values greater than 0.05 (Gall, Gall, & Borg, 2006). Thus, homogeneity of variance was examined using Levene's test. Scatterplots were used to detect outliers in the dependent variable groups. Effect size was determined using Cohen's d because *t* tests are being completed (Warner, 2013).

CHAPTER FOUR: RESULTS

Previous sections of this dissertation present the importance of nature of science instruction, the rationale for adoption of historical, explicit case-based instruction to effectively teach nature of science, and the related literature body associated with NOS knowledge, assessment, and instruction. This section presents the results of this study, aimed at answering the following research questions:

RQ1: Does case-based instruction enhance undergraduate biology students' understanding of the nature of science?

RQ2: Do male and female undergraduate biology students differ in their understanding of the nature of science?

RQ3: What are student perceptions of the use of historical case studies in an undergraduate biology classroom?

Prior to addressing the research questions individually, charts and graphs were constructed based of descriptive data related to this study to include; sample size (N), mean, standard deviation, standard error. Table 2 presents the descriptive data of this study. The total response rate from the pretest to posttest was 87%, with several students dropping the courses or choosing not to participate in the posttest questionnaire.

Table 2

Descriptive Data Across Course Sections for Pre and Posttest Mean NOS Scores

		PRETEST			POSTTEST		
Course Section	Sex	N	Mean	Std. Deviation	N	Mean	Std. Deviation
Experimental Cellular and Molecular Bio	male	12	2.9608	.25249	12	3.2448	.20479
	female	14	2.9307	.31950	11	3.2753	.19479
	Total	26	2.9446	.28525	23	3.2594	.19611
Control Cellular and Molecular Bio	male	7	2.8518	.26630	7	2.8190	.26003
	female	16	2.9399	.23320	13	2.8197	.14264
	Total	23	2.9054	.24466	20	2.8194	.19794
Experimental Human Anatomy & Physiology II	male	11	2.8145	.34981	11	3.1005	.20981
	female	32	2.9131	.27807	21	3.0228	.19838
	Total	43	2.8879	.29682	32	3.0495	.20247
Control Human Anatomy & Physiology II	male	26	2.9494	.24055	26	2.8619	.23005
	female	31	2.9008	.28626	29	2.9349	.30213
	Total	57	2.9229	.26519	55	2.9514	.28454
Total	male	58	2.9110	.26953	56	2.9983	.26112
	female	91	2.9157	.27705	74	2.9805	.28331
	Total	149	2.9139	.27324	130	2.9881	.27308

As seen in Figure 2, mean scores increased from pretest to posttest for both experimental sections of Cellular and Molecular Biology and Human Anatomy and Physiology II, with the largest improvements seen in the Cellular and Molecular Biology Course. A decrease in posttest scores was seen in the control sections of both Cellular and Molecular Biology and Human Anatomy and Physiology II course. See Figure 2 for the estimated marginal means of the different course sections and their subsequent mean scores on the pre and posttest. Since the VOSE score represents the average score on a number of NOS constructs, pretest and posttest means for each individual NOS construct were calculated. Figure 3 presents the total pretest and posttest means on the individual VOSE constructs related to the nature of science constructs of socio-cultural influence, use of imagination, tentativeness, theory epistemology, law epistemology, theory-law relationship, subjectivity of observations, and scientific methods across experimental and control course sections.

To address the first research question, ANCOVA tests were conducted using SPSS to compare the mean posttest scores among individuals within control and treatment groups, while accounting for the pretest score differences. Separate ANCOVA tests were conducted for Cellular and Molecular Biology and Human Anatomy and Physiology II. The two null hypotheses related to the first research question include:

$H_0$1: There is no statistically significant difference in the mean nature of science posttest scores between Cellular and Molecular biology students who received case-based instruction and those that did not.

$H_0$2: There is no statistically significant difference in the mean nature of science posttest scores between Human Anatomy and Physiology II students who received case-based instruction and those that did not.

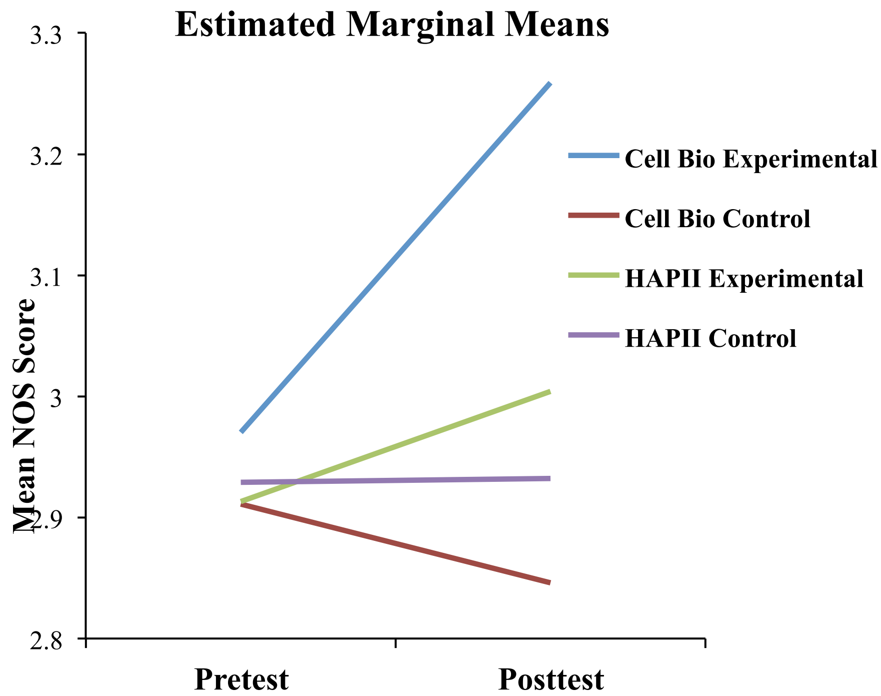


Figure 2. The estimated marginal means of the different course sections and their subsequent mean scores on the pre and posttest.

The second research question focusing on differences among sexes was addressed by analyzing mean pretest scores using a independent samples t-test. The subsequent null hypothesis associated with this research question was:

$H_0$3: There is no statistically significant difference between the understanding of nature of science of undergraduate biology major male and female students.

The final research question was not statistically analyzed, but frequencies of student responses related to perceptions of the effects of historical CBI on understandings of NOS and course content were compared.

Research Questions

Research Question One

To analyze differences between mean posttest scores between experimental and control course section groups, an ANCOVA was utilized. Since the historical case studies utilized in Cellular and Molecular Biology differed in content from the historical case studies utilized in Human Anatomy and Physiology II, two separate ANCOVA analyses were run to more accurately examine differences between experimental and control course sections and are included as a subset of hypotheses to the main hypothesis. However, since the ANCOVA's validity hinges on the assumption of normality and equal variances met with significances (p-value) greater than 0.05, data screening and assumption testing were completed for each course. While the course sections were analyzed separately, their results will be presented together below.

Data screening. Preliminary data screening is needed to determine if the data are normally distributed, lacking extreme outliers (Warner, 2013, p. 693-694). Scatterplots were used to determine a linear relationship and detect outliers in the dependent variable groups. While outliers were identified in the dataset, an examination of the data's scatterplots determined a lack of severity and due to the robustness of the ANCOVA the outliers were left in the data set.

It should be noted that the scenario of removing the outliers was run and it did not change the ANCOVA results. Furthermore, leaving the outliers within the dataset did not affect assumption testing across the research questions and most likely represent legitimate scores from the broader student population. See Figure 4 for pre and posttest scatterplots for control and experimental sections of the Cellular and Molecular Biology course.

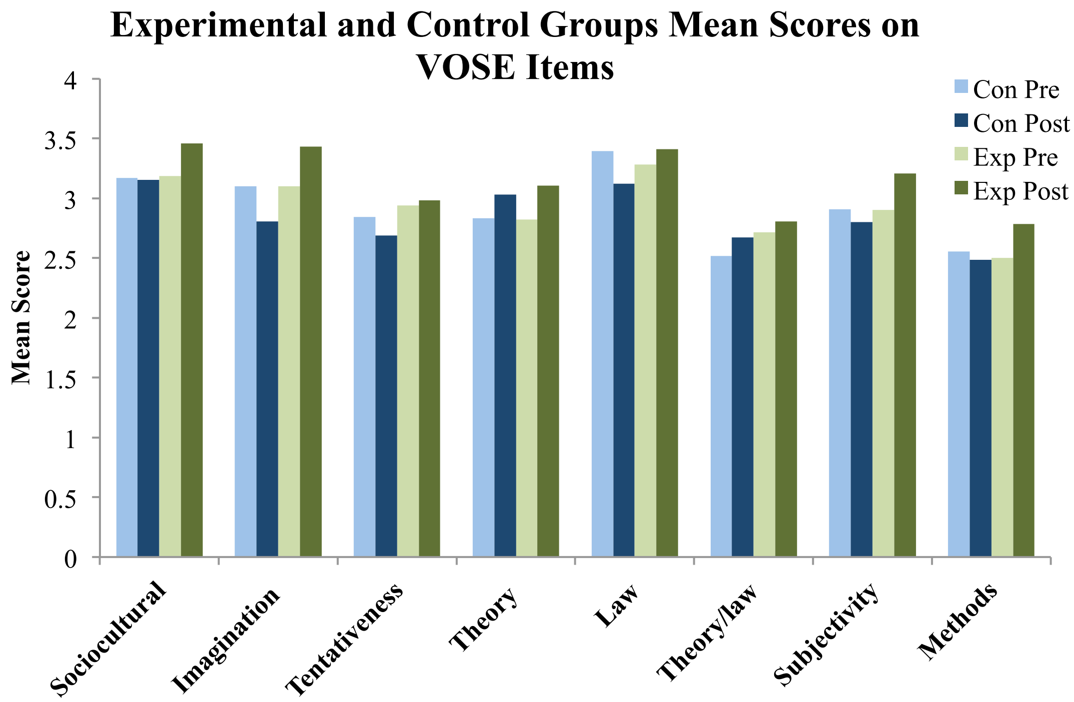


Figure 3. Experimental and control group means for the individual VOSE constructs.

Assumption testing. The subsequent assumption testing for the ANCOVA was completed on the posttest data set due to the pretest scores acting as a covariate to include tests examining normality, homogeneity of variance, and homogeneity of regression.

Normality. Due to the sample size of the Cellular and Molecular course sample being smaller than 50 (n=43), a Shapiro-Wilk test was used to assess normality. No violations of normality were found in experimental (p= 0.349) or control (p= 0.595) posttest scores. See Table 3 for the Shapiro-Wilk test. To assess normality in the Human Anatomy and Physiology II course data set, the Kolmogorov-Smirnov test was used due to the sample being larger than 50 (n= 87). No violations of normality were found in experimental (p= 0.100) or control (p= 0.200) posttest scores. See Table 4 for the Kolmogorov-Smirnov test.

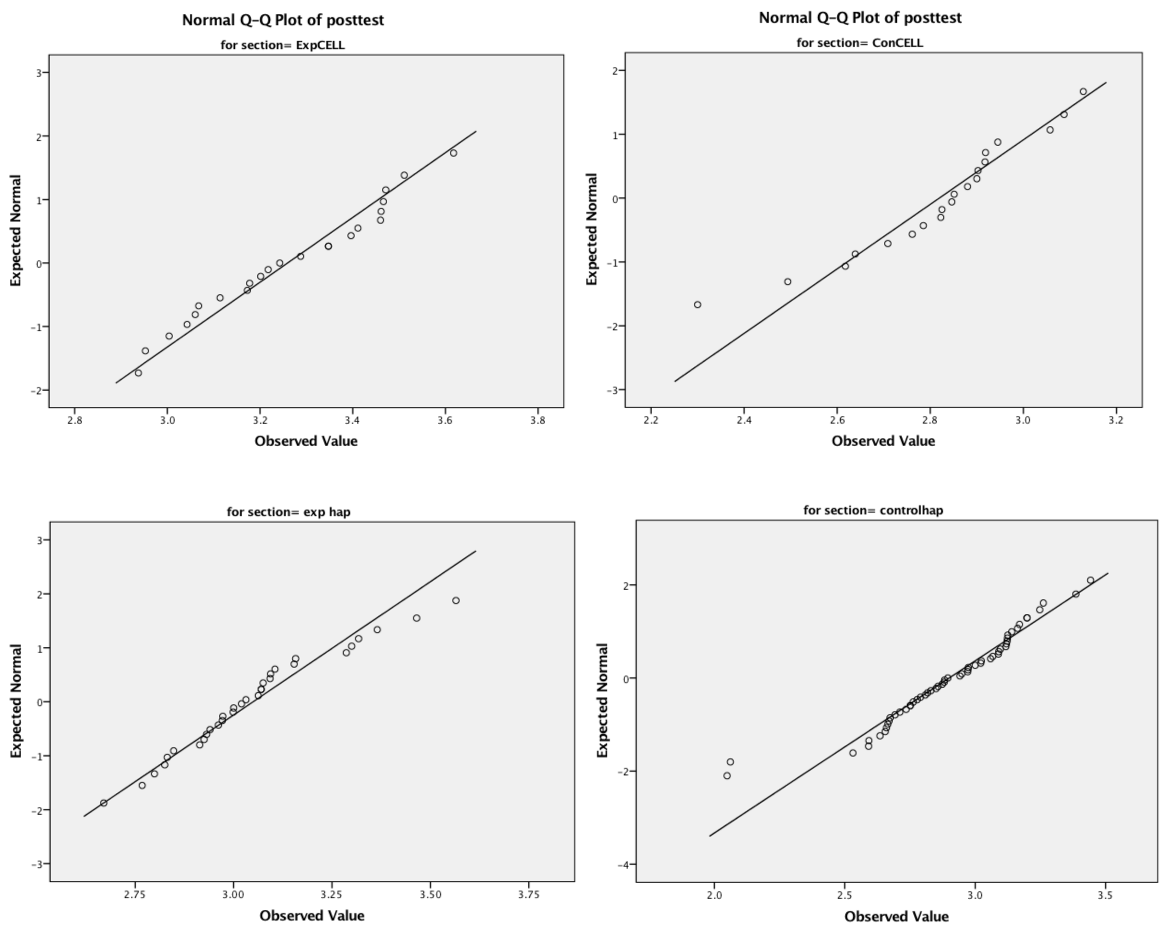


Figure 4. Scatterplots for mean NOS posttest scores for experimental and control sections of Cellular and Molecular Biology and Human Anatomy and Physiology II.

Homogeneity of variance. The assumption of homogeneity of variance was examined using the Levene's test, which examines whether sample variances differ significantly (Warner, 2013, p. 197). The results of the Levene's test, F (43) = .631, p = .432, indicated no violations in the Cellular and Molecular dataset and the variances of the experimental and control populations are assumed to be approximately equal (the p >.05). Similarly, no violations in variance was seen in the Human Anatomy and Physiology II dataset, F (87) = 3.581, p = .062. See Table 5 for Levene's Tests examining homogeneity of variance.

Table 3

Tests of Normality for Cell Bio Course Section - Posttest

Course Section	Shapiro-Wilk		
	Statistic	df	Sig.
Cell Bio Experimental	.959	23	.435
Cell Bio Control	.938	20	.223

ANCOVA analyses. The assumption testing demonstrated that all conditions for ANCOVA analyses were satisfied and two separate ANCOVA analyses were run on the different courses, Cellular and Molecular Biology and Human Anatomy and Physiology II. ANCOVA analyses resulted in significant differences between the control and treatment groups for Human Anatomy and Physiology II course (F (1, 84))= 7.165, p=.000, partial η^2= .790) and Cellular and Molecular Biology Courses (F (1,40)= 52.028, p=.000, partial η^2= .565). Both course sections reported large effect sizes as indicated by Cohen (1998), with 79% of the variance in the Cellular and Molecular Bio posttest scores being predictable by course section and 56.5% of Human Anatomy and Physiology II Bio posttest scores being predictable by course section. Overall, significant differences in NOS posttest scores were seen across all experimental course sections employing CBI (p< .001), but were not significant across the control sections of the courses (p>.05). The ANCOVA across course sections indicated significant differences across all experimental course sections that employed historical case studies (F (3,125)= 17.754, p< .01, partial η^2= .299). See Appendix C for ANCOVA results across courses and course sections.

Table 4

Tests of Normality for HAPII Bio Course Section - Posttest

Course Section	Kolmogorov-Smirnov		
	Statistic	df	Sig.
HAPII Experimental	.142	32	.100
HAPII Control	.073	55	.200

Due to the large effect sizes and a p-values being less than 0.05, the researcher rejected the first and second null hypotheses at a 95% confidence level, stating that there was no statistical difference in the mean posttest NOS scores between students in both Cellular and Molecular Biology and Human Anatomy and Physiology II receiving historical case-based instruction and those who did not. Thus, when pre-test mean NOS scores of the groups are controlled, a statistically significant difference is found between the posttest mean NOS scores of the experiment and control groups for both courses. Results of the Cellular and Molecular Bio ANCOVA are summarized in Table 6. Results of the Human Anatomy and Physiology II Bio ANCOVA are summarized in Table 7.

Table 5

Levene's Test of Equality of Error Examining Homogeneity of Variance

	Dependent Variable: Posttest			
	F	df1	df2	Sig.
CELL[a]	.631	1	41	.432
HAPII[a]	3.581	1	85	.062

Note. Tests the null hypothesis that the error variance of the dependent variable is equal across groups. [a] Design: Intercept + pretest + section

Research Question Two

The second research question explored differences in mean pretest NOS scores between males and females undergraduate students enrolled in biology courses. Since the aim is to compare means between two dependent groups, males and females, the independent samples t-test is appropriate to use. Similar to the ANCOVA, the t-test is a parametric test, requiring that statistical significance of the t-ratio is based on normality and equal variances (Warner, 2013, p. 186). Thus, prior to rejecting or failing to reject the null hypothesis, data screening and assumption testing needs to be completed.

Table 6

ANCOVA results for experimental and control sections of Cellular and Molecular Biology

Dependent Variable: Posttest					
Source	df	Mean square	F	Sig.	Partial Eta Squared
Intercept	1	3.049	76.870	.000	.658
Pretest	1	.004	.094	.760	.002
Cell Section	1	2.064	52.028	.000	.565
Error	40	.040			
Total	43				

Note. R Squared = .567 (Adjusted R Squared = .545)

As in previous analyses, scatterplots were used to detect outliers in the dependent variable groups. No outliers were identified. See Figure 5 for the scatterplots.

Similarly, the assumptions of homogeneity of variances and normality were tested using Levene's and Kolmogorov-Smirnov Tests, respectively. Levene's Test, F (149)= .162, p= .688, resulted in no violations of variance between males and females. See Table 8 for Levene's Test. Due to the large sample size (n= 149), a Kolmogorov-Smirnov test was used and indicated no violations of normality in either males (p= .200) or females (.173) individuals. See Table 9 for the Kolmogorov-Smirnov Test.

Table 7

ANCOVA results for experimental and control sections of Human Anatomy & Physiology II

Dependent Variable: Posttest					
Source	df	Mean square	F	Sig.	Partial Eta Squared
Intercept	1	8.106	133.465	.000	.614
Pretest	1	.121	1.998	.161	.023
HAPII Section	1	.435	7.165	.009	.079
Error	84	.061			
Total	87				

Note. R Squared = .101 (Adjusted R Squared = .079)

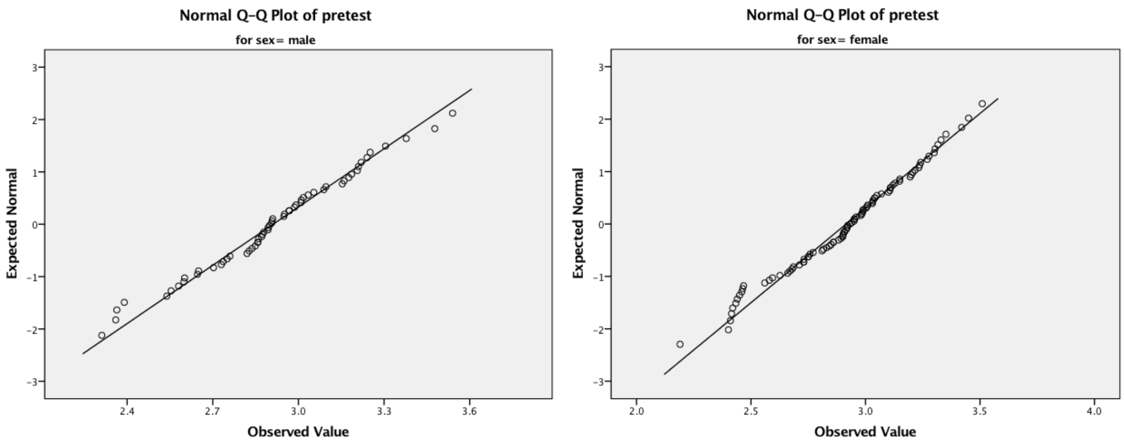


Figure 5. *Scatterplots for mean pretest NOS scores for male and female students.*

Table 8

Levene's Test of Equality of Error Variances[a] Examining the Homogeneity of Variance Across Sexes

Dependent Variable: Pretest			
F	df1	df2	Sig.
.162	1	147	.688

Note. a Design: Intercept + sex

Table 9

Tests of Normality - Pretest

	Kolmogorov-Smirnov[a]		
Sex	Statistic	df	Sig.
Male	.092	58	.200*
Female	.082	91	.173*

Note. *. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

With all assumptions met, independent t-tests were conducted on differences of mean pretest NOS scores between males and females study wide. The results of the cross course section independent t-test were not significant, t (148)= -.162, p=.919, df = 147, indicating that there were not significant differences in the mean NOS score between male and female undergraduate students across all course sections. See Table 10 for the independent samples t-test across course sections. Due to the p-value being greater than 0.05, the researcher failed to reject the null hypothesis, stating that there was no statistical difference in the mean NOS posttest score between male and female undergraduate students.

Table 10

Independent Samples t-test for Sex Differences Across All Course Sections - Pretest

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Sig. (2-tailed)	Mean Diff	Std. Error Diff
Equal variances assumed	.162	.688	-.102	147	.919	-.005	.0461
Equal variances not assumed			-.103	124.002	.918	-.005	.0458

Research Question Three

The third research question aimed to address students enrolled in experimental sections perceptions of the case based intervention. Students were instructed to circle a response, Yes, Partly, or No to two separate questions at the end of their post-test questionnaire, including;

1. Do you feel that the case studies positively affect your understanding of the nature of science?
2. Do you feel that the case studies positively affect your understanding of course content?

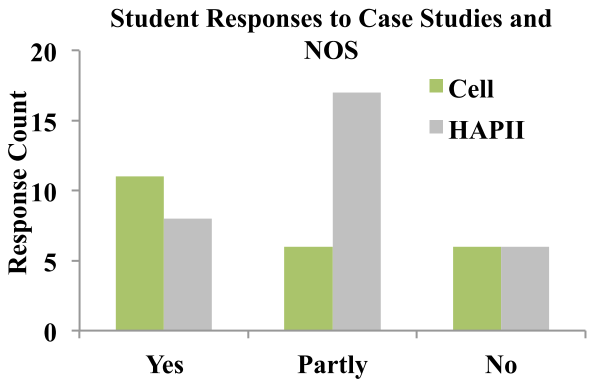
Totals of student responses are presented in Table 11.

Table 11

Counts of Students' Responses Indicating Affect of Case Studies on Understanding of NOS or Course Content

		Yes	Partly	No
Cell Bio	NOS	11	6	6
	Content	3	4	16
HAPII	NOS	8	17	6
	Content	2	5	24

Cellular and Molecular Bio students largely (47%) reported "Yes" for perceiving a positive affect from the case studies on their understanding of nature of science and largely (69%) reported "No" for perceiving a positive affect from the case studies on their understanding of course content. Human Anatomy and Physiology II students largely (54%) reported "Partly" for perceiving a positive affect from the case studies on their understanding of nature of science and largely (77%) reported "N" for perceiving a positive affect from the case studies on their understanding of course content. Figure 6 presents a graphical representation of these findings.



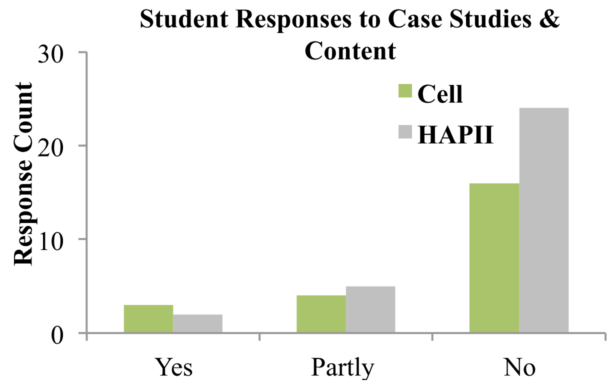


Figure 6. Graphical representation of student responses to the effects of case studies on their understanding of nature of science and course content.

CHAPTER FIVE: CONCLUSIONS

Overview

The results of this study highlight the strengths of historical CBI implementation to explicitly teach and impart greater understanding of the nature of science, chiefly related to sociocultural influences, role of imagination, tentativeness, epistemology of theories, epistemology of laws, theory and law relationship, subjectivity, and scientific methodologies. The experimental group sections included in this study were given historical case study assignments that explicitly addressed aforementioned NOS aspects as well as incorporated course content. On assessment of their understanding of NOS as measured by the VOSE questionnaire, experimental groups showed statistically significant increases in their NOS understanding as compared to their control group counterparts that were only taught with traditional, didactic pedagogies. This final chapter presents the overall findings of this research as related to other studies, presents limitations, and offers further recommendations for study.

Discussion

The main purpose of this study was to examine the effects of historical, case-based instruction on undergraduate biology students understanding of the nature of science. Heralded as a critical component of scientific literacy, nature of science refers to the epistemological and ontological underpinnings of science as an entity (Clough, 2006). Despite persistent calls from science education reform documents to address NOS concepts, NOS content and instruction remains largely missing within our Nation's educational arena. Meanwhile, reports of low scientific literacy and understandings of NOS within our student population remain subpar (Lederman, 2007; Whalen & Shelley, 2010).

After over a decade long dearth in the NOS literature body examining practical instructional strategies, a growing body of research is pointing to explicit, constructivist based strategies. However, due to the resistance to teach and learn NOS on the part of teachers and students, research has pointed to instructional strategies that also tie in the already designated content. With few studies incorporating all aforementioned elements and even fewer focusing on undergraduate science students, this study aimed to contribute to the slowly growing literature body by examining effects of historical case studies on undergraduate biology students on their NOS understanding, investigating differences in NOS understanding between males and females, and examining their perceptions of historical case study implementation.

Research Question One

The main research question for this study focused on the effects of implementation of historical CBI on undergraduate students enrolled in two separate biology courses, Cellular and Molecular Biology and Human Anatomy Physiology II. The Cellular and Molecular Biology course was a biology major's course, taught on the university's main campus, and offered two course sections. The two course sections were assigned to experimental and control conditions by the course instructor and consisted of a total sample of 26 students and 23 students, respectively. The Human Anatomy and Physiology II course was a non-majors course, taught on the sister campus and offered four sections. The course instructors were assigned experimental and control sections, which consisted of 43 students and 57 students, respectively.

Separate ANCOVA statistical tests were performed comparing the mean NOS scores between experimental and control sections of both courses. Significant differences in NOS scores between experimental and control sections were observed for both Cellular and Molecular Biology and Human Anatomy and Physiology II. However, it should be noted that Cellular and

Molecular Biology students exposed to historical CBI had a larger increase in their average NOS score when compared to their Human Anatomy and Physiology II counterparts. The Cell and Molecular Biology students had a mean gain between pre and posttests of 0.315, while the Human Anatomy and Physiology II students had a mean gain of 0.162. However, it is important to note that this difference in scores between majors and non-majors may be due to the selection of different course studies for the distinct courses.

In a similar study comparing NOS differences among natural science and non-science majors, Miller et al. (2010) found no differences in the understanding of NOS among the two groups. The two course section groups in this study also did not have significant differences between the pretest means prior to the CBI intervention. Further studies examining differences in affects of CBI on the two populations is warranted due to the limited literature body on the issue.

Overall, the positive effects of historical CBI as indicated by the results of this study are similar to Rudge and Howe (2009) who indicated increases in 8th grade student understanding of NOS following utilization of CBI and Paraskevopoulou and Koliopoulos (2011) who also reported enhanced high school biology students understanding of NOS as related to observations and inferences, empirical evidence, imagination and creativity, and subjectivity in science. More related to this study's population, Clough et al. (2010) and Eshach et al. (2014) also reported significant increases in undergraduate student understanding of NOS after utilization of historical CBI. Eshach et al. (2014) required undergraduate students to not only complete historical case based instruction, but also create their own historical case studies and present them to their class. This may be an option for increasing student and teacher buy-in, by having students responsible for the development of the cases and increasing the explicit-reflective aspect of historical CBI through student creation of historical stories.

Finally, there was a higher frequency of students have “stronger” opinions, worth a potential score of 5/5 on the VOSE instrument, within experimental course sections. Thus, it can be inferred that the intervention not only was successful in increasing student understanding of NOS, but also student confidence in their understanding, often referred to as self-efficacy. However, while both sections did showed statistically significant improvement in their understanding of NOS, both course sections mean score still is sub-par, indicating that more is needed to raise undergraduate students understanding of NOS.

NOS constructs. Looking more closely at the results related to the first research question, further inferences can be made. The VOSE instrument assessed eight main ideas related to the nature of science, including; socio-cultural influence, use of imagination, tentativeness, theory epistemology, law epistemology, theory-law relationship, subjectivity of observations, and scientific methods. While the overall mean score was used to statistically analyze the effects of the history based case studies, mean scores on individual NOS item analysis provides a greater picture of the sample’s NOS knowledge. Discrepancies in mean scores for the individual NOS items as included in the VOSE for pretest and posttest scores across all course sections can be seen in Table 12. These findings are similar to the findings of Miller et al. (2010) who also reported discrepancies of student understanding across NOS constructs.

Table 12

Pre and Post Mean Scores on Individual VOSE Items Across Course Sections

	Experimental Cell		Control Cell		Experimental HAP		Control HAP	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST
Overall	2.970	3.259	2.911	2.846	2.913	3.004	2.929	2.932
Sociocultural	3.36	3.608	3.456	3.225	3.014	3.304	2.887	3.086
Imagination	3.132	3.721	3.065	2.79	3.073	3.142	3.133	2.825
Tentativeness	3.051	2.968	2.765	2.512	2.825	2.999	2.923	2.862
Theory	2.849	3.214	2.795	3.124	2.799	3.000	2.873	2.937
Law	3.260	3.610	3.400	3.000	3.300	3.206	3.384	3.248
Theory vs. law	2.752	2.891	2.402	2.757	2.674	2.726	2.637	2.588
Subjectivity	2.992	3.347	2.855	2.660	2.807	3.068	2.959	2.942
Methods	2.404	2.714	2.527	2.447	2.597	2.859	2.583	2.524

Across the board, students held misinformed views on most of the NOS aspects, with the most uninformed views related to tentativeness, theory- law relationship, theory epistemology, and scientific methods. Meanwhile, students had retained higher scores on elements related to sociocultural, need for creativity, and epistemology of scientific law, which is in contrast to Allchin's (2001) statement that students naïve NOS perceptions often leads them to ignore the role of imagination and creativity. High scores related to the creativity of science were also seen in Parker et al.'s (2008) study examining NOS understanding among undergraduate atmospheric students and Smith's (2010) study examining historical short stories in a high school biology class.

Since this study was conducted at a Pennsylvania university, secondary education teaching standards for science were examined. Interestingly, out of all the NOS characteristics, the only ones that are included in PA State Teaching Standards are tentativeness, theory- law relationship, theory epistemology, and scientific methods (Pennsylvania Department of Education, 2017). It is not without coincidence that out of the few NOS concepts that are taught in Pennsylvania, undergraduate students score the most poorly on those specific concepts, with little change across pretest and posttest measures and experimental control groups. Thus, it can be inferred that these aspects are being taught inadequately and are resulting in strongly held misconceptions by the students.

The strength of these held misconceptions most likely resulted in the lack of significant change for students in the experimental sections and further studies would be needed to examine if a more intensive and longer study incorporating historical and explicit CBI could be effective in changing these strongly held misbeliefs. Similar strongly held misconceptions related to certain NOS aspects, such as scientific methods, were observed by Miller et al. (2010) who reported that their results indicated that

> faculty attempting to expand student views of the diversity in scientific methodology may face long-held student ideas about the "scientific method." This suggests that overcoming years of instruction depicting the empirical foundation of science as rigid or unidirectional will probably take more than isolated class activities to overcome. (p. 53)

An exception to aforementioned observations can be seen in the scores for epistemology of scientific laws. Across all course sections, student scores were adequate on pretest and posttests measures. It may also be worth noting that Pennsylvania remains one of the few remaining states to not yet adopt the Next Generation Science Standards, which emphasizes NOS, into their secondary science curriculum (Heitlin, 2015). A larger take away message can be seen in both the commonality and strength of these aforementioned misconceptions or inadequate understandings of NOS constructs, in that, a stronger pedagogical approach needs to implemented rather than a dismissive one. As Coley and Tanner (2015) state,

> the presence of misconceptions does not indicate deficits but rather a mind actively engaged with the world trying to construct explanations for complex phenomena. As such, misconceptions should not be regarded as simply wrong ideas to be fixed, but rather as common ways of thinking that can be important starting points for teaching and learning. In fact, misconceptions are likely key in driving conceptual change in education settings. (p. 3)

Research Question Two

The second research question for this study focused on assessing undergraduate students understanding of the nature of science, particularly differences in NOS between males and females. In total, 58 male and 91 female undergraduate students completed the VOSE pretest questionnaire. The results of the pretest revealed subpar understandings of nature of science across all of the course sections used in this study, which supports the notion that our students truly lack an adequate understanding of the underpinnings of science (Abd-El-Khalick et al., 2008; Lederman 2007).

The low level of NOS understanding was shown to be equal across student populations, with no statistically significant difference in NOS understanding in female versus male students. This is supported by Miller et al.'s (2010) findings that that undergraduate biology majors and non-majors had similar NOS views ranging from naïve to informed. The similarity of NOS understanding between sexes reported in this study is in contrast to Solomon, Scott, and Duveen (1995) who reported several sex differences related to NOS, which the researchers explained were related to the "well documented cautiousness of girls, or impetuosity of boys under test conditions" (p. 80). It is also in contrast to the notion presented by Mason, Boldrin, and Zurlo (2006) that gender and grade level can affect a student's understanding of NOS, with boys showing more absolutist positions than girls, leading to a hindered understanding of NOS.

Research Question Three

The third research question imbedded in this study focused on student perceptions of the effects of historical CBI on their understanding of NOS and course content. Consequently, the survey was only given to students enrolled in experimental sections of Cellular and Molecular Biology and Human Anatomy and Physiology II, resulting in a total of 54 students, 23 students in Cellular and Molecular Biology and 31 in Human Anatomy and Physiology II. Overall, the majority of students (77%) reported that the case studies at least partly affected their understanding of NOS knowledge. Conversely, the majority of students (96%) reported that the case studies did not affect their course knowledge.

From the responses on the student survey, it can be deduced that the case studies chosen for this study were not fully effective in incorporating the course content. This finding was further solidified in speaking with instructors of the experimental sections. All instructions felt that the case studies included some content that was not discussed in their courses and consequently became a frustration for the students. Thus, case studies must be more tailored, if not solely written for specific courses to increase student and teacher buy-in.

A significant portion of the literature surrounding NOS understanding and NOS instruction has been published related to students as well as instructors. For both populations, the research points to the need for NOS instructional activities to incorporate course content seamlessly within the activity or students and teachers will fail to see the importance of the activity (Abd-El-Khalick et al., 2008; Clough, 2006; Sahin & Koksal, 2010). In a similar study utilizing historical case studies, Smith (2010) found that students negative responses to the case studies, or a lack of student buy-in, could be due to their conceptions of a need for traditional learning, the skill level of the students, and a dissonance between their perceptions of their learning in comparison to their actual growth of knowledge related to NOS. For this study, similar observations were seen in scoring of the post-test VOSE questionnaires in which students scoring high NOS scores indicated no affect or partial affect of case studies on their understanding of NOS.

Implications

The results of this research have direct implications for both secondary and higher education educators, curriculum planners, and science education reformists. The inadequate NOS understanding demonstrated by undergraduate biology students, majors and non-majors, males and females, reaffirm the published works of Lederman (2007), reporting inaccurate NOS concepts in our student population. An understanding of nature of science has been postulated as the driving force behind scientific literacy, a foundation to a healthy democracy (Anastasia & Henry, 2015). Thus, the reoccurring findings of inadequate NOS understanding, especially in undergraduate students should be alarming to all.

Despite the reccurring findings and calls to include effective NOS instruction into curriculum, many educators are resistant in adopting instructional strategies often due to the need to cover specific course content. While this study reaffirms that historical case studies can be effective in increasing undergraduates understanding of science, many teachers and students, including the ones in this study, may still be resistant to implementation. Comments from course instructors involved in this study and results of student surveys indicated a stronger need for case studies to more intimately intertwined to specific course content.

Thus, historical case studies should either be constructed or at least adopted by the course instructor and with little time set aside for additional prep work, this could easily become one more obstacle related to teacher's adoption of NOS. For many teachers, a lack of knowledge related to historical events in science could be seen as a barrier. However, curriculum directors or case study developers could provide a list of historical events and NOS aspects highlighted, similar to Table 13, to educators to start them on a path of case study creation.

On a larger scale, curriculum and state standardized testing developers need to recognize the rationale and persistent call for adequate NOS instruction. For many states, including Pennsylvania NOS concepts fail to appear on state standardized tests, which indicates the failure of curriculum developers to recognize NOS' value. During the current age of high stakes testing and teachers prioritizing their content to prepare their students for standardized testing, the inclusion of NOS on such tests would increase the likelihood of educators seeing NOS as equal value to regular course content.

Table 13

Sample Historical Events in Biology that Could Be Used to Develop NOS Related Case Studies

General NOS Aspect	Biological Connections
Sociocultural Influences	Darwin not publishing after the reaction to the vestiges, but then changing his mind in order to publish before Wallace.
Creativity	Darwin, natural selection, and the analogy of artificial intelligence.
Tentativeness	The development of cell theory developed by collaborations by Schleiden, Schwann, and Virchow disproving spontaneous generation
Subjectivity	Pasteur, who was a devout Catholic, conducting experiments to prove that cells could not spontaneously generate.
Theories/Laws	Mendel's laws and the missing theory of heredity at the time.
No Universal Method	Watson and Crick relying on/ collaborating with many other researchers and methodologies to model the double helix structure of DNA.

Note. Adapted from McComas & Kampourakis (2015).

Finally, as one examines the different constructs that make up NOS, it should be noted that different science disciplines more heavily emphasize certain NOS aspects more than others. Biology rarely discusses epistemology of laws and more often emphasizes the development of theories, while for physics, the epistemology of laws is heavily emphasized. Thus, if the end result is to increase the scientific literacy of our population, which needs a foundational understanding of NOS, educational reform needs to consider recommending effective NOS instruction across science disciplines, rather than just in specific courses.

The significant increase in understanding of NOS across student types in this study speaks to the power of historical CBI as an instructional technique, which has the ability to affect both science major students and non-majors. However, while all experimental course sections in this study showed improvement of student NOS understanding following historical CBI, their collective posttest NOS scores are still subpar, which suggests the following: (a) More effective NOS instruction is needed to address deeply held misconceptions; (b) Effective NOS instruction needs to occur early on in a students education career; and (c) NOS concepts should be taught across science disciplines. Educational reformists, curriculum directors, secondary science educators, and higher education instructors should all heed the aforementioned suggestions, if the decades long call to increase NOS understanding in students is going to be achieved.

Limitations

Due to the nature of the design of this study, there are sufficient limitations arising from threats to both internal and external validity. Threats to validity stemmed from test sensitization due to students being exposed to the VOSE instrument during pretesting. The pretest also appeared to have an impact on external validity, with participants more frequently selecting "uncertain/ no comment" for entire items and in some cases, whole questionnaires increased on the posttest. Bryman (2015) explains that with a pretest design, individuals can become better at a test or become fatigued or bored with the test after having completed it before.

A similar study eliciting a Solomon Four Group Design is warranted to examine the affects of the pretest. The Solomon Four Group Design provides more rigorous control of a study by examining changes in groups after interventions in experimental and control groups by also including groups with pretests and groups with without pretests (Ary, Jacobs, Sorensen, & Walker, 2013).

Furthermore, the higher frequency of selecting one answer to whole portions of the posttest questionnaire could have also resulted as a compounded factor between test sensitization and impact of participant roles among the control group individuals since it was obvious that they did not experience any of the case based interventions. The aforementioned could have caused the aforementioned outliers and most likely explained the close to significant value ($p=.062$) on Levene's Test for normality of variance.

Additional threats to the validity of this study stemmed from the non-random selection of participants into groups. However, analysis of the pretest scores showed that despite the lack of randomness, course sections were equivalent in the inadequate understanding of NOS as indicated by the VOSE questionnaire. Further limitations of this study are found regarding the truthfulness of responses, which was addressed through emphasis of anonymity.

Moreover, since this study was conducted in introductory biology courses, the sample population of students was assumed to be homogenous, with no significant differences preexisting in the different groups due to the random assignment of course sections to either control or treatment groups. However, since students individually enrolled in course sections, rather than being randomly assigned, inherent differences among students in the different groups most likely resulted. The inherent differences within the student sample were evidenced by the wide range in age and life experience reported within the Human Anatomy and Physiology II courses.

The sample population also presents limitations of application to more diverse settings including other higher education institutions. Application of the results of this study is also limited by the small sample size, focus of content on one particular science disciple, and the lack of resources regarding quantitative assessment of student understanding of NOS and the implementation of historical case studies in undergraduate science courses. Another limitation stems from the instrument used in this study. The VOSE was initially written for Chinese students and was later translated to English. Some of the wording in the instrument reads somewhat awkwardly, most likely due to the language differences. Additionally, this study was conducted over a relatively brief period of time and included only three historical case studies. A longer intervention examining the impact of frequent case studies conducted over the duration of a semester may serve to provide more reliable and generalizable results. Finally, this study utilized different instructors with varying pedagogical practices, instructional techniques, and NOS understandings. The variance among the instructors can also be viewed as a limitation despite the consistency of the historical case studies and subsequent explicit NOS discussion.

Recommendations for Future Research

To further strengthen the argument that student understanding of NOS can be enhanced by historical case based instruction, the following additional research is recommended:

1. To increase student and teacher buy-in in regard to teaching or learning NOS, the case studies must be more tailored to the specific content taught in the course and the skillset of the student population. Thus, a similar study incorporating historical case studies that are tailored to specific courses is warranted.
2. There were several NOS constructs that were pervasive in their low scores across course sections and testing. These strongly held misbeliefs might need a stronger intervention with case studies incorporating elements that have students recognize their conceptions, rationalizing them within the context of the case study, and restructuring their conceptions towards more accurate understandings. It is

recommended that future NOS studies incorporating historical CBI also include components that students to reflect on previously held misconceptions.

3. As the individual mean scores on separate VOSE items revealed, a longer study across several modules and with more case studies is needed to see if strongly held misconceptions related to NOS aspects, such as those seen on the difference between a theory and law, can be effectively addressed using this intervention.
4. There was an apparent difference in NOS understanding between the students enrolled in the biology majors course, Cellular and Molecular Biology, and those enrolled in the non-majors course, Human Anatomy and Physiology II. A further study is warranted to examine possible differences in the two populations and the applicability of the historical, explicit case based instruction for both populations.
5. Since this study only focused on biology courses, a similar study focused on other science disciplines, particularly with the emphasis placed on different NOS aspects, is warranted.
6. This study only aimed to assess the understanding of NOS in undergraduate students. Meanwhile, the literature suggests that an instructor's understanding of NOS can impact their likelihood of adopting effective NOS instructional techniques. Consequently, further studies assessing higher education science instructors understanding of NOS are needed.
7. On a larger scale, this study recommends that primary and secondary education institutions focus and integrate NOS more heavily into the curriculum and more accurately, particularly in regard to tentativeness of science, the epistemology of a

theory, the epistemology of a law, the difference between theories and laws, and varying methodologies used in science.

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APPENDIX A: Survey Questions

Follow up Survey Questions on Posttest

Circle one answer.

1. Do you feel that the case-based instruction activities enhanced your understanding of the nature of science?

   Yes Partly No

2. Do you feel that the case-based instruction activities enhanced your understanding of the course content?

   Yes Partly No

APPENDIX B: Participant Letter

The Liberty University Institutional
Review Board has approved this
document for use from1/18/2017 to -- \s\

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

CONSENT FORM

The Effects of Case-Based Instruction on Undergraduate Biology Students' Understanding of the Nature of Science

Amy Burniston
Liberty University
School of Education

You are invited to be in a research study of the impacts of historical case-based instruction (CBI) on undergraduate students perceptions of the nature of science (NOS). You were selected as a possible participant because you are enrolled in an undergraduate biology course with an instructor participating in this study. Please read this form and ask any questions you may have before agreeing to be in the study.

Amy Burniston, a doctoral candidate in the School of Education at Liberty University, is conducting this study.

Background Information: The purpose of this research is to study the effects of historical case study implementation on undergraduate student's understanding of the nature of science.

Procedures: If you agree to be in this study, I would ask you to do the following things:
1. Complete the Views of Science and Education Questionnaire before an instructional unit. (15 minutes)
2. Complete the Views of Science and Education Questionnaire after an instructional unit. (15 minutes)

Risks and Benefits of being in the Study: The risks involved in this study are minimal, which means they are equal to the risks you would encounter in everyday life. No foreseeable risks are associated with participation in this study. While this study does not extend any direct benefits to you, information gained in this study may contribute to science education reform.

Compensation: Participants will not be compensated for participating in this study.

Confidentiality: The records of this study will be kept private. In any sort of report I might publish, I will not include any information that will make it possible to identify a subject. Research records will be stored securely, and only the researcher will have access to the records. The questionnaires will be anonymous, data from the questionnaires will be aggregated in a password protected Excel spreadsheet, and all data will be deleted after 3 years.

Voluntary Nature of the Study: Participation in this study is voluntary. Your decision whether or not to participate will not affect your current or future relations with Liberty University or Mercyhurst University. If you decide to participate, you are free to not answer any question or withdraw at any time prior to submitting the survey without affecting those relationships.

Contacts and Questions: The researcher conducting this study is Amy Burniston. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact her at aburniston@mercyhurst.edu. You may also contact the researcher's faculty advisor, Scott Watson, at swatson@liberty.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher, **you are encouraged** to contact the Institutional Review Board, 1971 University Blvd., Green Hall Ste. 1887, Lynchburg, VA 24515 or email at irb@liberty.edu.

Please notify the researcher if you would like a copy of this information for your records.

Statement of Consent: I have read and understood the above information. I have asked questions and have received answers. By completing the Views of Science and Education Questionnaire, I consent to participate in the study

APPENDIX C: ANCOVA Results for Experimental and Control Sections of Both Cellular and Molecular Biology and Human Anatomy and Physiology II Biology

Tests of Between-Subjects Effects

Dependent Variable: posttest

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2.911[a]	4	.728	13.560	.000	.303
Intercept	11.191	1	11.191	208.530	.000	.625
pretest	.105	1	.105	1.957	.164	.015
section	2.858	3	.953	17.754	.000	.299
Error	6.709	125	.054			
Total	1170.390	130				
Corrected Total	9.620	129				

a. R Squared = .303 (Adjusted R Squared = .280)

Pairwise Comparisons

Dependent Variable: posttest

(I) section	(J) section	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
ExpCell	ConCell	.446*	.071	.000	.256	.637
	ExpHAP	.216*	.063	.005	.046	.386
	ConHAP	.363*	.058	.000	.209	.518
ConCell	ExpCell	-.446*	.071	.000	-.637	-.256
	ExpHAP	-.230*	.066	.004	-.407	-.053
	controlhap	-.083	.061	1.000	-.245	.079
ExpHAP	ExpCell	-.216*	.063	.005	-.386	-.046
	ConCell	.230*	.066	.004	.053	.407
	ConHAP	.147*	.052	.030	.009	.285
ConHAP	ExpCell	-.363*	.058	.000	-.518	-.209
	ConCell	.083	.061	1.000	-.079	.245
	ExpHAP	-.147*	.052	.030	-.285	-.009

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.