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ARTICLE

An Explicit and Reflective Approach to Teaching Nature of Science in a Course-Based Undergraduate Research Experience

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Abstract

Involving undergraduate STEM majors in authentic research has been cited as being an imperative goal in advancing the field of science and preparing students for careers and post-graduate educational programs. An important component of authentic research that is often overlooked is student understanding of the Nature of Science (NOS) and how this relates to novel research. Previous research in these authentic settings appears to have depended upon an implicit approach to the teaching of NOS, and, not surprisingly, these studies revealed that students' understandings only marginally improved. Research in authentic setting since indicates students develop deeper understandings of NOS in general, but struggle with more abstract concepts, such as the role of social and cultural influences as well as imagination and creativity in science. Therefore, the purpose of this qualitative study is to examine student understanding of these NOS concepts as they are engaged in novel research. NOS concepts were introduced using an explicit and reflective approach. Specifically, students were engaged with reflection questions, in-class discussions, historical narratives, and autobiographical stories of the instructor as they explored the NOS concepts and how these relate to scientific research. Student NOS understandings ($n=16$) were measured pre/post using the SUSSI with semi-structured interviews taking place at the end of the course. The findings from the interviews revealed that students understanding of the NOS concepts improved. Students came to better understand how society and culture impact scientific research, and how imagination and creativity are used throughout the entire scientific process. Students largely cited the reflection questions and in-class discussions as contributing to their change in understanding in their responses to how their views changed. In discussing society and culture, students noted that they better understood how society impacts what and how research is conducted as well as noting instances where gender bias is still present in science today. Likewise, students indicated during the interviews how they came to understand how imagination and creativity can be found throughout the entire scientific process instead of just the stage where a research question is posed. This study shows the importance of discussing NOS using an explicit/reflective approach as it relates to authentic research in helping students develop deeper understandings.

Keywords Nature of Science · Narratives · Imagination and Creativity · CURE · Social and Cultural Influences

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1 Introduction

Educators and policymakers alike agree that student understanding of the Nature of Science (NOS) is an important component in scientific literacy (American Association for the Advancement of Science [AAAS], 2011; National Research Council, 2003; Weaver et al., 2008). NOS is often defined as the epistemologies that contribute to science as a way of knowing that differs from other disciplines (Akerson et al., 2000; Bell et al., 2003; Khishfe & Abd-El-Khalick, 2002). Whereas there is no definitive consensus on the components that define NOS, most writers appear to refer to NOS as a set of overarching concepts that relate to science as a process and how this process functions within a society and culture as it aims to contribute knowledge and understanding about our natural world. For students to have a firm understanding of science, they must come to understand and appreciate how science as a process works and how this process is a social and human endeavor that impacts daily life. Most science educators would regard merely understanding concepts associated with NOS as insufficient. To truly understand these issues with reference to the process of science, students need to go beyond reflecting on work done by others, they must themselves do science. These considerations point out the potential value of authentic research experiences in helping students develop a robust understanding of the nature of science as a process.

Authentic experiences can be defined as experiences where students are involved in the process of science itself (Auchincloss et al., 2014; Dolan, 2016; Wei & Woodin, 2011). These types of experiences have taken place in many forms including inquiry, undergraduate research experiences (URE), or course-based undergraduate research experiences (CURE). These authentic experiences are important for STEM majors because they can lead to the student persisting in the field, improving technical and cognitive skills related to science, and enhancing their content knowledge. Authentic experiences also enable enculturation within science itself and can even help the student develop more sophisticated understandings of science as a process (Sadler & McKinney, 2010). However, the assumption that students will develop more sophisticated understandings about NOS implicitly just by doing science is problematic. The sophisticated/informed view of NOS refers to a comprehensive understanding of what science is and what scientific practice involve. For example, the sophisticated view of NOS recognizes the role of creativity, imagination in scientific practice, as well as the influence of social, cultural factors on the development of scientific knowledge. By understanding the fundamental aspects of science, individuals can develop better scientific literacy, enabling them to make informed decisions when engaging with scientific issues.

Research on NOS understandings in an authentic context has shown that students do develop deeper understandings of certain aspects of how science is done. Often the findings of this type of research indicate more surface level understandings of data collection and analysis and the general "messiness" of science. In fact, this surface level understanding can reinforce misconceptions of other critical concepts, such as the belief of the lack of social and cultural influences and the lack of creativity and imagination in scientific investigation (Aydeniz et al., 2011; Bell et al., 2003; Russell & Weaver, 2011). In fact, studies have shown that even graduate students and professional scientists have misconceptions regarding NOS, which indicates that "doing science" is not enough to understand the epistemologies associated with understanding science as a process (Aydeniz & Bilican, 2014; Bayir et al., 2014; Schwartz & Lederman, 2008). Therefore, it stands to reason that science majors' views pertaining to NOS are probably unsophisticated and need to be addressed. A better approach has been found in an explicit and reflective approach to teaching NOS (c.f. Akerson et al., 2000). In this teaching approach, NOS is explicitly discussed, often through the use of contextualized examples, and students have opportunities to reflect on their learning as well as past and present learning experiences as they relate to NOS and science as a process. This explicit and reflective teaching approach has been shown to be more effective in lieu of an implicit approach that purports that students will naturally gain a deeper understanding of NOS through hands-on engagement, which often takes the form of inquiry or a CURE setting (Burgin & Sadler, 2016; Duschl & Grandy, 2013; Schwartz et al., 2004). However, more abstract NOS concepts such as social and cultural influences and imagination and creativity have been shown to need more contextualization even within an authentic context in order for students to develop more sophisticated views (Schwartz et al., 2004).

Promising research on the use of highly contextualized examples in the form of historical narratives to teach NOS has helped students develop deeper understandings (e.g. Dai et al., 2021). Moreover, the research on NOS that has been done in authentic settings still largely adheres to the implicit teaching approach. Therefore, the purpose of this study is to explore how an explicit/reflective approach using highly contextualized examples in an authentic context impacts undergraduate science majors' NOS understandings.

2 Literature Review

2.1 Student NOS Understanding in an Authentic Learning Context

Previous research examining student NOS understanding in an authentic learning context, such as a research-based course or a CURE, have done so largely while employing an implicit teaching approach (Charney et al., 2007; Jeffrey et al., 2016; Russell & Weaver, 2011). It was believed that the hands-on experience itself would help students develop more sophisticated views of NOS. For example, the study by Russell and Weaver (2011) compared student NOS understandings between students in a traditional confirmatory laboratory class, students in a lab class that used an inquiry teaching approach, and students in a CURE laboratory setting. The researchers concluded that overall students in the CURE setting developed more sophisticated views in comparison to students in the traditional or inquiry labs. However, the NOS views of students in the CURE largely pertained to the complexity of science itself, and students still maintained numerous misconceptions (Russell & Weaver, 2011). A lack of sophisticated NOS views has been shown to be problematic in that many of these students go on to enter into the scientific field and teach future generations. For example, the study by Aydeniz and Bilican (2014) examined science graduate students NOS understandings. The researchers found that many of the interviewed graduate students held naïve views pertaining to social and cultural impacts and the use of creativity and imagination in science. In fact, some graduate students stated that creativity plays no role in science. The researchers attributed the graduate students' naïve understandings to the lack of attention or explicit instruction on NOS within their own educational backgrounds. These findings are troublesome considering that many graduate students act as Teaching Assistants (TAs) to undergraduates, and if the graduate student possesses a naïve view of NOS, then that viewpoint may be perpetuated within their teaching thus reinforcing the misconceptions held by their undergraduate students (Aydeniz & Bilican, 2014).

These naïve views held by graduate students regarding NOS are not surprising when considering the results of studies that have examined NOS views of practicing scientists (Bayir et al., 2014; Schwartz & Lederman, 2008). For example, the study conducted by Schwartz and Lederman (2008) interviewed 24 scientists in order to better understand how scientists understand NOS across science disciplines and within the context of their work as a researcher. The researchers found that many scientists had informed views regarding certain aspects of NOS, but some of their views were considered more naïve. For example, not all of scientists interviewed believed creativity has a role in the scientific process, and many failed to see the social/cultural embeddedness of science and how that impacts how/why scientists pursue knowledge. Schwartz and Lederman (2008) concluded that engaging in scientific inquiry is not enough to ensure the development of sophisticated understandings of NOS, but that opportunities for reflection are crucial to helping the development of NOS understanding. The researchers conceded that not having NOS views that completely align with benchmarks of scientific literacy does not necessarily play a role in one's ability and success as a practicing scientist. But rather, when the scientists were asked to reflect upon their professional work and how NOS ideas played a role in that work many of the scientists revealed during the interviews that their original views had changed. In fact, several scientists stated that they had never been prompted to consider their work from a philosophical lens and the opportunity to reflect imparted a more elaborate reflection on their work and experiences. It is important to note that often scientists are the teachers of their craft to future generations. To help the general population, and even future generations of young scientists, develop informed views of what science is and how its process is influenced and practiced the appropriate epistemological understandings need to be taught explicitly and reflectively to advance understanding (Schwartz & Lederman, 2008). Moreover, opportunities of reflection on the engagement of research have been found to be important for both novice and seasoned scientists when developing views related to NOS.

Moreover, studies examining the use of an explicit and reflective teaching approach to NOS in an authentic context, such as a CURE, have shown to help students improve their understandings (Burgin & Sadler, 2016; Moss et al., 2018; Schwartz et al., 2004). These studies have found that when explicit and reflective NOS instruction is coupled with the CURE setting, students gain not only deeper understandings of NOS, but also better understand how NOS is related to the actual practice of science itself. Furthermore, these studies also indicated that reflection on NOS within the authentic context is not enough. For example, Burgin and Sadler (2016) compared student NOS understandings of students who participated in a CURE course where students were divided into groups where NOS instruction was described as reflection with no explicit instruction, and explicit and reflective instruction. The researchers found that student reflection on the authentic scientific practice was not enough for students to overcome misconceptions as it relates to NOS. However, when reflection is coupled with explicit instruction students made substantial gains in their understandings in comparison to students in the implicit instructional group. The students in the implicit group not only did not improve their NOS understandings, but also maintained misconceptions as well.

2.2 Contextualization of NOS Enhances Student Understanding

Research within authentic learning contexts has demonstrated that implicit inquiry instruction is not enough to overcome misconceptions related to NOS and indicates that NOS instruction should be an explicit cognitive learning objective (Clough, 2006). For example, a study by Khishfe and Abd-El-Khalick (2002) compared two inquiry-oriented classes where one instructional approach used an explicit/reflective approach to teach NOS and the other course followed an implicit method relying on the nature of the inquiry activities itself to inform the NOS concepts. In this study, the researchers found that students in the explicit/reflective group developed more informed views of NOS versus their counterparts. The researchers note a commonly held assumption about the implicit teaching approach to NOS is that students doing hands-on science will automatically develop more sophisticated NOS views as a by-product of engagement. This is an assumption that has been held by other researchers and has been shown to repeatedly fall short in comparison to students that are engaged in the same hands-on science and given opportunities to explicitly discuss and reflect on how the practice of that science relates to NOS (Burgin & Sadler, 2016; Charney et al., 2007; Moss et al., 2018; Schwartz et al., 2004).

However, many studies that utilize the explicit and reflective teaching approach report that students still fail to develop more sophisticated understandings of the NOS aspects of culture and creativity in science (Akerson et al., 2000; Duschl & Grandy, 2013; Khishfe & Abd-El-Khalick, 2002; Russell & Weaver, 2011; Schwartz et al., 2004). The researchers cite the reasons for these underdeveloped views being that these NOS conceptions of culture and creativity are more abstract and therefore require a richer contextualization beyond just an explicit and reflective approach while students are engaged in the actual practice of science (Schwartz et al., 2004). Therefore, it is understood that the explicit and reflective teaching approach is important in helping students develop more sophisticated understandings of NOS, but the explicit/reflective approach may not be enough. In order to help students overcome inherent misconceptions as they relate to science, the use of contextualized examples must be coupled with the explicit instruction (Clough, 2006; Williams and Rudge, 2019).

According to Clough (2006), the explicit and reflective approach to NOS instruction happens on a continuum of contextualization. Decontextualized examples, meaning examples not directly linked to subject matter, are important at the beginning when first introducing students to NOS concepts so as to not muddy the waters with complex science content. However, decontextualized instruction does not help the student overcome inherent misconceptions. It is through explicit and reflective instruction that is moderate to highly contextualized, meaning an example that contains science content and how that knowledge was developed, that will allow students to exit from the instruction with a new perspective. Research has shown that the use of moderate contextualization in the form of reflection questions followed by in-class discussion can help students deepen their understanding of NOS (Schussler et al., 2013; Schwartz et al., 2004). In these studies, the context is derived from the experiences students are participating in while engaged with either the inquiry-lab setting (Schussler et al., 2013) or in an authentic research experience (Schwartz et al., 2004). Both studies found that using reflection questions while maintaining an explicit and reflective teaching approach helped students gain a more sophisticated understandings of NOS. Schwartz et al. (2004) recommended that explicit and reflective NOS activities should be planned and that students' attention should be drawn to NOS ideas using a variety of methods such as discussion, reflection questions, historical examples, and authentic science experiences. Schwartz and colleagues concluded in their study that doing authentic science is not enough. Active reflection and explicit discussions are key to helping students develop more sophisticated NOS views. For students to gain deeper understandings their reflections require a context. Since the authentic context is not always enough, it is increasingly more important to provide students with examples to create a basis of understanding to then allow for a deeper and more sophisticated reflection of their experience within the authentic context. One way this may be accomplished is through the use of a historical or contemporary example. The use of a historical or contemporary episode may be viewed by the learner as a new or alternative perspective, which may enact enough cognitive dissonance to overcome the misconception and enact conceptual change (Clough, 2006).

Promising research using a historical narrative approach to teaching NOS has found that the rich contextualization of the narrative coupled with an explicit and reflective teaching approach has helped students develop more sophisticated understandings (Dai et al., 2021; Williams and Rudge, 2019). For decades, researchers have advocated the use of History of Science (HOS) as an effective strategy for helping students deepen their understanding of science as a process by offering a context that humanizes the practice of science (Allchin, 2011; Matthews, 1994; Monk & Osborne, 1997). In order to prevent the use of HOS as an "add-on" component within a science course, advocates have suggested that HOS be incorporated throughout the entirety of a course in the form of stories (Clough, 2011). Empirical research on the use of HOS in the form of narratives has found that students develop a more sophisticated understanding of NOS than their counterparts (Dai et al., 2021; Williams and Rudge, 2019). A recent study by Williams and Rudge (2019) assessed student NOS understandings following the use of a historical narrative pertaining to Mendelian genetics. Using the SUSSI instrument followed by semi-structured interviews, the researchers found that student NOS understandings pertaining to imagination and creativity greatly improved following the story intervention. Similarly, a study by Dai et al. (2021) found that students' understandings of NOS concepts relating to social and cultural influences, specifically relating to gender bias, and the use of creativity in science improved following a historical narrative pertaining to the discovery of the structure of DNA. These studies show how the use of HOS in the form of narratives can provide the rich contextualization needed to help students improve their NOS understandings.

3 Research Questions

The purpose of this study is to explore how the use of moderately contextualized reflection question and highly contextualized examples in the form of historical narratives coupled with an explicit and reflective teaching approach may impact students' NOS understandings. This study specifically targets undergraduate STEM majors enrolled in a CURE. The research questions that guide this study are as follows: 1. How does the use of reflection question, in-class, discussions, narratives, and participation in this CURE setting influence student understanding of the NOS concept related to the social and cultural influences in science?2. How does the use of reflection question, in-class, discussions, narratives, and participation in this CURE setting influence student understanding of the NOS concept related to the use of imagination and creativity in scientific investigations?

The framework that guides this study is Conceptual Change. Many of the studies cited within the literature review utilize conceptual change as the theoretical framework. This framework is most appropriate for research pertaining to NOS. Therefore, the theoretical framework that guides this study is Conceptual Change Theory. This theory purports that in order for a student to achieve either assimilation or accommodation, there must first be a dissatisfaction with the current order of understanding as it relates to a concept (Posner et al., 1982). In this theory, assimilation refers to the student applying a known concept to new knowledge. However, if the new knowledge does not align with what was previously believed to be "correct," then the student must undergo an accommodation where the existing knowledge is either reorganized or replaced by the new understanding.

The use of the explicit and reflective teaching approach used to introduce the targeted NOS concepts in this study aligns with the theory of Conceptual Change. *Explicit* refers to a teaching approach where the NOS concepts are discussed openly where students attention is drawn directly to the concept. *Reflective* refers to the student actively developing their own understandings based on explicit teaching. This explicit and reflective teaching approach provides the students with new knowledge and then allows for discussion and reflection to occur where students have the opportunity to either assimilate the new knowledge or create an accommodation to overcome a misconception.

4 Methods

4.1 Context and Participants

This study took place at a Midwestern university with biology majors in a CURE where the focus of the research was on regenerative pathways in planarian flatworms. A CURE can be defined as a course where students are involved in novel research (Auchincloss et al., 2014). The CURE met four days a week (Monday–Thursday) for four hours each day. The course had a total of 16 students ($n=16$). Student demographics for this study can be found in Table 1.

Table 1 Descriptive statistics of the study population ($n=16$)

Demographic	% of total responses
Gender	
Male	50% ($n=8$)
Female	50% ($n=8$)
Race	
Caucasian	62.5% ($n=10$)
Asian	31.25% ($n=5$)
Hispanic	6.25% ($n=1$)
Age range	
18–20 years old	37.5% ($n=6$)
21–24 years old	50% ($n=8$)
25 + years old	12.5% ($n=2$)
Year in school	
Sophomore	18.75% ($n=3$)
Junior	12.5% ($n=2$)
Senior	62.5% ($n=10$)
Senior that graduated	6.25% ($n=1$)

The learning goals of this course were two-fold: (1) to help students reflect on the practical experience they were gaining through conducting scientific research; (2) to gain deeper understandings of NOS through an explicit and reflective approach using reflection questions, historical narratives, personal stories of the instructor's work as a researcher, and in class discussions. The reflection questions, narratives, and in-class discussions were not in isolation of the research the students were involved in, but rather were designed to help students reflect upon how the research they were participating in has an impact on the scientific field. All NOS activities were discussed explicitly, and students were given opportunities to reflect individually, in their small groups, and with the class as a whole for each reflection question posed.

4.2 Study Design

This qualitative study ($n=16$) took place during an eight-week course in the Summer I 2019. Student understanding of NOS was measured pre/post (first day and last day of the course) using the Student Understanding of Science and Scientific Inquiry Questionnaire (SUSSI) developed and validated by Liang, Chen, and Chen (2008). This instrument utilizes both quantitative and qualitative measures using a Likert scale and open-response questions. The SUSSI measures six NOS concepts which are as follows: (1) observations and inferences; (2) change of scientific theories; (3) scientific laws vs. theories; (4) social and cultural influences on science; (5) imagination and creativity in scientific investigations; and (6) methodology of Scientific Investigation. For each NOS concept measured by the SUSSI, there are 4-Likert scale statements that students indicate whether they strongly disagree, disagree, uncertain, agree, or strongly agree for each statement followed by an open-response question for each concept where students can explain their reasoning and use examples to illustrate their thought process. The Likert items and scoring procedures can be found in Table 2. Following the post SUSSI, students were asked to participate in semi-structured interviews to better understand how their NOS conceptualizations may have changed over the eight-week course as well as to clarify how their answers had changed or stayed the same from pre to post. The interviews took place in a private room during the regular meeting time of the class and lasted approximately 30–40 min. The interviews were audio recorded and then transcribed.

Over the course of the 8-week summer session, students were introduced to the two targets NOS concepts, social and cultural influences and imagination and creativity, through a variety of methods which included reflection questions, in-class discussion, historical narratives, and personal autobiographical narratives of the instructor of record. Throughout the research that students were engaged in during the designated class time, there were numerous moments of what could be considered "downtime," meaning there was a waiting period between steps in the protocols students were using to investigate the research question and hypotheses. Often times, these periods of "downtime" would last upwards to an hour or longer. It was during these moments that students were asked to answer questions related to the targeted NOS concepts, engage in whole class discussions, and participate in listening to and responding to narratives used to further contextualize these concepts. The sections below described these reflection questions and narratives in more detail.

Table 2 NOS Likert items included in the SUSSI instrument

NOS concept	Statement item scoring
Observations and inferences	1A (+) Scientists observations of the same event may be different because the scientists' prior knowledge may affect their observations
	1B (−) Scientists observations of the same event will be the same because scientists are objective
	1C (−) Scientists observations of the same event will be the same because observations are facts
	1D (+) Scientists may make different interpretations based on the same observations
Change of scientific theories	2A (+) Scientific theories are subject to on-going testing and revision
	2B (+) Scientific theories may be completely replaced by new theories in light of new evidence
	2C (+) Scientific theories may be changed because scientists reinterpret existing observations
	2D (−) Scientific theories based on accurate experimentation will not be changed
Scientific laws vs. theories	3A (−) Scientific theories exist in the natural world and are uncovered through scientific investigations
	3B (−) Unlike theories, scientific laws are not subject to change
	3C (−) Scientific laws are theories that have been proven
	3D (−) Scientific theories explain scientific laws
Social and cultural influences on science	4A (−) Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies
	4B (+) Cultural values and expectations determine what science is conducted and accepted
	4C (+) Cultural values and expectations determine how science is conducted and accepted
	4D (−) All cultures conduct scientific research the same way because science is universal and independent of society and culture
Imagination and creativity in scientific investigations	5A (+) Scientists use their imagination and creativity when they collect data
	5B (+) Scientists use their imagination and creativity when they analyze and interpret data
	5C (−) Scientists do not use their imagination and creativity because these conflict with their logical reasoning
	5D (−) Scientists do not use their imagination and creativity because these can interfere with objectivity
Methodology of scientific investigation	6A (+) Scientists use different types of methods to conduct scientific investigations
	6B (−) Scientists follow the same step-by-step scientific method
	6C (−) When scientists use the scientific method correctly, their results are true and accurate
	6D (+) Experiments are not the only means used in the development of scientific knowledge

Developed by Liang et al. (2008). The statement items labeled as positive (+) were scored on a positive scale with strongly disagree scoring to strongly agree. The statement items labeled as negative (−) were scored inversely.

4.2.1 Reflection Questions Followed By In-class Discussion

During a standard class period, students were asked to answer reflection questions and then participate in a large group discussion. The reflection questions (see Appendix) were organized by topic and took place throughout the 8-week course. Each week focused on a different topic. Because of the nature of the course some topics spanned over two weeks depending upon the amount of downtime there was available as students engaged in the experiment protocols. The topics are as follows: (week 1) Media Myths of Research and Science (questions 1–3); (weeks 2 and 3) The Nature of Scientific Inquiry (NOSI) and Ethical Considerations (questions 4–7); and (weeks 4 and 5) Imagination and Creativity in Scientific Investigations & Social and Cultural Influence on Science (questions 8–10). Students would be asked to answer the assigned reflection question on their own in class, discuss in small groups, and finally participate in a large group discussion facilitated by the instructor of the course. The reflection questions were designed to give students an opportunity to reflect on the research they were doing in the CURE and how it related to targeted NOS concepts.

The topic of Media Myths of Research and Science was aimed to help students reflect on their own experiences of how they believe science is portrayed in the media, both news and popular culture, versus how they believe science actually is as a field in which they are majoring. During this topic, students watched clips from popular television shows and movies that portray science and were asked to note discrepancies between the fiction and reality of what they have experienced. These discussions were then further related to the research the students were engaged with in the course in that students were asked to reflect on how the novel research related to planarian regeneration may have a future impact on our society. This first topic introduces students to the NOS concept of how science influences society and culture and vice versa.

The next topic of the Nature of Scientific Inquiry (NOSI) and Ethical Considerations was used to help students understand the various aspects of the research process. Students were asked to reflect on a concept related to experimentation, such as the use of multiples, justification, replication, prediction, data/evidence, anomalous data, and purpose. Likewise, students were posed ethical as question relating to the planning and conducting of research with animals. This discussion led to how planarians are invertebrate animals, meaning they lack a spinal cord. This lack of a spinal cord means that these typical government regulations with regards to animal research are less strict. Discussions for this topic focused on the ethics surrounding the use of planarians as an animal model and how this impacts the research they were conducting in the course. Students also reflected and discussed how scientists handle anomalous data, how data is sometimes excluded from publications, and how scientists handle reporting this excluded data. These topics were further reinforced through the historical narrative about Edward Jenner (see Sect. 4.2.2).

The last topic discussed Imagination and Creativity and discussed Social and Cultural impacts in a more general context. Students were asked to reflect on whether or not they believed scientists used imagination and creativity in their investigations. Students were also asked to reflect on if they believed they had used their own imagination and creativity during the course. Likewise, students were asked to reflect on how society and culture impacts science and vice versa. These concepts were further reinforced through class discussions as well as through the use of the historical narrative pertaining to the discovery of the structure of DNA and through the use of autobiographical stories of the instructor of record (see Sect. 4.2.2). During the in-class discussion, the instructor of record discussed her personal experiences with how she has used imagination and creativity and how society and culture has influenced her research through funding opportunities as well as her experiences as a female scientist. These concepts were reinforced in the historical narrative related to DNA, thus giving students an additional opportunity to see examples of these concepts in play and reflect on how they relate to the scientific research in which they were engaged in the course.

4.2.2 Narratives — Historical and Autobiographical

As mentioned above, narratives were used to reinforce the NOS concepts first addressed using the reflection questions. These narratives also aided in further contextualizing the concepts as well as providing alternative examples to how these abstract NOS concepts can be exemplified. These stories were either historical narratives or personal stories from the instructor's professional research experiences. The purpose of these stories was to help students better understand the science concepts needed to understand the procedures used to conduct the research taking place in the course as well as to help students gain deeper insights into NOS and how it pertains to their current experience in the course.

4.2.3 Historical Narratives

Two historical narratives were used in this course. Both narratives were told using an interrupted story approach where during natural pauses in the story students are asked specific questions related to the NOS concept that is being exemplified. After students have a chance to write down their responses, a large group discussion takes place where students have an opportunity to voice their views regarding the topic. In this way, the instructor is able to determine student understanding and to help correct misconceptions or guide students to think deeper about the NOS topic and how it relates to the story and to the current research being done in the course and in the scientific community as a whole.

4.3 Edward Jenner and Vaccines

The first narrative focused on the story of the early smallpox epidemic and Edward Jenner's research into creating the first vaccine against the virus. This narrative lesson was written by the first author. This narrative took place during the week where ethics and NOSI were the themes that students were discussing.

This narrative was told in two parts. The first half of the story focused on historical accounts of the first records of the smallpox virus as well as how England handled outbreaks in the 1700s through the practice of inoculation, which was first tested on prisoners and orphans to determine its effectiveness. Following this account, the story was interrupted with reflection questions regarding the ethics of this practice as well as the necessity of evidence-based research. Following an in-class discussion, the story resumes with the history of Edward Jenner and how he created the first vaccine using the cowpox virus. At the conclusion of this half of the story, students are asked to reflect and then discuss how scientific understandings change with new or additional research as well as the importance of communicating scientific findings with the larger community. The ultimate purpose of this story is to help students understand how ethics in science changes over time, how scientific knowledge and understanding changes with research, and the importance of research and communication within the scientific community. Using an explicit and reflective approach to these concepts, these students were guided by the instructor during the class discussions to think about how the novel research they are doing in the course may impact the scientific community as well as the ethical precautions that must take place when conducting any research.

4.4 The Discovery of the Structure of DNA

The second historical narrative used focused on the discovery of the structure of DNA written by Dai et al. (2021). This narrative took place during the week where imagination/creativity and social/cultural factors in science were the themes that students were discussing. This story was also told using an interrupted technique where students were asked to reflect on the NOS concepts being conveyed in the story followed with in class discussions. The first half of the story told the traditional perspective of how James Watson and Francis Crick played crucial roles in discovering the structure of DNA. This half of the story focused on the NOS concept of imagination and creativity in scientific investigations demonstrated through Watson and Crick's unique approach of synthesizing data from other researchers to build a model of the structure of DNA. Students were asked whether they believed Watson and Crick used their imagination/creativity and if imagination/creativity are used in scientific investigations in general. Following the in-class discussion regarding this half of the story, the narrative resumes with the retelling of the same story (the discovery of the structure of DNA) only this time it is told from the perspective of a lesser known, yet very important, historical figure: Rosalind Franklin. This half of the story focuses on social and cultural influences in science noting how difficult it was for Franklin to conduct scientific research being a woman in the 1950s. At the conclusion of this half of the narrative, students are asked to reflect upon how culture impacted Franklin as well as how social and culture factors may continue (if at all) to impact scientific research today. The purpose of this narrative was to help students appreciate how scientists do use imagination and creativity in their investigations as well as how social and cultural factors impact what and how science studies occur. Through the explicit and reflective approach, students are asked to think and discuss how the research they are doing in the course may impact society as a whole and how they are using their own creativity to perform the procedures and interpret the data they are collecting.

4.4.1 Autobiographical Narratives from the Instructor

In addition to the historical narratives used in this course, the instructor used personal stories from her experiences as both a graduate student and a new faculty member doing research. The purpose of the instructor telling these personal stories was two-fold. First, the intention behind these stories was to help students find a connection with the instructor and to convey that she is a member of the scientific community who is still learning and making discoveries. Second, the additional purpose of these stories was to give the students a contemporary example of the NOS concepts that were conveyed in the historical narrative examples. The stories that the instructor told were specifically geared towards helping the students come to appreciate how she has used imagination and creativity during her career, and the types of social and cultural impacts her research does have and may have in the future. These personal stories were not shared in a structured manner nor did they have associated reflection questions, but rather the stories were shared as a large group discussion where students were able to ask questions during the telling.

4.5 Data Collection and Analysis

Informed consent took place on the first day of the course. All 16 students enrolled in the course consented to the study. To protect their anonymity, all identifying information and names were removed from all student artifacts and surveys. This study used the SUSSI to examine changes to students' views related to NOS as well as semi-structured interviews. The SUSSI was administered as a pre and post instrument. The semi-structured interviews took place following the students' completion of the post SUSSI, which took place on the last day of the course. Interviews lasted approximately 30–40 min to gain insight into their experience in the course specifically focusing on their views of the activities used in the course to deepen their NOS understandings (i.e., reflection questions, narratives, in-class discussions, participation in research). These semi-structured interviews were audio recorded and transcribed verbatim. All instruments, student artifacts, and interviews were built into the course as assignments. These measures were approved by and in compliance with the university HSIRB.

4.5.1 Quantitative Data

The SUSSI was administered to students on the first and last day of the course. The SUSSI has been tested for validity and reliability by Liang et al. (2008). Moreover, the study by Williams and Rudge (2019) has done additional reliability testing and has confirmed Liang et al. (2008)'s conclusions that this instrument is valid and reliable. The SUSSI was chosen for this study in lieu of the VNOS. The SUSSI has both quantitative and qualitative components to the instrument. Moreover, the Likert scale statements are repetitive in such a way that allows for ensuring consistency in student responses. Having both the quantitative and qualitative aspects within the same instrument also enables a triangulation of the data collected. The VNOS, though a popular instrument, is one that requires at least an hour for a student to complete. Interviews are also a necessary component for the interpretation of student responses to the open-ended questions. For the study described in this manuscript, timing would not have allowed for interviews to have taken place at the beginning of the course. Timing for this course schedule only allowed for interviews to occur at the conclusion of the course. The VNOS requires follow-up interviews when it is administered, meaning if the VNOS is used as a pre/post instrument then pre/post interviews will also need to take place. On the other hand, the SUSSI does not require interviews to occur for interpretation because of the quantitative and qualitative components built into the instrument. Interviews with the SUSSI can still aid in the interpretation of the student responses to the open-ended questions and clarify potential inconsistent answers to the Likert scale statements. Notably, previous research has utilized the SUSSI qualitatively with interviews to gain deeper insight into student NOS understandings and have found this method to be reliable (Dai et al., 2021; Williams and Rudge, 2019). Likewise, the SUSSI has also been found to be effective and reliable with small sample sizes when interviews are utilized (Cessna et al., 2013; Williams and Rudge, 2019).

The SUSSI was administered to students on the first and last day of the course. As stated above in Table 1, the SUSSI measures six concepts related to NOS understanding. Each concept consists of 4-Likert scale items, and each item is rated on a five-point scale from strongly disagree to strongly agree. These responses were assessed according to the scoring scheme created by Liang et al. (2008). Responses on the Likert scale indicating a one is interpreted as the least sophisticated in understanding, whereas responses scored as a five are interpreted as the most sophisticated understanding. The mean scores for the targeted NOS concepts were calculated.

The Kolmogorov–Smirnov and Shapiro–Wilk are common tests used to test for normality to determine if the data is evenly distributed. These tests were conducted using SPSS with a significance level of 0.05. The null hypothesis (H_0) states that the data is evenly distributed, and the alternative hypothesis (H_1) predicts that the data is not evenly distributed with a p-value of less than 0.05. The Wilcoxon signed-rank test is a nonparametric equivalent used to determine if there is a difference between two dependent samples when the data does not meet a normal distribution (Gehan, 1965). The Wilcoxon signed-rank test was used in this present study to assess the potential changes of targeted NOS concepts from pre to post.

Likewise, the effect size (r) was calculated for the Wilcoxon test. To calculate the effect size, the recommended formula is $r = Z/\text{sqrt}(N)$. The r value is calculated by dividing the Z value by the square root of the total number of observations (N). The effect size or r value for the Wilcoxon test is considered small when $r = 0.1$, medium when $r = 0.3$, and large when $r = 0.5$ (Cohen, 1988; Pallant, 2007).

4.5.2 Qualitative Data

Semi-structured interviews were conducted on the last day of the course with the help of a research assistant. The interviews were audio recorded and transcribed by the first author. Student's individual pre/post SUSSI and reflection question responses were used to prompt additional interview questions by asking students how their views had changed from pre to post. Students were also asked to further clarify their responses on the open-ended questions. Additionally, the students' reflection questions were used to triangulate the SUSSI and student interviews in order to better understand how the students NOS views had been impacted by participating in the CURE and by the NOS activities embedded within the course. Students were asked to clarify their responses to reflection questions during the interview, which was also used to ask follow-up questions during the interview. An iterative emergent coding process was used to code the interviews as described by Campbell et al. (2013). Interviews were initially coded by the first author who created a codebook which included tentative codes and rules for applying these codes using NVivo software. The codebook and rules were then shared with a fellow researcher who provided feedback. The codebook was adjusted based on this feedback. Campbell et al. (2013) described the problem with unitizing data when using software in the analysis of qualitative data. Campbell and colleagues explained that often a page of a transcript is used as the unit of analysis; however, with software, such as NVivo, to aid in qualitative coding, the transcript is presented as a continuous page. Similar to the experiences of Campbell et al. (2013), the interviews for this study were pages long with units of analysis often as long paragraphs of text. In order to ensure interrater reliability, we followed the

Table 3 Wilcoxon signed-rank of the NOS Concepts captured by the SUSSI

NOS concept	Pre score	Post score	*p*-value
Observations and inferences	3.93	3.96	0.762
Change in scientific theories	4.03	4.17	0.078
Laws vs. theories	2.85	2.89	0.718
Social and cultural influences	3.40	4.06	0.006*
Imagination and creativity in scientific investigation	3.65	4.20	0.004*
Methodology of scientific investigation	3.46	3.62	0.323

An asterisk indicates significant difference from pre to post

interrater process as described by Campbell and colleagues. An interview was first coded by the first author. Then the same interview transcript and codebook was provided to a fellow researcher. The transcript indicated which blocks of text were coded, but not what the codes were. From here, the fellow researcher would use the codebook and code the same text as the primary researcher. Coding was then compared, and discussions between researchers occurred to handle discrepancies between coding and to revise and refine the codebook. Several more transcripts were chosen at random and the two researchers coded them independently. Once the coding was complete the researchers would discuss any discrepancies and revise the codebook as needed. From the process a high rate of interrater reliability $\geq$ 83%) was calculated (Campbell et al., 2013). From the coding process, patterns were identified, and themes emerged. These themes explained student understanding of NOS concepts as well as changes that may have occurred because of participation in the course or the interventions (i.e., narratives, reflection questions, and in-class discussions).

5 Results

The two NOS concepts that this course specifically targeted using an explicit/reflective approach through reflection questions, in class discussions, and narratives (both historical and personal stories) were social and cultural influences in science, and imagination and creativity in scientific investigations. On the SUSSI instrument, students had an opportunity to provide insight into their views regarding other NOS topics (i.e., observations/inferences, change in theories, theories vs. laws, and methodology). However, these topics were not discussed explicitly, and students were not directed to reflect on these NOS concepts during class time. A Wilcoxon signed-rank was performed, and the results were found that there was no significant difference for the following NOS concepts on the SUSSI: Observations and Inferences, Change in Scientific Theories, Laws vs. Theories, and Methodology of Scientific Investigation (see Table 3). This result was anticipated and acts as a natural control in this present study because these NOS concepts were not targeted in the course. Previous research has shown that students do not develop more sophisticated understandings of NOS concepts that are taught implicitly (Charney et al., 2007; Russell & Weaver, 2011).

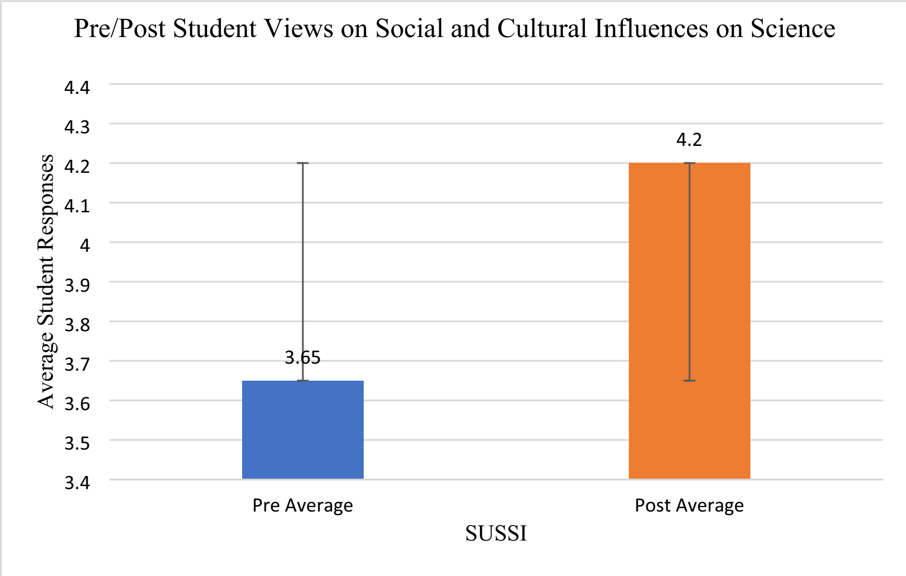

Fig. 1 Students' NOS views pertaining to Social and Cultural Influences on Science were assessed using the SUSSI (n = 16). The average score on the pre SUSSI is 3.40, whereas the average score on the post SUSSI is 4.06. This shift indicates a positive improvement to student understanding of this NOS concept

5.1 Changes to Student Understanding of Social and Cultural Influences in Science

5.1.1 Quantitative Analysis

The Kolmogorov–Smirnov and Shapiro–Wilk tests were conducted in SPSS to determine the normality of the data distribution. It was determined that the data was not normally distributed with p values less than 0.05. Therefore, the Wilcoxon signed-rank test, a nonparametric equivalent to the t-test, was used to evaluate the pre to post differences in the NOS concept of Social and Cultural Influences on Science. The results of the Wilcoxon test suggest that there is statistical significance from pre to post in students' understanding as it relates to society and culture in science. Mean scores for this NOS concept increased from pre 3.40 (SD = 0.815) to a post mean score of 4.06 (SD = 0.335) with a p value of 0.006 (see Table 3; Fig. 1). These statistical results indicate that students' understanding of the role society and culture play in science significantly improved. The reasons for this significant increase will be further discussed in the next section pertaining to the qualitative data.

Furthermore, the effect size (r) was calculated using the formula $r = Z/\text{sqrt}(N)$ in SPSS and Excel (Pallant, 2007). The statistical result for the effect size of social and cultural influences ($r = 0.685$) in science to be greater than 0.5. According to Cohen (1988), the effect size for this NOS concept indicates that the statistical differences in the Wilcoxon test (pre- to post-SUSSI) is strong.

Table 4 Interventions cited by students during the interview on what influenced their viewpoint with regards to the NOS concept Social and Cultural Influences on Science

Student cited topic/activity that helped shift view/understanding	Number of students ($n=16$)*
Reflection questions/in-class discussion	67% (12 students)
Historical narratives	28% (5 students)
Other	5% (1 student)

*Some students cited more than one intervention; therefore, percentages are greater than 100%

5.1.2 Qualitative Analysis

In reading of the interviews, students cited specific interventions from the course as they explained their understanding of the impact society and culture has on science and vice versa (see Table 4). Twelve students cited topics about the reflection questions followed by in-class discussions in the interview, specifically nine students cited the media myths topic, and three students cited the discussion on ethics. Five students cited the historical narratives as helping them better understand the role of society and culture in science. Of those five students, four specifically cited the narrative pertaining to the discovery of the structure of DNA and one student cited the narrative about Edward Jenner. Lastly, one student cited a topic unrelated to the in-class discussions or narratives shared during the course, but rather shared cultural differences of his country of origin. It should be noted that some students cited more than one intervention that led to their deeper understanding of this NOS concept.

In the interview analysis, several trends emerged that were further corroborated by the open responses on the SUSSI where students indicated that the combination of reflection questions followed by in-class discussions, and the historical narratives, helped them gain new perspectives on how society and culture influence science. One of the reflection questions that students mentioned frequently in the interviews was the discussion of how the media portrays science in popular culture (as discussed in Sect. 4). This topic of media portrayal was accompanied by clips from popular movies and television shows, where students were asked to pay attention to several factors which included (1) how the science being conducted was portrayed and whether that portrayal was realistic or not; and (2) who, men or women, were often involved in conducting the science.

5.1.3 Portrayal of Science in the Media

These in-class discussions prompted many students to reflect on how the media portrays science and, in some cases, has the potential to manipulate public perception of science. This newfound realization prompted students to reflect more deeply on how science is impacted by society and culture in terms of what scientists decide to study and how research gets funded. This realization is evident in the following student quote:

> I feel like with the whole media and science question, media definitely affects scientists a lot more than I realized. It makes sense because we display scientists in a certain light, but the way that that could even affect something like their grants for research could affect what they might be able to do or how other people try to push them. (Student 919)

Similarly, another student echoed this new realization and indicated that initially she did not believe culture and society played a role in what scientists' research or what types of research receives funding. The student revealed that the in-class discussions changed her views and helped her better understand the role society and culture play in scientific endeavor:

> Initially, I was very much like, "Science has nothing to do with culture. There's nothing that Twitter can have an effect on science," and that's why I like science so much is because it's pretty much kind of black and white like I was originally thinking. But as we talked about it [in class discussions], I was like, "You know what? That makes a lot of sense that society can really influence," especially with like who people vote to put in office and who's in office kind of decides where the money goes like with global warming and green energy and all that stuff. Whoever's in office decides where the money goes to research for that stuff and that really depends on their cultural views. (Student 519)

Several students ($n=7$) also pointed out how they had never thought about these impacts regarding society/culture and science before, and they felt that these discussions were not only interesting, but important for STEM majors. These students indicated that in order to change public perception of science, topics relating to how science impacts society and vice versa need to be discussed. Students also commented that they had not had conversations pertaining to public perception of science.

> I feel like before going into this, the only perspective I had on these questions was the perspective of the scientific community and for the first time, I was seeing the outside perspective of it and how science can be viewed from the public's perspective and that was new to me. (Student 1219)

The sentiment of being able to understand science from a non-science person's perspective was echoed by other students. The students ($n=6$) indicated that the use of the reflection questions helped them step outside of themselves and consider the impact science has on society from a different perspective.

> And I guess, you know, I didn't really think about how non-science people think of science sometimes. And so, a lot of the reflection questions did make me kind of step outside of myself and think about what science means to other people. (Student 519)

5.1.4 Portrayal of Gender in Science

Numerous students ($n=7$) also came to realize the differences in gender representation through the various media and pop culture clips shared. During the in-class discussions students reflected upon how many of these gender stereotypes regarding who does science are perpetuated through our pop culture, and how this stereotyping can cause unnecessary challenges for women who want to pursue science.

> When we were watching all those videos of different scientists and all this stuff, like the idea that most people view scientists more as men rather than women. Like I saw in the video that there was only one woman in them. That puts a lot of pressure on the woman to try to put herself out there and explain what she wants to do. (Student 819)

Additionally, some of the female students ($n=5$) indicated how the in-class discussions related to gender helped them reflect and better understand their personal experiences. For many of these women they had a realization of how the media plays a role in our socialization and perpetuating those stereotypes; however, having these conversations and gaining the new experience in the course has helped them take back their confidence.

> Gender stereotyping and like the underrepresentation of women in the science field, I never really thought about it until now, but I feel like since I've been so socialized to be basically not confident enough to get into the science field, and everything's shown in the media that socializes you, I feel like I saw that when I was younger and something resonated with me and now I've always believed that I wasn't going to be that person that was the top scientist, like the senior scientist doing the research. I was just going to be either like an assistant or something, but now, I'm getting a little more and more confidence and I actually want to go in that position one day, but it'll take a while. (Student 1519)

These female students also acknowledged that even with positive female role models in their lives, these conversations on the media's portrayal of gender stereotypes as well as the persistent inequity that still occurs are important for students to be aware of within their science field.

> Being a woman that's always been interested in the sciences, interested in getting a doctorate, interested in going the extra mile and maybe not always having the most supportive male colleagues or friends, it really made me think about how the media kind of portrays scientists or how it kind of portrays the STEM field as mostly being male-dominated. And so, when we talked about how our culture and how our society influences that, coming from my background of having a really, really strong mother, it's just like, there's obviously a lot of ways that a culture can shape how someone views a certain career field and stuff. That was, I thought, good for us to discuss in class because I feel like not a lot of that really gets discussed for people my age and younger just because sometimes it's kind of a hot, touchy topic and people don't want to like – it's kind of like politics – people want to talk about it but they don't want to talk about it. (Student 519)

For two of the male students, they came to realize and acknowledge the gender disparities through the sharing of the historical narrative of the discovery of the structure of DNA and Rosalind Franklin's under-credited role in that discovery. One indicated how this narrative helped them truly see how society and culture played a role in influencing science and made the examples of gender disparity more tangible.

> We all know that there was sexism and it was rampant up until, I don't know how many years ago, it's still going on. It's just crazy to hear specific examples and try to put yourself in her [Rosalind Franklin] shoes and just imagine the frustration. (Student 1319)

However, not all of the male counterparts understood the necessity of the conversation regarding gender in science. One male student believed that the issue of gender disparity is not as prevalent as in years past.

> People have viewpoints of the gender part of it because I think that [media clips] was supposed to be jarring just to kind of see. I would say nowadays…in my opinion, I've seen less and less of it [gender disparity]. But she [the instructor] said in the higher-up

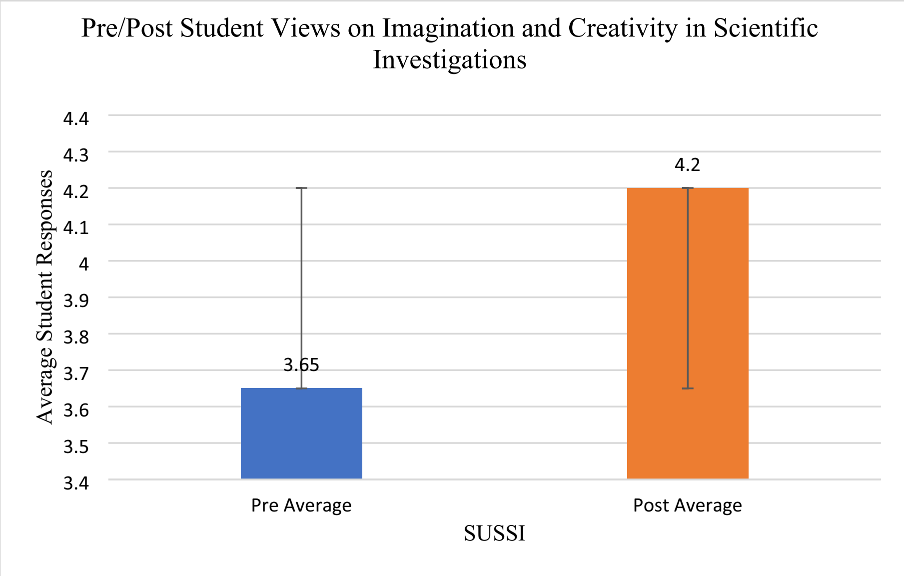

Fig. 2 Students' NOS views pertaining to Imagination and Creativity in Scientific Investigation were assessed using the SUSSI ($n=16$). The average score on the pre SUSSI is 3.65; whereas the average score on the post SUSSI is 4.20. This shift indicates a positive improvement to student understanding of this NOS concept

fields [there are] less and less women in scientific fields. But from my perspective, I feel like I've seen the opposite. (Student 1419)

This perspective is not shared by the female students within the course and indicates the importance of having these conversations with students in that it may help them gain outside perspectives. In fact, many of the students indicated that discussions relating to society and culture helped them better understand the role it plays in science. The students indicated that understanding this NOS topic is important for STEM majors, but it is not often discussed within core science courses.

5.2 RQ 2: Changes to Student Understanding of Imagination and Creativity in Scientific Investigation

5.2.1 Quantitative Analysis

The results of the Wilcoxon test suggest that there is statistical significance from pre to post in students understanding of how scientists use imagination and creativity in investigations. Mean scores for this NOS concept increased from pre 3.65 (SD = 0.740) to a post mean score of 4.20 (SD = 0.493) with a p-value of 0.004 (see Table 3; Fig. 2). These results indicate that students' understanding of how scientists use imagination and creativity in science improved. The reasons for this significant increase will be further discussed in the next section pertaining to the qualitative data.

Furthermore, the effect size (r) was calculated using the formula $r = Z/\text{sqrt}(N)$ in SPSS and Excel (Pallant, 2007). The statistical result for the effect size of imagination and

Table 5 Interventions cited by students during the interview on what influenced their viewpoint with regards to the NOS concept Imagination and Creativity in Scientific Investigation. During the interview, each student indicated only one intervention that contributed to their understanding: therefore, percentages equal 100%

Student cited topic/activity that helped shift view/understanding	Number of students ($n=16$)
Reflection questions/in-class discussion	50% (8 students)
Historical narratives	19% (3 students)
Course participation	25% (4 student)
Maintained misconception	6% (1 student)

creativity (r = 0.729) in science to be greater than 0.5. According to Cohen (1988), the effect size for this NOS concept indicates that the statistical differences in the Wilcoxon test (pre- to post-SUSSI) is strong.

5.2.2 Qualitative Analysis

In reading the interviews, students cited specific interventions that helped change their view or deepen their understanding of how scientists use imagination and creativity in their investigations (see Table 5). During the interview, four students indicated that participation in the research of the course helped them better understand how imagination and creativity are used during scientific investigations. Three students indicated that it was the historical narrative pertaining to the discovery of the structure of DNA that influenced their understanding. Eight students indicated the reflection questions and in-class discussions about imagination and creativity deepened their understanding. Conversely, one student maintained their misconception believing that imagination and creativity is only part of the initial questioning stage of science and that it is not found throughout the entire process. For this particular NOS concept, when asked during the interviews, each student only indicated one intervention that led to their deeper understanding of the role of imagination and creativity in science. The analysis of the interviews revealed that all students came to better understand that imagination and creativity are used throughout the entire scientific investigative process.

In further analysis of the interviews, two major themes emerged in how students discussed imagination and creativity in scientific investigations. The first theme is students who discuss imagination and creativity in scientific investigations by giving specific examples of how they themselves used their imagination/creativity while participating in the research of the course. The second theme is students who are able to define and articulate what imagination/creativity means in science, where it can be found, and provide external examples of the types of questions scientists may unconsciously ask illustrating the use of imagination and creativity.

5.2.3 Student Actively Uses Imagination and Creativity in Course

During the interview, several students ($n=4$) indicated that they had used their own imagination and creativity while participating in the course. This use of creativity was attributed to the PI modeling how they used their own imagination and creativity and encouraging the students to do the same. One student indicated how through the instructor modeling the use of imagination and creativity during data analysis it made him realize that he should also use his creativity during the analysis phase:

> Basically, it was when I was looking at my results with [the PI] and we were just looking at it and figuring out why did this come to be? How did this come to be? And I was thinking more of a straightforward fact, while she was just going off, like, it could be this, maybe, it could be this? She was just being all creative about it. And that made me think, "Okay, maybe I should be creative about results too." (Student 1019)

Likewise, another student indicated that as they worked through the protocols the PI offered advice pertaining to the methodology:

> And I remember when we had to see the color change for our worms, for the staining and then she [the PI] says there's no specific time, you just have to kind of wing it, you know, you just have to look and then kind of follow your feelings and instincts. If you kind of feel like that's good enough or you have to leave it longer and things like that. (Student 119)

As indicated by these students, as they were working through the research protocols and analyzing data, through the PI's guidance, they came to understand that they would have to use their best judgement, and for some students they equated this to using imagination and creativity. Another student echoed this same idea of using their own imagination to work through the protocol.

> I kind of had to use my imagination to figure out the best way that it was going to work for me, like something very simple just like, where should my hands go? What should I use with what? And just kind of envisioning that. (Student 519)

As well as having to use imagination to work through the protocols successfully, another student indicates that imagination and creativity were necessary to use during the scientific process in order to overcome challenges and failures that took place in the course.

> We had a lot of failures, which depends on your definition of failure in science. But we had a lot of failures and then we kind of turned that into something that could be used as useful information. So, we definitely used our imagination to get useful information. (Student 1519)

As indicated by the above student quote, this student came to understand the necessity of using imagination and creativity when interpreting data, especially when the results do not turn out as expected or when needing to understand and explain why an experiment failed.

5.2.4 Student Understands the Definition of the Concept of Imagination and Creativity in Scientific Investigation

All of these student quotes above indicate that students believe they are actively using their imagination and creativity in the research process. However, a majority of students (n = 12) did not provide examples of how they used their imagination and creativity during the course. Instead, these students provided definitions of the use of imagination and creativity in science.

Many of these students (n = 8) revealed in the interview that on the pre-SUSSI they did not believe science involved creativity or imagination, or it was at least present minimally being utilized in identifying a research question only, but they now have a new understanding of imagination and creativity being part of the entire scientific process. One student explained how initially they believed creativity to be only in the arts, but now they understand it is in the sciences, too:

> When you think of creativity, you think of art and not necessarily science, but more artistic things. The word imagination sounds like you're making things up, going back to fudging data. But really when you use your imagination to collect data. That was my original thought was making things up in parts and stuff. But when you use your imagination to analyze data, that's figuring out, "Okay, are there any outliers? Can I exclude this population? If I do, how does that change the results? Is that ethical?" (Student 1119)

Another student echoed this sentiment above, and included the data collection process in the imagination and creativity definition:

> Originally, I thought that in the pursuit of collecting data, scientists, they've always had to have a very calculated process, you know, just so it's repeatable. But the stuff we talked about is that you have to have creativity to collect data on something that's difficult to collect data on. The idea that you can't observe a particle without changing its trajectory or its velocity, I mean, how do you collect data on that? You have to have some creativity to kind of process." (Student 1219)

As shown by this student comment, imagination and creativity are not only used when deciding what a scientist is studying but also how a scientist will study the topic, what will be used to measure or gather evidence, how that evidence will be interpreted, and how that interpretation adds to a body of knowledge. Similarly, another student echoed this same sentiment that imagination and creativity are not only used throughout the entire process but is also used to understand how the findings add to the current understanding of the field being studied.

> It takes a certain amount of creativity even to be able to ask the question of like, why does this happen? What's happening? What if I did this? And then even at the end, when you have all your data and everything laid out in front of you, how to interpret it. Well, I noticed this trend here. What if that relates back to this and that? (Student 919)

Unlike their counterparts above, these students did not insert their own personal experiences within the course doing research into their explanations of how their views pertaining to imagination and creativity changed. This prompted a further investigation in the analysis, specifically into the reflection questions students were asked to answer during the course. One specific reflection question asked students the following, "Do you feel you have been imaginative/creative in this course?".

Four students stated "yes" on this question and then provided examples of how they had used their imagination and creativity while participating in the bench research of the course. However, twelve out of sixteen students stated "no" on this question. These students indicated that they did not necessarily feel like they were using their imagination/creativity or were a part of the creative process because of their status as a student. They felt that because they were still learning as students' they were not using creativity in the same way as a formal scientist. These students also indicated that they felt that they were limited in the use of their imagination and creativity because the protocols (i.e., protocols for PCR, immunoassays) used in the course were already established.

6 Discussion

The findings presented in this study illustrate that by the end of the course students were able to better articulate their understandings pertaining to the NOS concepts of social and cultural influences and the use of imagination and creativity in scientific investigations. This indicates an improved understanding from the beginning to the end of the course experience. In the interviews students cited a variety of interventions that they believed helped them either change their current viewpoints on the concept or helped them deepen their understanding and allowed them to discuss the concept more concretely.

In particular, students came to better understand how society and culture impact science and were able to provide specific examples. The most cited intervention for helping improve understanding of this NOS concept was the reflection questions followed by in-class discussions, specifically the questions that examined how the media portrays science in popular culture and news. For this intervention, students were asked to answer reflection questions and view clips from a variety of movies and television shows that portrayed the happenings of scientific research and scientists. During the interviews, students indicated that these discussions following the reflection questions and video clips helped them better understand the role society and culture plays in science. In addition, students also noted that these discussions were important to have, especially with undergraduate science majors wanting to pursue careers in science. Several students indicated that they had never been included in a conversation pertaining to how science and research plays a crucial role in society, and how so often the public has misperceptions of science because of how science is portrayed in media. As indicated by previous literature, graduate students (Aydeniz & Bilican, 2014) and even established practicing scientists (Bayir et al., 2014; Schwartz & Lederman, 2008) have had misconceptions pertaining to the social and cultural influences on science. As noted by students within this course, they had not previously had explicit and reflective discussions pertaining to this NOS concept. The students' revelations during the interview and the persistent misconceptions noted in the literature show that the discussion of this NOS concept is important to have with undergraduate students pursuing science as a future field of study and career.

Notably, during the interview, many of the female students discussed the persistence of stereotypes linked to gender within popular culture portrayals of science. These media clips sparked the conversation of the importance of representation and having positive female role models during the interviews. Interestingly, few female students cited the historical narrative pertaining to Rosalind Franklin's neglected role in the discovery of DNA as being what helped them have a new understanding for social and cultural influences in science. Many of the female students indicated that they already knew the story of Rosalind Franklin. This does not mean the historical narrative was not meaningful to the female students as it has been shown in previous research to be useful in helping students, especially female students, understand the persistent gender biases still present in science (Dai et al., 2021). It may be for this reason that viewing the media clips had a greater impact on their views pertaining to social and cultural influences. It could be that the media clips also provided more contemporary examples of how gender bias is still present today since the clips showed popular movies and television shows that the students recognized. Regardless, both the historical narrative and the media clips provided highly contextualized examples of the impacts society and culture play on scientific research. Providing students with multiple contextualized examples while employing an explicit and reflective teaching strategy has been encouraged in the literature to help students develop deeper understandings of these nuanced concepts (Clough, 2006, 2011).

Likewise, students largely cited the reflection questions and in-class discussion as helping them either change their views or deepen their understanding of the role imagination and creativity plays in scientific investigation. Many of the students entered the course believing that imagination and creativity are used at the initial phase of the scientific process in posing a research question, but this is where the use of imagination/creativity ended. Nonetheless, by the end of the course all but one student came to understand that imagination and creativity are used throughout the entire scientific process from posing the research question to collecting and analyzing the data.

While a majority of students provided details of where imagination and creativity could be found in the scientific process, only a small minority of students ($n=4$) inserted themselves into these discussions. This small group of students, in addition to describing where imagination/creativity can be found in scientific processes, also described how they themselves used their imagination and creativity while participating in the research of the course. In order to better understand this division amongst students, the reflection questions pertaining to this NOS concept were examined further. Students were asked to answer these reflection questions prior to any in-class discussion or narrative intervention. Thus the reflection questions aimed to capture the students initial understanding prior to the intervention (i.e. in-class discussions, narratives). The interview captured the newfound understanding after the intervention at the end of the course. For the reflection question of interest, students were asked whether they felt they had used their imagination and creativity during the course. A majority of the students indicated that they had not used their imagination because of the structure of the course itself. Many students indicated that because they were given specific protocols on how to collect the data this limited their use of imagination and creativity. These responses shed light on why a majority of students did not insert their own personal experiences of the course into their new definition of the role of imagination and creativity. This may allude to the larger role students wish to play in the design of the research methodologies. Even though the vast majority of students in this study developed a more sophisticated understanding of the role of imagination and creativity, being able to flex that creativity has been shown to be an important to students in the research experience (Moss et al., 2018; Russell & Weaver, 2011).

Nevertheless, this study has indicated that it is important to provide a variety of examples to discuss NOS concepts in order to appeal to all learners. Students largely cited the reflection questions and in-class discussions as having the greatest impact on their understanding, but the narratives helped further understanding by providing concrete examples for students to latch on to as they began to think differently about these abstract ideas. Previous literature has indicated the importance of providing numerous opportunities for students to reflect and discuss ideas related to NOS concepts as being beneficial in helping them develop more sophisticated understandings (Clough, 2011; Schwartz et al., 2004).

Moreover, this study also illustrates the importance of using an explicit and reflective instructional approach to teach NOS concepts. Studies have shown how using an explicit and reflective approach to teaching NOS has been effective at helping students develop deeper understandings of the nuanced concepts relating to society and culture and imagination and creativity (Burgin & Sadler, 2016; Moss et al., 2018). Through providing numerous examples, both contemporary and historical, coupled with explicit and reflective discussion students were able to better articulate their understanding as well as explain the importance of these newfound ideas as they related it back to the research in which they were engaged.

These findings provide insight and implications for teaching. As educators are developing lesson plans to introduce NOS concepts to their students, they should consider using a variety of both historical and contemporary examples as well as reflection questions. Having multiple examples will help reinforce abstract ideas and provide more opportunities for students to discuss these concepts to deepen their understanding. It is recommended that these examples and reflection questions align with the content being taught in order to help students develop a connection with the material.

Likewise, it is recommended that instructors follow the explicit and reflective teaching approach when introducing NOS as a way to help students overcome misconceptions and to add more insight to the knowledge about NOS that they already possess. As described in this study, the explicit and reflective teaching approach took the form of narratives, reflection questions, and in-class discussions. This allowed for concepts to be introduced explicitly and then provided time for students to reflect, develop their own understanding, and refine that understanding by sharing their views with the instructor and their classmates. It is recommended student reflection should be followed by class discussion. During the class discussion students have the opportunity to state their views as well as hear additional perspectives from their fellow students. This also provides an opportunity for instructors to hear student views and to be able to correct misconceptions that students may still possess.

7 Limitations and Future Work

This study has some potential limitations. First, the study takes place within a single course where there are a total of 16 participants. However, the interviews reached a level of saturation within the qualitative data, thus helping to overcome the potential limitation of the number of participants. Guest et al. (2006) suggests that saturation is met when 15–20% of participants within the sample have been interviewed. At this level, no new information pertaining to the subject matter is likely to surface. However, for this study, 100% of the participants were interviewed thus ensuring saturation was met. Second, there was not an alternative treatment group to compare student NOS understandings in the absence of explicit and reflective interventions. However, the literature indicates that in the absence of explicit and reflective instruction student understanding only marginally improves (Burgin & Sadler, 2016; Jeffrey et al., 2016; Russell & Weaver, 2011).

Additionally, there was a missed opportunity to discuss imagination and creativity with the students within the structure of the course because of the protocols provided for the bench research. During the interview, most students mentioned that because the protocols were provided for them, their use of imagination and creativity was limited. However, there seems to be a disconnect in students' understanding of scientific research. Each field of science has a set of techniques and protocols that are used to conduct research. For example, the field of molecular biology uses techniques such as PCR, immunoassays, and in situ hybridization. All of these techniques were used by students during this course. The protocols for these techniques are very specific and provide unique information that is applied to the data analysis in the attempt to answer the primary research question. In this course, students felt that because the course was structured in such a way that they were provided with these protocols they did not use imagination and creativity. The disconnect here may stem from the students own lack of experience in conducting novel scientific research. Instead, a conversation could have occurred to help students understand that scientific research is conducted within the parameters of what is known and available in an attempt to push the boundaries to discovery.

Therefore, future iterations of this course should involve students in discussions pertaining to how and why scientists choose the methods that they use when conducting novel research. These conversations should also highlight how these choices in methods used employ creativity and imagination on the part of the scientist. Likewise, future research should examine how different contexts or examples may impact students' NOS understanding. This study has shown that using contextualized examples in the forms of reflection question followed by in-class discussions and narratives has helped students develop deeper understandings related to the two targeted NOS concepts. In this study, students largely cited the reflection questions as impacting their understanding. Future research could evaluate the effectiveness of these different teaching approaches on student NOS views. This study also identified gender discussions as having a meaningful impact, especially on female students, when discussing how society and culture impact science. Future research should also explore how this role of identity impacts students' NOS views.

Appendix. Reflection Questions

1) How do you imagine the typical day of a research scientist goes?
2) How do the media clips and your views of a research scientist compare? How are they different?
3) How do your experiences in the lab so far compare/contrast to previous conceptions? How do your experiences thus far compare/contrast to how science is depicted in the media?
4) What makes up the practice of scientific inquiry?
5) Which aspect(s) of NOSI do you think are most important? Why?
6) Do scientists need to take ethical considerations when planning and conducting research on animals? On humans? How do they make these ethical considerations?
7) Is it ever appropriate for a scientist to "fudge" or even exclude data just to get a publication?
8) Do scientists use their imagination/creativity? If so, then how? If not, then why not?
9) Do you feel you have been imaginative/creative in this course?
10) Do society and culture impact science and vice versa? Why or why not?

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Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

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