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ARTICLE

Emphasizing the History of Genetics in an Explicit and Reflective Approach to Teaching the Nature of Science

A Pilot Study

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Abstract Science education researchers have long advocated the central role of the nature of science (NOS) for our understanding of scientific literacy. NOS is often interpreted narrowly to refer to a host of epistemological issues associated with the process of science and the limitations of scientific knowledge. Despite its importance, practitioners and researchers alike acknowledge that students have difficulty learning NOS and that this in part reflects how difficult it is to teach. One particularly promising method for teaching NOS involves an explicit and reflective approach using the history of science. The purpose of this study was to determine the influence of a historically based genetics unit on undergraduates' understanding of NOS. The three-class unit developed for this study introduces students to Mendelian genetics using the story of Gregor Mendel's work. NOS learning objectives were emphasized through discussion questions and investigations. The unit was administered to undergraduates in an introductory biology course for pre-service elementary teachers. The influence of the unit was determined by students' responses to the SUSSI instrument, which was administered pre- and post-intervention. In addition, semi-structured interviews were conducted that focused on changes in students' responses from pre- to post-test. Data collected indicated that students showed improved NOS understanding related to observations, inferences, and the influence of culture on science.

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1 Theoretical Background

Science educators have long held that an understanding of the nature of science (NOS) is an important and uncommon outcome of science instruction (Monk and Osborne 1997; Lederman et al. 2002; AAAS 2009). An adequate understanding of science goes well beyond familiarity with science content knowledge, such as the fact that matter consists of atoms. Students should also know something about how scientific knowledge is generated, and also the limits of scientific knowledge. A deeper understanding of science also includes considerations from a broader cultural and historical context (Matthews 1994). Although there is wide agreement among science educators about the importance of NOS, there is no single agreed upon definition.

There are several ways in which views of the nature of science have been conceptualized and studied. One of the most widely used frameworks for studying NOS views, particularly in recent literature, is the multidimensional framework (Deng et al. 2011). This framework conceptualizes NOS as being based on some agreed upon epistemological characteristics of science, such as the creation and development of theories, the tentativeness of scientific knowledge, theory-laden NOS, and the distinction between scientific theories and scientific laws (Lederman et al. 2002; McComas 2004; Lederman 2007). Importantly, many authors utilizing the multidimensional framework make a distinction between the epistemological features above and the process of science or scientific inquiry which is defined as "activities related to collecting and analyzing data and drawing conclusions" (Lederman et al. 2014). Studies under the multidimensional framework often rely on method triangulation between assessment instruments (both open-ended and close-ended) and interviews.

An alternative framework for studying NOS views is the argumentative resource framework (Deng et al. 2011). Researchers working under this framework focus on students' ability to construct and evaluate scientific arguments. Allchin (2011) suggests that instead of students learning particular characteristics of scientific knowledge, they should learn how to interact with expert scientists, to distinguish between relevant and irrelevant data, to recognize the limits of new scientific claims, and to handle uncertainty in science. These types of studies often employ observation and interview methods using discourse analysis (Deng et al. 2011).

This emphasis on NOS has also led to several attempts by researchers to improve students' NOS views (Akerson et al. 2000; Kim and Irving 2010; Rudge et al. 2014). Collectively, these studies have highlighted how resistant students' NOS views are to change. In part, the difficulty reflects how rigorously students often hold to misconceptions about NOS topics (Clough 2006). Students' difficulty with NOS is likely the result of implicit experiences with what science is, both inside and outside of the classroom. Students receive inaccurate implicit messages through "cookbook" laboratory activities, textbooks, and media reports. These implicit messages lead to students developing deeply held misconceptions regarding NOS, which are difficult to change even through explicit instruction (Clough 2006). Another contributing factor is science teachers' understanding of NOS. Research on teachers has shown that misconceptions related to NOS also extend to science teachers (Lederman 2007).

Much of the disagreement noted above in how to conceptualize, assess, and teach NOS reflects the relatively independent development of research on NOS by science educators and work on these issues in the context of academic research on the history and philosophy of science. Clough (2006), for instance, argues that nineteenth-century views of science, aligned with positivism, drive many teachers' practice. This can be problematic because positivism, the idea that all knowledge is derived from sensory experience, logic, and mathematics, provides an inaccurate and simplistic view of science. As far as learning NOS is concerned, cookbook laboratory activities and the general structure of science teaching promote a sterilized version of science. This version of instruction is removed from social influences of science and the creativity involved in conducting science (Hodson 2014). In order for these issues to be addressed, the need for effective approaches to teaching NOS is clear.

One method that has been advocated for teaching NOS is through the use of the history of science (HOS) (Matthews 1994; McComas 2010; Rudge et al. 2014). Using HOS is promising because it provides a highly contextualized approach to teaching NOS. Context introduces a human element to NOS instruction. More importantly, it allows for intertwining NOS instruction with science content. Historical accounts of scientists are necessarily tightly bound with science content (Clough 2006). An area of the biological sciences that can particularly benefit from HOS is genetics. Gericke and Smith (2014) point out that, historically, the field of genetics has developed several explanatory models including classical genetics, molecular genetics, and genomics. The difficulties students often have in genetics typically mirror a classical view of genetics. For example, many students have the misconception that genes are the only factor in the development of phenotypic traits. As a result, researchers such as Gericke and Hagberg (2007) have advocated teaching students about historical explanatory models in genetics. It is thought that these models could help students to clarify their own thinking and show them that there is no one "correct" model waiting to be discovered (Gericke and Smith 2014). Despite the advantages, teachers use HOS sparingly. This may reflect many factors including lack of teacher knowledge of the HOS and the practical realities of the classroom such as limited time and the need to teach toward formal exams (Monk and Osborne 1997).

The importance of melding NOS instruction with science content cannot be overemphasized. Science instructors often view NOS instruction as wasting time, particularly decontextualized teaching approaches. Decontextualized approaches (e.g., silver box activity, mystery tube activity; see NAS 1998) can be problematic for instructors and students because they require the instructor to explain the similarities between an abstract activity and science. Instructors can see these decontextualized activities as taking time away from science content. Students can develop multiple views related to NOS, including personally held views and those that are appropriate for school settings (Clough 2006). This is not to say that there is not value in decontextualized approaches, but rather to illustrate the importance of historical or contextualized approaches. Decontextualized approaches provide a way of introducing NOS concepts prior to exposing students to more contextualized examples.

2 Purpose of the Study

The purpose of this study is to determine the influence of a historically based instructional unit on undergraduate students' understanding of NOS. For the current study, NOS is defined as the philosophy and sociology of science related to the meaning of science, the justification of scientific knowledge, and the approaches taken by scientists toward scientific investigations (Bird 1998; Liang et al. 2009). The current study falls under the multidimensional framework as it focuses on students learning particular epistemological features of scientific knowledge. It should be noted that some may take issue with the multidimensional approach because it can be interpreted as teaching students a list of NOS tenets. Allchin (2011) has been highly critical of condensing NOS instruction to having students learn standardized tenets. He argues that this kind of approach does not give students an appreciation of the full spectrum of scientific practice. An example of a study that takes the standardized NOS tenet approach is one by Westerlund and Fairbanks (2010). In their study, students are taught six standardized NOS tenets through reading excerpts from Gregor Mendel's original 1866 paper. Allchin argues that this type of approach leads to students learning a core set of statements about NOS without learning how these NOS tenets are embodied in actual scientific practice. However, teaching NOS consistent with the multidimensional framework should not necessarily be conflated with simply teaching students a list of generalized NOS statements. Instead, the goal is to have students reflect on realistic examples of science, either historical or modern, to gain insights into the methods and practices of science (Abd-El-Khalick 2012; Kampourakis 2016).

To avoid the issues raised by Allchin (2011), the instructional approach used in the current study departs from that taken by Westerlund and Fairbanks (2010) in two respects. First, in the current study students are not presented with standard tenets to memorize but instead learn about NOS explicitly through engagement with a historical case. Particular aspects of the case were selected that embody the aspects of NOS of interest for this study. Second, part of the unit has students engage in authentic problem-solving related to the historical case. Students participate in a group problem-solving activity that involves data analysis and sharing results with their classmates. Authentic problem-solving can lead to a deeper understanding of scientific evidence and the development of scientific explanations (Allchin et al. 2014), which are important parts of the NOS. Both departures are intended to give students the opportunity to learn about particular aspects of NOS through engagement with the historical case. The specific aspects of the historical case that connect with the NOS and the details of the problem-solving activity are described in the outline of the intervention unit below.

The historically based intervention developed for this study uses the history of Mendel's work on hybridization to teach students about tentativeness in science. Oftentimes, the development of scientific knowledge is contingent on scientists' background, their culture, and current theoretical frameworks among many other factors. Researchers often refer to this contingency in science as contributing to the tentative nature of science (the fact that in principle, we can never know whether scientific claims are "true"). We chose to focus on Mendel because Mendelian genetics is one of the most commonly taught subjects in introductory biology courses (Smith and Gericke 2015). Associated textbook accounts of Mendel often provide a simplified account of his story that do not mention several other scientists who were actually trying to develop theories of heredity (Kampourakis 2013). Allchin (2003) also notes that typical accounts romanticize Mendel. He is presented as an "ideal scientist," one who works in isolation, is hard working, and in the end discovers a scientific truth. The widespread use of Mendel in the classroom and the romanticized account mean that students are often implicitly receiving incorrect messages regarding NOS. We see Mendel's story as well suited to teaching students about the influence of scientists' prior knowledge and the influence of culture on science. The unique reception of Mendel's work, his motivation for conducting his experiments, and his background offer rich examples of social and cultural influences on science (Smith and Gericke 2015).

In this study, we tried to provide answers to the following research questions:

1. How does the Mendel unit influence students' understandings of the role of scientists' prior knowledge and background in observations?
2. How does the unit influence students' understandings of how culture can affect the way science is conducted?

3 Research Design

In order to address the research questions above, the primary researcher developed an intervention unit spanning three 2.5-h class periods based upon the history of Mendel's classic research on genetics using the edible pea plant. The unit was evaluated in a pre-/post-manner to determine whether it influenced undergraduate students' NOS understandings. The research design section of this paper begins by walking the reader through the context of the implementation of the intervention unit. The intervention unit is then outlined followed by a description of the data collection and analysis procedures.

3.1 Context

The intervention unit was implemented in an introductory biology course for pre-service elementary teachers at a large Midwest university. The instructor of the course was an experienced professor of biology who had taught the course many times previously. The instructor also had extensive prior experience teaching NOS explicitly and incorporating history into instruction, as both have been a regular part of his teaching practice and research. It should be noted that the instructor was also the second author of the study and gave advice related to the design and planning of the research. However, all data collection was conducted by the first author. The course is a lecture-laboratory format that meets twice a week for 2.5 h. Students are primarily taught through guided problem-solving, consisting primarily of mini-lectures that give students background on a given topic, small group work, and discussion. There are four units devoted to taxonomy, anatomy, physiology, and ecology and evolution. The intervention took the place of part of the evolution unit near the end of the semester. The class was split evenly between males and females. There were 12 total students in the course, and 11 of them participated in the study. All participating students self-identified as Caucasian and were between 18 and 26 years old. All participants completed a pre- and post-assessment related to NOS, and seven also participated in interviews. Only one participant reported having taken a philosophy course previously. This class was targeted for the study because of the potential for valuable insights into the utility of the proposed historical unit plan for pre-service teachers.

Aspects of NOS and the history of science were emphasized throughout the course. The course goals and objectives included in the syllabus emphasized the importance of NOS as it relates to biology. Additionally, the course goals included the expectation that students would be able to relate contemporary and historical examples to their understanding of NOS. Two examples of the focus on NOS prior to the intervention are the silver box activity and the circulatory system unit. On the first day of the course, students completed "the silver box" activity. This activity requires students to use observations to hypothesize about a hidden mechanism inside a silver box (similar to the "mystery tube" described in NAS 1998, pp. 22–25). Later in the first unit of the course, students learned about blood circulation through examining the work of William Harvey (the English physician who first fully described the process of blood circulation in humans). Students experienced many of the anomalies that Harvey did in his investigation of blood circulation. In both units, students' attention was explicitly drawn to the relevant aspects of NOS and they were given multiple opportunities to reflect on their understanding. It should be highlighted that the activities prior to the intervention focused on different aspects of NOS than the intervention itself.

3.2 Theoretical Framework

The intervention unit takes an *explicit and reflective approach* to using the history of science to teach NOS concepts (Rudge and Howe 2009; Abd-El-Khalick and Lederman 2000). *Explicit* in this case refers to planned instructional practices that allow for NOS aspects to be openly covered in class. *Reflective* refers to students having the opportunity to come to their own conclusions about NOS aspects and not just repeating what the instructor tells them (Akerson et al. 2000). This approach has its origins in two separate theoretical frameworks. One theoretical basis for this approach can be found in constructivism, which says that students need to incorporate new understandings into previously learned constructs (Ausubel 1960; Matthews 1997). This means that the instructor must be aware that students have previously held beliefs about NOS (Clough 2006). The historically based intervention developed for the current research accomplished this by asking students to share their NOS understanding at the beginning of instruction. In the first activity of the intervention, students were asked to reflect upon the decisions that Mendel made in his experimental design and their implications for the tentativeness in science. By having students share their reflections in a follow-up class discussion, the instructor was able to get a sense of students' understandings of tentativeness in science coming into the intervention. Constructivism also holds that learning is an active interaction with new material. Students must be given opportunities to incorporate new information and rearrange their constructs. The instructor plays a pivotal role in facilitating this process. Throughout the intervention, students were given opportunities to engage with material through discussion questions and class discussions led by the instructor. In addition, during the second and third days of the unit students participated in a group investigation using simulation software to explore inheritance patterns in imaginary flies.

A second theoretical basis for the explicit and reflective approach can be found within conceptual change theory (Posner et al. 1982; Duit and Treagust 2003). Appleton (1997) provides a useful empirically based framework for relating conceptual change to NOS instruction. The basis of the framework is that learners seek a "best fit" understanding of a given concept, which minimizes cognitive conflict between new information and previously held understandings. Appleton proposes three pathways that stem from learners' conflict between previous and new knowledge. The first pathway is that learners will exit instruction with an understanding of a given concept that they believe fits with their previous knowledge but does not follow the accepted understanding of the concept. The second pathway says that learners will see an approximate fit of new information with previous understandings. The learners may then see the approximate fit as being close enough and exit instruction or may seek additional information and reexamine their ideas. For the third pathway, learners acknowledge an incomplete fit of new knowledge or cognitive conflict. Students use the new knowledge and new ways of thinking to create a better fit between previous understandings and the new knowledge.

Appleton's framework has implications for NOS instruction in that students' typical encounters with NOS concepts often reinforce previously held misconceptions. Common textbook accounts, lectures, and "cookbook style" activities present students with a portrayal of science that aligns with previous misconceptions (Clough 2006). Even if an instructor designs a lesson to address NOS, students may exit instruction with their misconceptions intact. People naturally interpret new information through the lens of their previous understandings. As a result, they will likely look for aspects of new information that align with previous knowledge. Additionally, they may ignore information that is contrary to their previous conceptions and even modify new information to fit these conceptions (Clough 2006). The above reasons are likely a major contributing factor for why previous research has supported the use of explicit approaches to teaching NOS instead of implicit approaches (Akerson et al. 2000; Kim and Irving 2010; Rudge et al. 2014). The principles of conceptual change were addressed in the current research by facilitating students' active engagement with historical and contemporary understandings of Mendelian genetics. Active engagement with historical understandings of science can help students' learning by allowing students to compare their understanding with current scientific ideas, in an environment that legitimizes students' thinking (Monk and Osborne 1997).

3.3 Outline of the Intervention Unit

The intervention unit is intended to serve as an introduction to a larger unit related to the concepts of Mendelian genetics and heredity. The NOS learning objectives of the intervention were limited to the influence of scientists' background and prior knowledge on their observations and interpretations and the influence of culture on science. These objectives are emphasized throughout the unit in the form of discussion questions, assignments, and mini-lectures. A brief review of the history used as the basis for the intervention is provided below followed by an outline of the 3 days of the unit. A more thorough discussion of the unit is provided elsewhere (Williams and Rudge 2015). In what follows, the pre-service elementary teachers who participated in the unit are described as students.

3.3.1 Historical Background

During the nineteenth century, many people were interested in understanding heredity. For example, Herbert Spencer was the first to attempt a theoretical explanation for heredity. He believed that physiological units from the parents competed with one another resulting in traits from both parents being present in the offspring. Charles Darwin put forward pangenesis, which is the idea that all organs in the body released units called "gemmules." These "gemmules" were aggregated in the reproductive organs and passed on to the offspring. Importantly, Darwin believed the reproductive organs were particularly susceptible to changes in the environment and that this was the source of variation. Following these initial attempts, several other scholars explicitly tried to develop theories of heredity, but Gregor Mendel was largely an outsider to their community (Kampourakis 2013).

Gregor Mendel (1822–1884) was born in a small Austrian village. He was a talented student as a child and excelled in all subjects. After completing high school, his physics professor recommended him to the Augustinian monastery in Brünn (Brno). After becoming ordained in 1848, it was determined that Mendel would be better suited toward teaching as opposed to a more pastoral role. After failing the teaching license exam multiple times, Mendel became a permanent substitute teacher at Brünn Modern School. Here, Mendel conducted his famous pea experiments. Mendel was aware of previous hybridization research by scientists such as Joseph Koelreuter and Karl von Gärtner. By the time of Mendel's pea research, it was already known that hybrids in plants tend to be uniform in the F1 generation and that they revert to parental forms in the F2 generation. However, little was understood about how many hybrid forms existed in the natural world and more importantly the rules that governed their production (Olby 1985; Dunn 1965). Developing an understanding of how hybrids are produced was important to the community where Mendel lived. Local sheep farmers had an economic interest in being able to predict the offspring of their sheep. In fact, the Sheep Breeding Society of Brünn actively encouraged research on heredity during Mendel's time. It is likely that these local economic interests were an important sociocultural factor in Mendel undertaking his work with pea plants (Orel 1996).

To gain insight into hybrids, Mendel bred thousands of pea plants and observed several traits including seed shape, height, and flower color among many others. Several other researchers during this time had conducted similar breeding experiments with plants. However, Mendel's research was unique for its time in that it applied a statistical approach. Mendel's approach to his research was likely a result of his strong background in math and physics (Dunn 1965). Through his experiments, Mendel laid some of the groundwork for what would later become the classic 3:1 and 9:3:3:1 phenotypic ratios and the laws of independent assortment and segregation (Kampourakis 2015).

Despite the current recognition of the importance of Mendel's work, the acceptance of his ideas by the scientific community has not been and is not without controversy.[1] After the initial publication of Mendel's pea experiments in 1865, his work was largely ignored until 1900. This oversight is likely due to a variety of factors chief among them the lack of readership of Mendel's published results and the lack of a statistical basis in Mendel's field of study during his time. After 1900, Mendel's work was rediscovered by three separate researchers and given its proper recognition. However, this was not the end of controversy surrounding Mendel's work. A 1936 paper by R. A. Fisher called into question whether Mendel's results were too good. Fisher's argument revolved around the statistical unlikelihood, based on Chi square, that Mendel would have obtained results that fit so well with his classic ratios. Fisher's article sparked a debate in the literature that persists to the present. This being said, Mendel's contributions have led most current researches to recognize Mendel as one of the founders of modern genetics.

3.3.2 Day One

During the first class, students were given background information regarding Mendel and the experimental design of his classic pea experiment. This was presented in a short PowerPoint. The presentation covered information about Mendel's life including his education, occupation, and the local area where Mendel lived. Students were told about Mendel excelling in physics in his early life, becoming a physics instructor, and how this background influenced his experimental work (Dunn 1965). They were also told about the circumstances leading to Mendel becoming a permanent substitute teacher at the monastery, including his failure of multiple teaching certification exams. In addition, the presentation focused on the motivation behind Mendel's experiments. For example, the possible economic factors that may have contributed to Mendel's work were shared with students, including the interests of local sheep farmers who were interested in being able to predict hybrids (Orel 1996). They were also informed of the interest of the scientific

[1] All claims made in this paragraph regarding the controversy surrounding Mendel's work are based on Franklin et al. (2008).

community in hybrids during Mendel's time (Stansfield 2008). The discussion of Mendel's early life and the possible motivations for his work was intended to give students examples of how scientists' background and culture can influence their work.

After the background information presentation, students were given an excerpt of Mendel's original paper created by the primary researcher, which only included the portions detailing Mendel's experimental design (Westerlund and Fairbanks 2010). Nothing was included at this point about Mendel's interpretation of his data. After students read the excerpt, they were asked to complete discussion questions in small groups. These discussion questions asked students to reflect on the tentative nature of science in relation to Mendel's experimental design, including sources of error and Mendel's comments regarding the difficulties of classifying pea plant species.

The students were then brought together for a discussion about Mendel's basic experimental design and were asked to evaluate some of Mendel's actual data (Stansfield 2008). Any similarities that can be drawn between the students' explanations of Mendel's data and those of nineteenth-century scientists were used to transition to a more detailed discussion of the beliefs about heredity during Mendel's time. Examples of scientists that can be included in this discussion are Charles Darwin and Jean Baptiste-Lamarck. The students were asked to reevaluate the data, given from Mendel's paper earlier in the unit, using the ideas of nineteenth-century scientists. These activities and discussions led to several ideas about heredity, but the main takeaway was intended to be the classic 3:1 and 9:3:3:1 phenotypic ratios. The discussion of nineteenth-century scientists' views of heredity was also intended to give students examples of how scientists can interpret the same scientific phenomena in different ways.

3.3.3 Day Two

During the second day of the unit, the students were asked to apply these ratios to scenarios that illustrate patterns of inheritance different from classic Mendelian inheritance, including incomplete dominance and sex-linked traits (Cartier and Stewart 2000). The scenarios were presented to students using simulation software called Virtual Genetics Lab (VGL) (White 2012). VGL allowed the students to make unlimited crosses using imaginary flies. While there are advantages to using a real organism (e.g., bench science skills), simulation software was selected because simulations have been shown to be particularly effective in the laboratory setting (Rutten et al. 2012). In addition, VGL allows students to develop problem-solving skills necessary for understanding inheritance in a shorter time period and prevents them from finding answers on the Internet since the flies are fictional. Finally, students gain experience with manipulating software, which is an increasingly important skill in science. Students were not told anything about the inheritance patterns illustrated by the software. The activity put students into the position of trying to confirm the classic 3:1 phenotypic ratio in the imaginary flies suggested from Mendel's results. The students completed two scenarios in small groups. The first followed a 3:1 phenotypic ratio. This scenario was intended to be relatively easy for students and allowed them to familiarize themselves with the software. The second scenario was about either incomplete dominance or sex-linked traits. The instructor assigned one of the scenarios to each group and did not tell students anything about the inheritance patterns. As a result, students had the opportunity to engage with the Mendel story through an authentic problem-solving experience.

The students used the results of the simulation to create a laboratory report. The report required students to explain their experimental design, provide an inheritance pattern, and include an argument for the inheritance pattern based on cross data from their investigation. For the experimental design portion, students discussed the traits they were observing in the flies. They also included a description of the crosses they conducted to explore their assigned scenario. In providing an argument for their proposed inheritance patterns, the students were told to only include data that were necessary to explain the inheritance pattern. In addition, the laboratory report concluded with a section where students reflected on NOS. This section focused on the relationship between the VGL activity and tentativeness in science. Students also responded to whether they thought the activity was reflective of actual scientific process. The intention of the VGL investigation was to give students experience with tentativeness in science. Students had to work through scenarios on their own that do not fit with the classic Mendelian model. Through the first half of the VGL investigation, students worked from the assumption that traits in the imaginary flies would follow the 3:1 phenotypic ratio. Students were forced to reevaluate their assumptions in the second half of the investigation when the inheritance patterns departed from traditional Mendelian inheritance.

3.3.4 Day Three

On the third day of the unit, students presented the results of their VGL investigation to the rest of the class. These presentations led to a discussion about where the study of heredity has gone since Mendel. A mini-lecture covered incomplete dominance and sex-linked traits. The mini-lecture was intended to fill in gaps in understanding of these inheritance patterns. It also served to give students another opportunity to reflect on aspects of NOS. After learning about inheritance patterns that contradict Mendel's results, students were asked whether they thought that Mendel was wrong. The aim was not to tell students that Mendel was wrong but instead to have them reflect on how science is continually changing over time. The question for students to consider was whether the discovery of inheritance patterns different from those of Mendel means that his work should be dismissed as wrong. This leads into the unique story of how Mendel's work was received by the scientific community and the controversy after its acceptance. Students were told about the delayed rediscovery of Mendel's work in 1900 by three separate scientists. They were also told about the controversy that has surrounded Mendel's work related to the argument that his results were statistically improbable (Franklin et al. 2008). The discussion concluded with students answering questions regarding Mendel's findings, the reception of Mendel's work, and the controversy surrounding his work. The goal of the discussion was to give students an additional opportunity to reflect on scientists' interpreting results differently based on their backgrounds and tentativeness in science.

3.4 Data Collection and Analysis

The impact of the intervention was assessed using a pre-/post-administered survey instrument and semi-structured interviews after instruction. The surveys were administered by the first author without any involvement from the instructor. The surveys were not anonymous in the sense that the primary author knew the identities of the students who completed them. However, no personally identifiable information or survey results were shared outside of the research team. Additionally, the second author (course instructor) had no knowledge of which students completed the surveys and interviews or the data collected until after the completion of the course. NOS understandings were captured using the *Student Understanding of Science and Scientific Inquiry* (SUSSI) instrument (Liang et al.

2008). The SUSSI was chosen for a variety of reasons. First, it is hoped that this study can serve as a pilot for a larger-scale quantitative study. Therefore, an instrument was needed with the flexibility to be used qualitatively and quantitatively. The qualitative nature of the development of the SUSSI makes it equally useful for small-scale studies (Liang et al. 2008). Indeed, other researchers have used the SUSSI to qualitatively evaluate student NOS understandings (e.g., Herman and Clough 2016). In addition, SUSSI also allows for measuring students NOS understandings without relying on students having extensive writing skills or NOS knowledge. One drawback of more open-ended instruments, such as the VNOS, is that they may underestimate student NOS understandings based on students' poor writing skills (Rudge and Howe 2013). Finally, SUSSI has items relevant to the research questions related to the influence of scientists' backgrounds and culture on science.

The SUSSI consists of six different NOS areas, each made up of four Likert response items and one open-response item. Students responded to each Likert item on a 5-point scale (strongly disagree to strongly agree). For the open-response questions, students were asked to provide examples to support their ideas regarding each area of the SUSSI. The areas covered by the SUSSI include observations and inferences, change of scientific theories, scientific laws versus theories, social and cultural influence on science, imagination and creativity in scientific investigation, and methodology of scientific investigation.

Based on the intervention's focus on scientists' prior knowledge and the influence of culture on science, change was only expected for the observation and inferences and the social and cultural influence on science areas. The other areas of the instrument were included to maintain validity and to serve as a form of control. Since the focus of the intervention unit was limited to two aspects of NOS, one would not necessarily expect students to make gains in their understanding of the other NOS concepts that were not addressed by the intervention. The instrument was administered immediately before the beginning of the intervention unit and again right after the conclusion of the unit.

In addition, semi-structured interviews were conducted within 2 weeks of the end of the intervention. The interviews focused on clarifying students' responses to the assessment instruments. Students were given both their pre- and post-assessment and were asked to explain changes they made in their responses pre to post.

The SUSSI Likert items were scored using a coding scheme created by the authors of the SUSSI (Liang et al. 2008; Miller et al. 2010). Each item was scored on a 5-point scale with a one given to the least sophisticated NOS view and a five given to the most sophisticated one. The SUSSI open-response questions were examined to determine whether the examples provided by students were related to the intervention unit. Only responses that explicitly mentioned Mendel or some aspect of the intervention unit were considered relevant to the intervention.

Patterns were identified in the SUSSI scores and were used to focus the analysis of the interview data. The patterns of most interest for the study were those items on the SUSSI instrument for which students showed the most change from the pre- to post-test. Through the analysis of the interview data, we hoped to learn what led students to change their responses to the SUSSI after instruction. No a priori codes or frameworks were used to analyze the interview data. Transcripts of the interviews were inductively coded to identify possible reasons for changes observed from the pre- to the post-test. The first author read through the transcripts multiple times to develop codes in students' responses. The second author then applied these codes to the transcripts independently. There was high agreement between the first and second authors in the coding of the transcripts (Cohen's $\kappa = 0.733$).

Patterns were then identified in the codes to create themes. The coded transcripts and themes were used to inform the results from the SUSSI instrument (Creswell 2007).

4 Results

The responses to SUSSI instrument, and the interviews, are summarized below. The results for all items on the SUSSI have not been included in this paper. Only those items on which students scored particularly low or showed change from the pre- to post-test are included. For the results for the other items and the full SUSSI instrument, please see the electronic supplement.

4.1 Student Understandings Prior to the Intervention Unit

Scores on the SUSSI pre-assessment indicated that overall the students in this study had inaccurate NOS understandings prior to the intervention. Students scored lowest on items related to the distinction between scientific laws and theories. The items with the lowest scores can be seen in Fig. 1 below. For SUSSI 3A on the pre-test, nine of eleven students felt that theories exist naturally and are waiting to be discovered by scientists. On SUSSI 3C, eight of the eleven students believed that laws are proven theories. There was little change in these items on the SUSSI post-test. On the post-test for statement 3A, three students improved their scores, five did not change, and three scored lower. For SUSSI statement 3C on the post-test, three students improved, seven remained the same, and one scored lower. Only one student mentioned the intervention unit in the scientific laws and theories open-response question on the post-test. This student noted that Mendel's laws ended up being challenged by later scientists.

The most common opinion expressed during the interviews was that there is a hierarchical relationship between theories and laws in science. Five of the seven students talked about laws being ideas that have been proven and/or tested numerous times. Theories on the other hand were described as ideas that scientists are less sure of than laws.

Other aspects of NOS for which students had low scores were the objectivity of scientists and the influence of culture on science. This being said, there were some areas that students did have more sophisticated NOS understandings. Students scored relatively

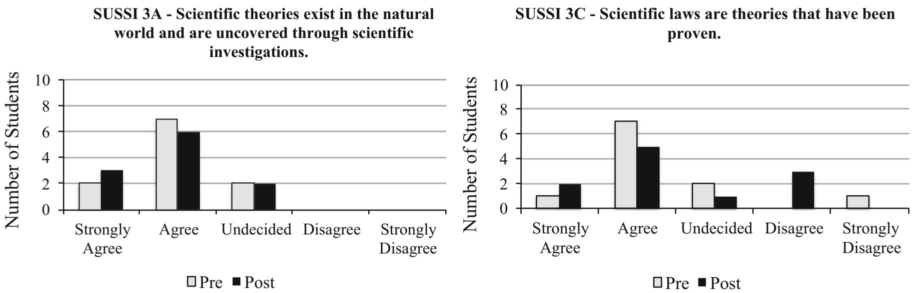

Fig. 1 Frequency charts of student responses for item 3 "Scientific Laws versus Theories" on the SUSSI instrument. Students' responses are listed from least sophisticated to most sophisticated (*left* to *right*) on the *x*-axis

higher on items related to the tentativeness of scientific theories and the role of prior knowledge in scientists' observations and interpretations.

4.2 Question 1: How Does the Mendel Intervention Unit Influence Students' Understandings of the Role of Scientists' Prior Knowledge and Background in Observations?

A comparison of student responses from the pre- and post-test showed improvement of some student NOS understandings after the intervention unit. Students showed the most change in the "Observations and Inferences" and the "Social and Cultural Influences on Science" sections of the SUSSI instrument. On both sections, students made positive gains in their NOS understandings. Specifically, students' understandings seemed to improve on items related to the influence of prior knowledge on observations and the influence of society and culture on what and how science is conducted.

For the "Observations and Inferences" item (Fig. 2), the main differences between the pre- and the post-test were found in statements 1A and 1B. On the post-test for statement 1A, four students improved their scores and seven remained the same. For statement 1B, six students improved, four did not change, and one student scored lower. Both of these statements were related to the influence of scientists' backgrounds on their observations. Teaching students the influence of scientists' backgrounds was a priority of the intervention unit. Scientists' backgrounds were discussed in relation to Mendel himself and prominent nineteenth-century scientists who worked on heredity such as Darwin and Lamarck. Students were also given multiple opportunities to reflect on the influence of individuals' backgrounds. These opportunities take the form of discussion questions and the activity where students speculate on how other nineteenth-century scientists would have interpreted some of Mendel's data. For these statements, five of the eleven students made reference to the intervention unit in the interviews or in their open-response answer on the post-test. Two students mentioned the intervention during the interview, one participant in both the interview and their open response, and two students in only the open response.

Statement 1A asserts that scientists' observations can be different based on their prior knowledge. Although a majority of students supported this statement on the pre-test, the post-test indicates a stronger shift of support, with a majority of students indicating strong

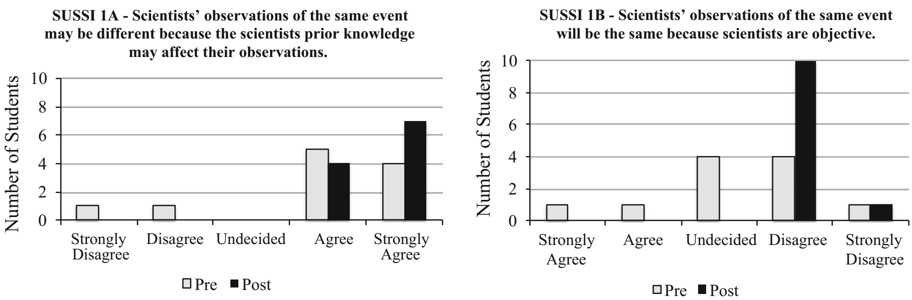

Fig. 2 Frequency charts of student responses for Sect. 1 "Observations and Inferences" on the SUSSI instrument. Students' responses are listed from least sophisticated to most sophisticated (*left* to *right*) on the *x*-axis. Students improved on item A and item B

agreement with the statement. Additionally, two students moved from disagreeing to agreeing with the statements. Findings from an analysis of the interviews suggest that this shift is associated with the objectives of the intervention unit. For example, one student used the rediscovery of Mendel's work as a case for how prior knowledge affects science observations:

> The first time I didn't take into consideration that people were going to have different backgrounds. What was it Mendel that had a basis in statistics and …uh I am blanking on his name. I can't remember but anyway his basis wasn't on statistics and they looked at it from two points of view. (Interview; Student 4)

This student is highlighting the idea that what individual scientists bring, in terms of their backgrounds, can be important when scientists interpret observations. Many of the students shared similar viewpoints.

Statement 1B posits that observations of the same event will be the same because of scientists' objectivity. On the pre-test, six students either agreed with the statement or were unsure. This seems to indicate that there was considerable confusion regarding scientists' ability to be objective. However, in the post-test the majority of students disagreed or strongly disagreed with statement B. The interview data again indicated that this change was related to the intervention unit. Two students brought up that scientists after Mendel disagreed with his results.

> Well if you take Mendel's experiment and like people disagreed with him over time and so…that's basically why I decided to disagree for that one. (Interview; Student 1)

> …it reminded me of the whole Mendel experiment um the three scientists after how they continued different observations from what he originally went with so like his experiment was like the basis about there experiments so I definitely think that prior knowledge will affect the experiments and their observations because they know more than before. (Interview; Student 7)

These students seemed to be making a connection between the controversy surrounding Mendel's work and the idea that scientists' observations of the same phenomena may differ. Similar ideas were given in response to the open-response question for this part of the SUSSI, "With examples, explain why you think scientists' observations and interpretations are the same OR different."

> Scientists' observations are different because when you look at the same thing in different ways, you're going to get different data. This is what scientists do, they look at other people's work and make new observations like the 3 scientists did with Mendel's work. (Open response; Student 5)

> Looking at Mendel's work with all the controversy it can be seen that things might not always read the same to others. (Open response; Student 9)

It seems that the discussion of the rediscovery of Mendel's work on the third day of the unit was particularly influential for students. The VGL fly investigation also seemed to play a role in influencing students' understandings for statement B as multiple students mentioned the activity. For example, one student described the experience of making an incorrect prediction during this activity.

> They might go into an experiment looking for something and then like test it and find something completely different like in the fruit fly experiment we would mix two groups thinking one outcome would come of it and something completely different. (Interview; Student 7)

This student was able to experience making a prediction and collecting anomalous data. The student's attempt at reconciling this data seemed to give them some insight into the scientific process.

4.3 Question 2: How Does the Intervention Unit Influence Students' Understandings of How Culture Can Affect the Way Science is Conducted?

The influence of society and culture was emphasized multiple times during the intervention unit. During day one of the unit, Mendel's motivation for his experiments was one of the focus points. Part of that discussion was the idea that local sheep farmers' interest in hybrids likely contributed to Mendel's interest in hybridization. Additionally, the third day of the unit includes the story of the acceptance of Mendel's work and the surrounding controversy.

For the "Social and Cultural Influence on Science" SUSSI item, students made gains on statements 4B and 4C. For statement 4B on the post-test, six students improved their scores and five remained the same. On statement 4C, three students improved their scores and eight students did not change. Statement 4B presents cultural values as being an important influence on what kind of science is conducted. Statement 4C provides a similar position as it describes culture as being important in determining how science is conducted. As shown in Fig. 3 below, a shift from disagreement or undecided to agreement was characteristic of the change from the pre- to post-test on both statements. There was no mention of the intervention unit in students' answers to the SUSSI open-response question for this SUSSI item.

There were three students who mentioned the intervention unit in relation to statements 4B and 4C during the interview. The most common reasoning given, for changes in responses on statements 4B and 4C, was related to animal testing. Three interview students talked about the idea of themselves or others being uncomfortable conducting investigations with live animals. Two of these students talked about animal testing in relation to other course activities. One student made a connection between animal testing and the fly investigation portion of the intervention unit.

> Um I guess the whole fact that the fruit fly experiment was an actual simulation and not real fruit flies… I don't know I just don't think I would want to perform experiments on animals. (Interview; Student 7)

It seems that the experience of working on their own investigation prompted this student to consider his/her own values. In considering his/her values regarding using live animals in scientific investigations, the student gained insight into the role of culture in science. The discussion of the rediscovery of Mendel's work seemed to play a role for statements 4B and 4C as well. One student made specific reference to it during the interview.

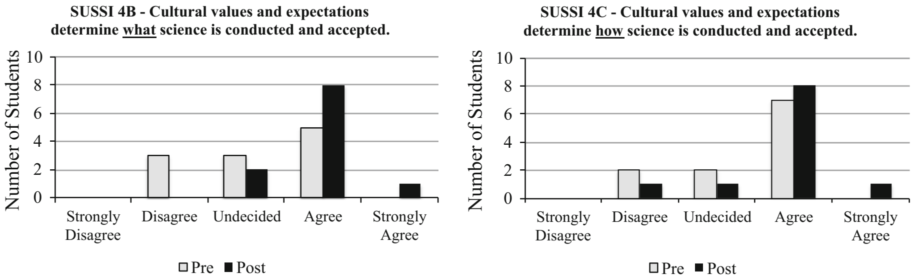

Fig. 3 Frequency charts of student responses for Sect. 4 "Social and Cultural Influence on Science" on the SUSSI instrument. Students' responses are listed from least sophisticated to most sophisticated (*left* to *right*) on the *x*-axis

> …we were talking about Mendel and you know his research…they didn't acknowledge it for years later. Now it is like a foundation for genetics. (Interview, Student 2)

The remaining three interview students' responses were fairly inconclusive regarding the shift seen on statements 4B and 4C. Many of the students made vague references to the course and how it made them think more deeply about the influence of culture on science. One student, however, gave a more specific reason for their changed perspective related to the intervention unit.

> I think because in the unit since I like realized um… a lot of the ways I already thought of things weren't necessarily exactly right or even true that it was making me like second guess myself more the second time. (Interview; Student 8)

This student seems to have come to the realization that many of their previously held understandings of the content covered in the intervention unit were incorrect. In turn, they began questioning all of their responses on the SUSSI instrument.

5 Discussion

The students in this study had largely inaccurate NOS understandings before the intervention unit. This is not surprising, as often individuals develop NOS understanding across multiple contexts over time. Since many students likely had limited prior experience with NOS, they were not expected to develop sophisticated NOS understandings after a single course. Additionally, students' naïve NOS understandings are consistent with previous findings that pre-service teachers typically have difficulty with NOS (Akerson et al. 2000; Rudge et al. 2014). The area that students struggled with the most, and the distinction between scientific laws and theories, showed little improvement on the post-test. This is to be expected, as the instructional unit was not designed to teach students about this distinction. The students' lack of improvement on areas not covered by the intervention provides support for the argument that the intervention influenced students' NOS understandings and not some other aspect of the course.

This being said, the students showed relatively accurate NOS understanding for the tentativeness of scientific theories and the influence of prior knowledge on scientists' observations on the pre-test. It may be that the higher scores seen on the pre-test were a result of students' previous exposure to these NOS concepts. Two example activities prior to the intervention were the silver box activity and the William Harvey blood circulation unit. The silver box activity was intended to help students understand the difference between observations and inferences, tentativeness in science, and the importance of evidence in science. The blood circulation activity was intended to help students understand the importance of evidence and tentativeness in science. During the interviews, these examples were mentioned by some of the students. The emphasis on NOS concepts throughout the course may have primed students for the intervention unit. However, the NOS learning goals for these activities were distinct from those of the intervention. Since the areas of most improvement on the SUSSI were directly related to the learning goals of the intervention, the results suggest that the intervention influenced students NOS understandings. It is important to note that areas of the SUSSI not addressed by the intervention did not show improvement on the post-test instrument.

The results suggest that the intervention unit influenced student NOS understandings for some areas but not others. The post-test results and the interviews indicated that students' NOS understandings related to the influence of scientists' backgrounds on their observations, and to the role of culture in science improved. It is interesting that these areas showed the most change on the SUSSI, as they are both related to the NOS learning goal of the intervention unit. The unit was designed to teach students about the tentativeness of scientific knowledge. Two factors that contribute to this idea are the influence of scientists' backgrounds and culture on science (Schwartz et al. 2004). The students' improvement on SUSSI items related to these two factors supports the idea that students had an improved understanding of the tentative NOS after the intervention. One could argue that the improvements seen after the intervention were primarily the result of the explicit and reflective instructional approach and not related to the historical material. However, the interviews and open-response question answers provide some support for the importance of the history influencing students' NOS understandings.

For the influence of scientists' background on observations aspect of NOS, the interviews and the open-response questions indicate that the story of the controversy surrounding the acceptance of Mendel's work was particularly important. Many students raised the notion of scientists' differing opinions about Mendel's line of inquiry. Students also mentioned the rediscovery of Mendel's work by three separate scientists' multiple times. For the influence of culture aspect, the discussion of the economic pressures of Mendel's home region and their influences on Mendel's work may have made students think about the importance of culture in science. Indeed, the fact that multiple students mentioned animal testing, when asked about their responses to items in the culture portion of the SUSSI, indicates that something about the unit or course made students think of this in relation to culture. There is some evidence from the interviews that the intervention unit was responsible for getting students thinking about animal testing. One student mentioned that the fly investigation made them consider what it would have been like to do testing on real flies. The focus on animal testing generally and specifically related to the fly investigation during the interviews suggests the intervention unit may have encouraged students to consider cultural issues related to science.

6 Limitations of the Study

The current study has certain limitations. First, the choice of a force choice instrument (SUSSI) for evaluating students' NOS understanding may not have allowed students to fully or accurately describe their understandings. However, this limitation is at least somewhat mitigated by the use of semi-structured interviews, which allowed students to expand upon and or explain their responses to the SUSSI instrument. In the pilot testing of the SUSSI, the authors modified the Likert response statements included in the instrument based on interviews with participants (Liang et al. 2008). Therefore, the statements included on the final SUSSI should be more reflective of actual student understandings. Next, the sample of students is small and there was no control group. Additionally, the sample chosen was one of convenience and not randomized. These three limitations do not allow for generalizing the results. The students in this study do, however, provide insight into the influence of the intervention and the particular portions of the intervention that may have been most helpful for them. Nevertheless, the intervention may not be effective for all types of students.

Another potential limitation of the study is the length of the intervention itself. It could be argued that three class periods are not enough time for students to achieve adequate NOS understandings. However, previous studies have shown that shorter interventions can have positive effects on NOS views (Howe and Rudge 2005; Kim and Irving 2010; Rudge et al. 2014). There are no claims made about the intervention unit being able to achieve adequate NOS conceptions on its own. Instead, the claim is that the intervention can be useful for improving certain aspects of students' NOS understandings. Our data do provide support for this claim. Finally, one could argue that the students were primed for learning about NOS through other activities in the course. This being said, the last limitation could be seen as a strength. Despite the short duration of the unit and students' prior exposure to NOS through other activities, gains in student NOS understandings were still observed in some areas.

7 Conclusions and Future Work

This study indicates that historically based curricula can be used to influence students' NOS understandings. There have been several previous studies that have been conducted on the use of historical instructional approaches for improving students' NOS understanding. Abd-El-Khalick and Lederman (2000) evaluated full courses utilizing the history of science and found minimal improvement in student NOS views. Similarly, Dass (2005) examined the effect of a history of science course on students' NOS views and found little improvement. In contrast, studies involving shorter interventions (Lin and Chen 2002; Kim and Irving 2010; Rudge et al. 2014) have shown evidence for improved NOS views after instruction involving the history of science. Reasons for the discrepancies among the results of previous studies conducted on historical interventions may include differences in the NOS assessment instruments used, the level of students included in the studies, and the length of the interventions. As noted by Rudge et al. (2014), evaluating course length interventions may introduce noise that masks the effects of historical instructional approaches. The current study provides additional support for the ability of interventions that are shorter than course length to influence student NOS understanding.

The intervention unit used in the current study was designed to address the influence of scientists' prior knowledge and culture on science. The Mendel unit seems to be useful for improving these NOS understandings, but not others. It is not surprising that this unit would lead to improvement in only some aspects of NOS. One would not expect to see changes in students' understanding of other NOS aspects not covered by the unit. While the unit was not the only exposure students participating in this course had with NOS, there were improvements seen in students' NOS understandings from immediately before to after the unit. Therefore, science educators should consider using the history of Mendel's work as a tool for improving their students' NOS understandings. Other researchers have made similar recommendations on the basis of analysis of textbook representations of Mendelian genetics (Campanile et al. 2015).

It is not clear from the results of this study whether the history of science used or the explicit and reflective instructional approach was primarily responsible for the positive gains in NOS understanding observed in the study. Since the history of science was used to teach NOS concepts, it was not possible to separate the use of history from the instructional approach. A larger study involving a control group taught NOS concepts using an explicit and reflective approach without history is needed in order to gain further insight into the specific utility of the history of science for improving NOS understanding. We hope to complete such a study in our future research.

In addition to NOS learning goals, history of science has also been touted as a potential vehicle for helping students learn science content (Matthews 1994). This is a particularly important consideration when one notes teachers are unlikely to adopt NOS focused unit plans if they view them as sacrificing content (Monk and Osborne 1997). Some researchers have shown that science content, such as evolution (Lombrozo et al. 2008) and concepts in the geosciences (Nadelson and Viskupic 2010), is related to students' understanding of NOS. Therefore, one goal for future research will be to determine whether there is an empirical relationship between students' understanding of NOS and their understanding of science content.

Compliance with ethical standards

Conflict of interest The authors declared that they have no conflicts of interest.

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