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ARTICLE

Rosalind Franklin and the Discovery of the Structure of DNA

Using Historical Narratives to Help Students Understand Nature of Science

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Abstract
Issues associated with nature of science (NOS) have long been recognized as an essential component of scientific literacy. While consensus exists regarding the importance of an explicit reflective approach, precisely how to teach NOS remains elusive. The present study explores one particularly promising approach, namely the use of historical narratives. The purpose of the study was to examine whether narratives based on the history of research on the structure of DNA shared using an explicit and reflective approach would affect students' understandings of NOS. A mixed method approach was used to assess students' NOS understanding in two different versions of a biology course. In the intervention version, students learned about research on the structure of DNA through historical narratives. In the alternative version, students learned the same material without historical narratives. The Student Understanding of Science and Scientific Inquiry (SUSSI) instrument was administered pre- and post- intervention to all students. Semi-structured interviews with a total of 27 participants from both treatments were conducted to further clarify students' responses. Results indicate that most of the participants in the intervention treatment made significant changes from pre- to post-assessment in their understanding of two targeted aspects of NOS including scientists' use of creativity and imagination, and social and cultural influences on science. Female participants in the intervention treatment also stated that learning about Rosalind Franklin's contributions by way of the story had given them additional confidence to learn science.

Keywords History of science · Nature of science · Narratives · DNA structure · Gender · Rosalind Franklin

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1 Introduction

It is widely recognized among science educators that a fundamental component of scientific literacy involves understanding the nature of science (NOS) as a process (National Research Council [NRC] 1996; American Association for the Advancement of Science [AAAS] 2009). A particularly influential perspective on NOS, developed by Norman Lederman and his associates identifies NOS with a set of epistemological issues, such as the empirical and tentative nature of science, creativity and subjectivity in science, the distinction between observation and inference, social and cultural influence in science, and the difference between theory and law (e.g., Lederman and Abd-El-Khalick 1998). More than a few scholars have expressed reservations about conceptualizing NOS in this way if indeed the goal is to provide students with more authentic views about the process of science (McComas et al. 1998; Allchin 2011; Irzik & Nola 2011; Matthews 2012; Erduran et al. 2019). Nevertheless, the Lederman approach remains the consensus approach among science educators on how NOS should be characterized for use by teachers and students. Research by Lederman and his associates, as well as others, has documented that despite its prominent attention in standards documents, students continue to have widespread misconceptions regarding NOS, such as the presumption that all scientists follow the same steps in the same order in the conduct of scientific investigations (Lederman 2007; Liang et al. 2008; García-Carmona & Acevedo-Díaz 2018; Olson 2018). It has been argued that these misconceptions about the nature of science are potential causes of many long-term academic, economic, political, and social problems (Clough 2006).

Precisely how best to teach science in a manner that draws student attention to issues associated with the nature of science without promulgating misconceptions is unclear. Many have suggested the use of history in the science classroom (HOS), which on the surface appears to be an ideal way to help students learn science and learn about the process of science (McComas et al. 1998; Rudge et al. 2014; Aragón-Méndez et al. 2019). Scholars have advanced numerous motivations for using history to teach NOS, such as its potential to humanize the scientific process and provide students a highly contextualized setting within which to integrate NOS ideas and science content (Abd-El-Khalick et al. 1998). HOS instruction has also been advocated as a way to help teachers appreciate students' misconceptions that are broadly similar to views held by past scientists (Matthews 1994). While there is widespread agreement that history of science has the potential to promote student understanding of NOS, there is no consensus on how best to use it in the science classroom (Akerson et al. 2000). One possible solution is to share history by means of stories or narratives. Historical narratives by their nature contextualize instruction in a way that draws students' attention to NOS issues entangled with scientific knowledge (Williams & Rudge 2016). Historical stories have been shown to enhance students' attitudes towards science and improve students' class engagement. They also provide a specific structure that can help students better recall class content (Clough 2011).

Numerous empirical studies have shown that NOS is best learned through explicit and reflective instruction, specifically when teachers explicitly design lessons to include NOS issues and provide students with opportunities to reflect on their class experiences (e.g., Lederman 2007). In the present study, historical narratives were shared by means of an interrupted story technique (c.f. Klassen 2009), with students being given explicit opportunities to reflect on the targeted aspects of NOS in class discussions. Such an approach is consistent and indeed recommended from the standpoint of conceptual change learning theory.

It embodies the idea that learners actively make connections with their prior knowledge and cognitively restructure their essential schema to minimize conflict between preconceptions and new knowledge (Ausubel 1960; Posner et al. 1982; Appleton 1997). For the present study, we developed a two-class lesson using historical narratives with an eye to bringing students' attention to NOS issues associated with the history of research on the structure of DNA, and in particular Rosalind Franklin's role in the process (Dai and Rudge 2018). One of the narratives was intended to help students appreciate the fact that science is a creative endeavor; the second, to illustrate the role that gender often plays in science. The goal of this study is to systematically analyze whether and how these narratives helped students appreciate the targeted aspects of NOS.

2 Literature Review

2.1 Teaching and Learning of NOS

American science education organizations have long advocated that integrating NOS into classroom instruction is essential to improve students' scientific literacy (e.g., National Science Teachers Association [NSTA] 2000; NGSS Lead States 2013). Olson (2018) documents that many international science education organizations are doing so as well. NOS includes the consideration of the nature and limits of scientific knowledge, such as the fact scientific knowledge while durable is subject to change and also an appreciation of how science is affected by the social and cultural context within which it occurs (Clough 2006; Allchin 2011). Although the importance of understanding NOS has been advocated for decades, controversy persists among many philosophers, historians, science scholars, educators, and teachers regarding which ideas about NOS should be integrated into science class and how best to do this. In addition, Olson (2018) noted that there is no consensus on the status of NOS among international science education standards documents. For example, Clough (2007) points out that science teachers may easily misinterpret the commonly advocated NOS tenets. His analysis suggests teachers often transmit NOS tenets as established knowledge rather than having students reflect on these issues and reach their own perspectives through investigation and discussion. Kampourakis (2016) nevertheless defends a "general aspects" approach to NOS as a valid starting point for helping students develop more sophisticated points of view.

An increasing number of science educators have called for "an authentic view" of science, which addresses a broader scope of issues by focusing on the role of social and cultural values in contextualized science. Allchin (1999) cautions making a rigid distinction between epistemic and cultural values of NOS. He points out epistemic values of NOS are often mistakenly taken to refer to "guide the pursuit and methods of science," while the cultural values "enter science through the work of individual scientists." Allchin (2011) advocates a "Whole Science" approach that involves a more comprehensive approach to NOS (including experimental, conceptual, and social elements) as a framework to guide students to conduct scientific investigations or teachers to design the NOS curriculum. He emphasizes social values should receive equal attention as the epistemic aspects of science in school.

Similarly, other researchers such as Irzik and Nola (2011) identified the distinction between cognitive-epistemic and social-institutional systems. They emphasize including social components of science when designing curricula and lesson materials. In the same vein, Erduran and Dagher (2014) propose that the values of science should be considered from multiple perspectives, including epistemic, cognitive, cultural, social, political, moral, and ethical. Both epistemic and social values need to be integrated in the teaching of school science. Furthermore, Erduran et al. (2019) draws attention to the importance of using broader and more inclusive NOS categories. They conclude by proposing an alternative framework for the teaching of NOS, the Family Resemblance Approach (FRA), which conceptualizes science as a cognitive-epistemic and social-institutional system.

Misconceptions about NOS continue to be prevalent among students and teachers despite widespread recognition of the centrality of NOS to scientific literacy. Part of the problem reflects the difficulties many instructors have in teaching NOS (Lederman 2007; Liang et al. 2008). Teachers often lack training specific to the teaching of NOS and are poorly positioned to make sense of extensive empirical studies that have analyzed the effectiveness of various approaches on the understanding of NOS over the past decades. Simply put there is no agreement on how teachers should introduce NOS conceptions in science class (Lederman and Abd-EI-Khalick 1998; Clough 2006).

Many instructional approaches, such as inquiry-based learning, activity-based instruction, and laboratory-centered curricula are suggested to enhance student NOS conceptions (Akerson et al. 2000). In recent decades, several empirical studies came to support the claim that explicit and reflective NOS instruction can effectively promote students' understanding of NOS and help teachers transfer their NOS knowledge into actual classroom practices (Clough 2006; Rudge and Howe 2009). By using the explicit and reflective NOS instruction, teachers can provide more opportunities for students to discuss relevant NOS issues explicitly. This is a crucial process to foster students to compare and modify their previous ideas in the case of conflicts between preconceptions and new knowledge.

For example, Akerson, Abd-EI-Khalick, and Lederman (2000) examined the effectiveness of a set of activities implemented in the explicit and reflective approach for improving pre-service elementary teachers' understanding of some targeted NOS aspects. An open-ended NOS questionnaire accompanied by semi-structured interviews was used to assess participants' NOS views. The results revealed that most of the participants significantly improved in their understanding of NOS, specifically in empirical, tentative, imaginative, and creative aspects. However, the participants had less gain in their appreciation of the role that subjective, social, and cultural aspects play in science. Additionally, the authors mentioned that it is difficult to convey the social and cultural aspects of science in the absence of a rich and extensive contextualization. The authors further suggested that adding examples with extensive contexts describing the development of scientific knowledge and scientists' work would facilitate students to obtain substantial gains in their understanding of NOS.

Similarly, Clough (2006) acknowledged that multiple activities such as the "black-box" (Lederman and Abd-El-Khalick 1998) could be used to explicitly introduce NOS concepts and draw students' attention to related issues. He nevertheless criticized artificial, non-content-related stand alone NOS activities as insufficient and misleading. His worry is that students who are taught NOS in the absence of an authentic science context would have difficulties applying their understanding to other situations. Accordingly, Clough advocates the use of highly contextualized situations that seamlessly integrate NOS issues as a better way to help students learn NOS. He concludes that an explicit and reflective, highly contextualized NOS instruction entangled in science content presents students with a better understanding of how authentic science works and what scientists do.

2.2 Implementing HOS to Teach NOS

There are many effective ways to use history in the science classroom to foster student NOS views and learn science content (Matthews 1994; Clough 2006; McComas 2011). Historical approaches to the teaching of science provide a context for integrating authentic science and social-scientific issues in the science classroom. Use of history demystifies the process of science and provides students with a better insight of how science deals with other aspects of the world, such as social, cultural, and ethical issues. It can also help teachers better understand their students' misconceptions regarding some particular scientific knowledge by drawing attention to how past scientists overcame similar misconceptions. Despite these advantages, teachers rarely adopt HOS in their classrooms for at least four basic reasons (Monk & Osborne 1997). First, most science teachers view HOS as "add-on" knowledge with no benefits in improving students' scientific content learning. Second, a great number of teachers suffer from a lack of confidence in the understanding of history and their abilities to teach it. A third reason centers around the lack of examples about how to incorporate HOS in class. Finally, to get buy into the approach, we need far more empirical studies on using HOS to teach NOS.

Several studies have indicated the positive impacts of HOS on students' NOS views, without providing consistent guidance on how best to use HOS in the classroom (Matthews 1994; Akerson et al. 2000; Rudge et al. 2014). Many studies by scholars of science provide rationales for why history of science should be used, with the particular dictum that it not be viewed as simply an "add on" item, without providing specific guidance on how to do it. Over the course of the past few decades, a trend among science education studies has begun to emphasize the importance of the use of stories, and in particular narratives, to teach NOS. Clough (2006) emphasizes how stories based in history can create a rich context as a way of drawing students' attention to NOS issues entangled with scientific knowledge. Highly contextualized stories based in history of science not only can improve students' cognitive abilities to recall the class content but also enhance students' engagement to intentionally draw student's attention to a deeper reflection of NOS views (Rudge and Howe 2009).

While much has been written in terms of the rationale for using historical stories in the classroom, until recently it has not been the object of a great deal of empirical research by science educators. Hadzigeorgiou et al. (2012), for instance, proposed the positive effects of using a "romantic understanding" type of storytelling in science instruction on students learning of NOS and science content through the Nikola Tesla story. Rudge et al. (2014) noted that student views of NOS were improved during the intervention of a short-term historically based unit on the phenomenon of industrial melanism. Research conducted by Aragón-Méndez, Acevedo-Díaz and García-Carmona (2019) illustrated that the historical case of Semmelweis and childbed fever delivered by means of an explicit and reflective approach improved participants understanding most of the NOS aspects.

A study by Williams and Rudge (2016) implemented historical short stories with an embedded explicit and reflective instructional approach to introduce Mendelian genetics. The effect of this instructional approach was measured by means of a mixed-methods study using the SUSSI and semi-structured interviews. The results indicated that students' understanding of NOS was enhanced after the intervention of a historically based genetics unit. However, the study was conducted without incorporating a comparison treatment, which makes it difficult to disaggregate the unique effects of whether the intervention was indeed responsible for the observed changes in students' views of NOS. A study by Williams and Rudge (2019) involved with direct comparisons of the effectiveness of a version of a course that uses historical narratives with an alternative version that does not represented a more powerful way to gauge the effect of the intervention on students' NOS understanding.

Of particular interest to the present project is a study conducted by García-Carmona (2018) that focused on evaluating the effectiveness of an activity based upon the critical and reflective reading of the structure of DNA and the historical case of Rosalind Franklin on pre-service elementary teachers' NOS learning. This qualitative study analyzed the groups' class responses to the NOS questions through a rubric designed and validated by the author and his research colleagues (Acevedo & García-Carmona 2017). The results indicated that the participants improved their understanding of the aspects of NOS discussed in the activity. A potential limitation of the study is that the responses to the NOS reflective questions were discussed as a group, which might not represent the opinion of each member in the group. The framework this study used to structure and create historical cases is unclear. As a result, it was not clear whether the historical reading activity affected students' understanding of NOS.

Klassen (2009) provides a promising theoretical framework for constructing and evaluating science stories, based on narrative theory and learning theory. Klassen's framework identifies ten essential narrative elements that must be present for something to be called a story, including event-tokens, the narrator, narrative appetite, past time, the structure, agency, the purpose, and the role of the reader or listener (Appendix 1, Table 5). Klassen (2014) discusses the concept of stories within the narrative genre. The purpose of characterizing a story as a narrative in writing is to purport that it follows a set of criteria that can be utilized to assess the effectiveness of the story's use in science instruction. Although Klassen's framework for creating historical narratives has been published for more than 10 years, there is still limited empirical study testing the effectiveness of the methodology. Research by Williams and Rudge (2019) indicates that narratives developed with reference to Klassen's (2009) framework had a positive influence on students' NOS views and science content, but both studies concluded more research is needed. The current empirical study is used to further test the impact of historical narratives created based on Klassen's framework (2009) on undergraduate students' understanding of NOS.

2.3 Teaching the Structure of DNA and NOS Through Historical Narratives

In this section, we briefly describe the historical narratives developed for the intervention, and in particular the rationale for why we developed it the way we did. (Additional detail on how it can be used in the science classroom is provided in Dai and Rudge 2018).

While a discussion of James Watson and Francis Crick's discovery of the structure of DNA is frequently included in textbooks, the information provided is often presented in a piecemeal fashion that neglects issues associated with the nature of science, such as the roles of creativity and imagination, cooperation, and competition in the process of scientific discovery (Gericke and Smith 2014; García-Carmona 2018), most neglect the important and indeed crucial role Rosalind Franklin played. Our point of departure in developing a story based on this episode was to include these neglected aspects. We decided to tell the story twice, first with an aim of helping students appreciate the science behind Watson and Crick's discovery with an aim to helping them appreciate the role of creativity and imagination in their work. A second narrative was developed that not only drew more explicit attention to the crucial role evidence provided by Rosalind Franklin played in the discovery (including not only the famous Photo 51 X-ray diffraction image of DNA, but also her notes and contributions to a report that are often ignored or minimized (Maddox 2002). Our specific goal in this second retelling was to draw student attention to social and cultural aspects of scientific work that not only constrained Franklin's ability to function as a scientist at the time, but also how these same factors have tended to obscure the important role her research played in subsequent sanitized historical accounts, such as Watson's autobiographical account of the discovery (Watson 1968). Our goal was not merely to help students appreciate the role gender played in the 1950s, but invite students to consider whether social and cultural factors continue to play a role in contemporary science.

We created a unit that shares a more accurate representation of the history of research on the structure of DNA with particular emphasis on the roles creativity imagination, social, and cultural factors play in science, using an interrupted narrative technique (c.f. Klassen 2009; Rudge et al. 2014). In the intervention treatment, historical narratives were presented by the instructor during class meetings, with students being given explicit opportunities to reflect on targeted aspects of NOS in-class group discussions. With this in place, we developed an alternative version of the course without historical narratives in which NOS was also taught by means of an explicit reflective approach (details below).

3 Research Questions

The research questions that guided this study are as follows:

1. Do historical narratives that share the role of Watson, Crick, and Franklin in the identification of the structure of DNA promote students' understanding of the creativity and imagination, and social and cultural aspects of NOS based on the SUSSI instrument, compared to the alternative treatment?
2. If so, how do historical narratives impact students' understanding from pre- to post-instruction, as revealed by participant interviews, compared to the alternative treatment?

4 Methodology

4.1 Study Context and Participants

Our empirical research is a pilot project for a larger-scale study conducted in order to assess the effects of historical narratives on undergraduate students' understanding of NOS concepts. The first author designed the study and was responsible for all aspects of its execution; the second author assisted in the interpretation of the results; the third author assisted in data collection; and the fourth author was the instructor of record. The current study was conducted with approval from the Human Subjects Institutional Review Board (HSIRB). The HSIRB requires that research on human subjects be conducted in conformance and compliance with all applicable federal, state and other regulations. The purpose of HSIRB is to ensure the protection of the rights and welfare of human subjects. It is important to note that the information provided to participants as part of the informed consent follows appropriate laws, regulations, and international standards. The study compares two treatments that took place in a non-major introductory biology course at a large Midwest university (see Table 1). During the first week of class each semester, researchers informed students about the study and distributed consent forms to students. It was essential that students from both semesters had no knowledge about which version of the unit they would have in their biology class.

Table 1 Research design

Semester	Fall 2017	Spring 2018
Intro-biology course	Alternative treatment	Intervention treatment
Teaching techniques	Minimal exposure to history and alternative in-class preassessments and activities; explicit and reflective approach to teaching NOS	Historical narratives regarding Rosalind Franklin and the discovery of the structure of DNA; explicit and reflective approach to teaching NOS
Klassen's narrative elements	None	All ten of Klassen's elements (Appendix 1, Table 5)
HNOS instruction	Decontextualized approach	Highly contextualized approach
NOS issues	The general NOS ideas throughout the course	The general NOS ideas throughout the course and two targeted NOS aspects in the intervention treatment: (1) creativity and imagination (2) social and cultural influences
Assessment	Pre-SUSSI, post-SUSSI and semi-structured interviews	Pre-SUSSI, post-SUSSI and semi-structured interviews

In the Fall 2017 semester, 124 students enrolled and received the invitation to participate in the research. Among them, 81 confirmed to participate in the study for a 65% response rate. Among them, a total of 63 respondents who completed both pre- and post-assessments were selected as qualified participants for the data analysis in the alternative treatment (63 out of 124 participants in the alternative treatment were qualified [50.8%]). Participants consisted of 41 female students (65%) and 22 male students (35%).

In the Spring 2018 semester, 88 students enrolled and received the invitation to participate in this study. Among them, 66 consented to join the research for a 75% response rate. A total of 32 respondents who completed both pre- and post-assessments and attended the 2-day intervention were selected as qualified participants for the data analysis in the intervention treatment (32 out of 88 participants in the intervention treatment were qualified [36.4%]). Participants consisted of 18 female students (56%) and 14 male students (44%). It is important to note that only research assistants knew which responses were qualified for the interview invitation and further data calculations.

The t test was used to determine if there was a statistically significant difference between the two treatments. The results indicated that there were no significant differences in gender, age, and race between participants in the Fall 2017 and Spring 2018 semesters (see Table 2). Additionally, the Pearson Chi-Square Test of Independence indicated that no association was found between gender and race; with the p value for the intervention version being 0.37 and the alternative treatment being 0.11.

It was a typical pattern for the introductory biology course because students primarily take the introductory level course during the first semester of enrollment, and a comparatively smaller number of students register this course during the Spring semester, despite the fact that there was dissimilar in the number of enrolled students between the Fall 2017 ($n = 124$) and Spring 2018 semesters ($n = 88$). There were no significant differences in the ratio of students who consented and qualified for the data analysis ($p = 0.16$) between the two semesters.

Table 2 Demographic data for the intervention and alternative treatments

Demographic information	Alternative treatment (n = 63)	Intervention treatment (n = 32)	Pearson Chi-square
Gender			
Female	65%	56%	$p = 0.16$
Male	35%	44%	
Age			
18–23	94%	91%	$p = 0.16$
24+	6%	6%	
Race			
Caucasian	73%	56%	$p = 0.19$
African American	16%	22%	
Asian-American or	3%	6%	
Pacific Islander	8%	9%	
Hispanic/Latino	0%	3%	
Other			

4.2 Course Instruction

The introductory biology course was taken by undergraduate students. It is a large lecture course that was taught by means of a flipped classroom style. The class met three times a week for 50 min each time. Students were expected to view online lectures, complete online quizzes, and homework, and read the textbook outside of class. During the class, students reviewed and learned new class materials through brief presentations, class discussions, i-clicker questions, short writing essays, and in-class activities. The instructor provided some time in each class for a question and answer period in which students could ask any questions related to the current class content they had encountered while working on the outside of class materials. Importantly, all class sessions of the course have been taught by the instructor who is an experienced biology instructor and has expertise in teaching NOS explicitly by means of historical narratives. The instructor was also the fourth author of the study and provided suggestions related to the research design. However, the instructor was not involved in the process of data collection. Two assistant researchers conducted all of the data collection. It should be noted that informed consent was solicited by the two assistant researchers, who are not the instructors of record. The instructor was required to leave the classroom while the consent forms were collected. The instructor had no knowledge of which students participated in the study and interviews. The first and third authors observed the classes of interest in both in the intervention and alternative treatments to ensure the fidelity of instruction.

The course learning objectives included the expectation that students would be able to understand and reflect on the importance of biology in our own lives and society and recognize the role of observation and experimentation in the development of scientific knowledge.

Each version of the course started each unit with a brief lecture providing a historical overview. These overviews included activities that drew student attention to NOS issues. For example, an in-class activity called the "mystery tube" before the intervention treatment engaged students in the scientific process to illustrate the role of inference in science (Lederman and Abd-El-Khalick 1998). This being said, the overviews did not include discussions of the specific NOS topics that are the object of this study. The course textbook used in both versions provides a general historical context for understanding the topics covered in each unit, and specifically had a section devoted to sharing the story of the discovery of the structure of DNA. We note these brief textual references to history of science in the textbook focused on names and dates, not the targeted NOS issues that are the object of this study.

4.3 Implementation of the Intervention and Alternative Treatments

The study compared two different versions of a non-major introductory biology course taught by means of the "flipped classroom" approach. In one version (the intervention treatment), students learned about DNA using narratives based upon the history of the discovery of DNA. The DNA narratives were developed with reference to Klassen's (2009) framework. Examples of how the ten essential narrative elements were incorporated into the DNA narratives are included in Appendix 1, Table 5. In the alternative treatment, students learned about the same material without the involvement of any historical narratives.

The Spring 2018 section was assigned to the intervention treatment where students learned about DNA with narratives regarding the history of the discovery of DNA introduced during regular class meetings. In the intervention treatment, the instructor shared two narratives over the course of two classes (days 1 and 2) by means of the PowerPoint presentation, first reviewing a traditional account of the discovery with reference to James Watson and Francis Crick. The second class retold the story from the perspective of Rosalind Franklin, whose work is now recognized to be far more significant by historians than textbook accounts would have us believe. The historical narratives sharing historical research on the discovery of structure of DNA for days 1 and 2 were developed by Dai and Rudge (2018) and adapted by the same authors for the use in this study (Appendix 2). The intervention narratives were intended to help students better understand two targeted aspects of NOS: creativity and imagination, and social and cultural influences on science. The stories were conveyed by means of interrupted narratives punctuated by reflection questions asking participants to explicitly reflect on whether science is a creative endeavor and whether gender plays a role in science in general and with reference to this specific episode. For example, students were asked to consider would Franklin have received the Nobel Prize with Watson, Crick, and Wilkins if she were alive at the time (see Table 3). Students were explicitly asked to reflect on the questions, first individually and then in groups. The interrupted narrative format helped students make sense of the class experiences and drew their attention to more accurate ideas regarding NOS. In this way, students were put in the position of having to construct their own

Table 3 Questions included in the historical narratives

Question	NOS concepts
1. Did Watson and Crick use their creativity and imagination during their investigations? Please provide examples and explain why they wanted to use creativity and imagination? If not, please explain why and provide examples.	Imagination and creativity
2. Did the social and cultural environment in England at that time influence female scientists and scientific activities? If yes, how did it influence?	Social and cultural influences Scientists' personality and personal relationships among the scientists
3. Would Franklin have received the Nobel Prize with Watson, Crick, and Wilkins if she had lived? Why or why not?	Scientific collaboration and cooperation Gender influence

Note. All three questions were developed by Dai and Rudge (2018). Question 1 was included in Part I story. Questions 2 and 3 were included in Part II story understanding of the nature of science instead of having the instructor as a presenter "tell" them what science is and how it works (Rudge et al. 2014).

Three questions addressing the two targeted NOS aspects were included during the historical narrative version (see Table 3). The overall instructional flow of the historical narratives was structured in segments by each question in order to provide students opportunities to reflect and discuss their understanding of NOS concepts in small groups and later, in the whole class.

The alternative treatment of the course was taught in Fall 2017. In this version, students learned about the same content as the intervention treatment except for the two narratives related to the history of DNA. Two alternative in-class activities were included to replace the narratives incorporated in the intervention treatment. One of the activities was related to a cell cycle assessment distributed on day 1, and the other was a mid-term evaluation distributed on day 2. Each of these assessments took about 30 min to complete, which is about the same total amount of time as was spent on the stories used in the intervention treatment. The cell cycle assessment was a worksheet emphasizing the cell content without the involvement of any of the history or DNA content. The mid-term evaluation was an assessment of the course as a whole. Additionally, neither of those assessments had open-ended questions where students had the opportunity to discuss anything related to NOS or HOS. It is worth mentioning that the two alternative activities were selected in terms of timing and unit content. These activities were expected to not have an impact on this study. In the intervention course, the mid-term evaluation was assigned later in the course.

5 Data Collection and Analysis

5.1 Quantitative Data

This study used a mixed-methods approach that involved both quantitative and qualitative sources of data. The SUSSI (Student Understanding of Science and Scientific Inquiry) instrument is widely used to assess student understandings of issues associated with NOS (Liang et al. 2008). Semi-structured interviews were conducted to provide students further opportunities to clarify their responses on the SUSSI assessment (Appendix 3). The study measured students' change in NOS understanding from pre- to post-intervention by use of the SUSSI surveys during the Fall 2017 and Spring 2018 semesters. The SUSSI assessment was a regular part of class activities. Students received a small amount of course credit for completing the survey. The SUSSI instrument has been validated for reliability with the overall population by the development team (Liang et al. 2008). Additionally, a set of recent studies (e.g., Herman and Clough 2016; Williams and Rudge 2019) have investigated students' NOS conceptions using the SUSSI instrument. In the dissertation, Williams (2017) further established the validity and reliability for the six NOS aspects on the SUSSI instrument with a sample similar to the current study.

The SUSSI instrument measures six core NOS concepts, including observations and inferences, tentativeness, scientific theories and laws, social and cultural embeddedness, creativity and imagination, and scientific methods. Each component of NOS contains four Likert scale items and one corresponding open-ended question. Each Likert item is on a five-point scale from strongly agree to strongly disagree (Liang et al. 2008). Students' responses to each Likert item were scored based on a scoring scheme developed by the original authors

(Appendix 4, Table 6) (Liang et al. 2008). Student responses corresponding with one point were noted as the least sophisticated NOS view, and five-point responses were noted as the most sophisticated view. The mean scores of the four Likert items under each NOS aspect in both treatments were calculated. The effect size (ES) of the comparison of the alternative and intervention treatments was calculated using Cohen's d to determine if there were any significant differences for the interaction between treatments. An ES of 0.0 notes that 0% nonoverlap between the intervention treatment and the alternative treatment. An ES of 0.8 notes a nonoverlap of 47.4% in the two distributions. An ES of 1.7 notes a nonoverlap of 75.4% in the two distributions (Cohen 1988). The paired sample t test is one of the most common statistical procedures used to check the mean difference between the two variables separated by time from the same subject. In this study, a paired sample t test using SPSS was performed to determine if there were significant differences in participant's SUSSI scores for two targeted pairs of NOS aspects between pre- and post-instruction in both treatments.

5.2 Qualitative Data

For the SUSSI open-ended questions, students needed to explain their ideas about each aspect of NOS with examples. It should be noted that responses to open-ended questions were required to be at least three sentences long to get full credit. Students were provided enough time in class to complete the SUSSI assessment. Student SUSSI open-ended responses were used to prompt further probing students' answer in the interviews. In this study, the qualitative data comes from the semi-structured interviews and the quantitative data comes from the SUSSI Likert scales.

Semi-structured interviews were conducted to allow students to further clarify their responses to the SUSSI assessments. In this study, 13 out of 63 students from the alternative treatment and 14 out of 32 students from the intervention treatment were recruited for the interviews within 2 weeks after they finished the genetic unit in each semester. Recruitment was conducted through email invitation after participants completed the post-assessments. The students who participated in the interviews gained a small amount of extra credit in this class. Those who did not have the interviews still had opportunities to gain the same amount of extra credit by submitting reflection essays. All the students were notified that participation in the research would not influence their grades in the class. All the interviews were audio-recorded and transcribed by two assistant researchers without any involvement of the instructor. One assistant researcher also manually validated the transcriptions using the One-Pass Check validation method (Barras et al. 2001).

During the interview, students were provided with their pre- and post-SUSSI responses and asked to explain the changes they made on the targeted NOS aspects (1) creativity and imagination, and (2) social and cultural influences. Initially, the interview transcripts were read through multiple times to find patterns and develop codes in students' responses using the emergent coding process (Creswell 2007). The primary researcher shared the initial coding schema with the research group (the other three authors) who provided feedback on the coding schema. All discrepancies or disagreements were discussed in group. The coding schema was continually revised based on the feedback until all researchers in the group were satisfied that no new information should be added. After achieving high inter-rater reliability ($>= 75\%$) in the coding of the transcripts among all authors, the primary researcher (the first author) coded the remaining interview data (Campbell et al. 2013). Patterns were identified in the codes to create themes with the help of NVivo software. The themes were used to explain the reasons for the change that students made on the understanding of the targeted NOS aspects.

6 Results

6.1 Results from Quantitative Data

The SUSSI instrument was administered as a pre- and post-instruction survey to both the alternative treatment (without historical narratives) and the intervention treatment (with historical narratives). The mean scores of the four Likert items under the two targeted aspects of NOS from the pre- and post-SUSSI questionnaire for both the alternative treatment ($n = 63$) and the intervention treatment ($n = 32$) were compared using paired sample t test (Figs. 1 and 2). The Cohen's d (Cohen 1988) was measured using an online calculator of effect sizes (Lenhard and Lenhard 2014). The effect size of the comparisons of treatments was calculated to determine whether the two treatments were equivalent enough to draw conclusions from the following data. For the pre-intervention measure of the Mean scores, Cohen's d values ranged from 0.042 to 0.661 (ES > .5). The effect size measures are included in Table 3 below. Given the effect-size values for the six-individual NOS aspect measured, it is important to note that the equivalency of two treatments was sufficient for the following statistical analysis (Cohen 1988) (Table 4).

For the alternative treatment, the results from the paired sample t test showed statistically significant increases in mean SUSSI scores for the creativity and imagination aspect ($p = .003$). Mean scores for the creativity and imagination increased from 2.67 (SD = 1.047) on the pre-SUSSI to 2.92 (SD = .984) on the post-SUSSI. These results suggested that students in the

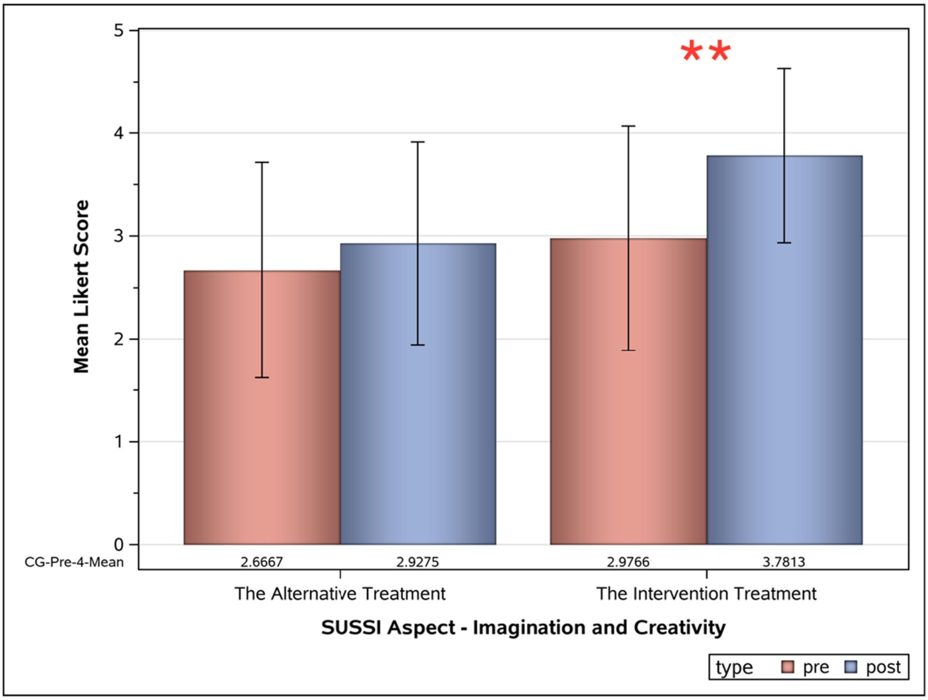

Fig. 1 SUSSI mean Likert scores for the imagination and creativity aspect of NOS in the alternative treatment and intervention treatment. Error bars represent standard deviation. The asterisk (**) indicates significant increase from pre- to post-SUSSI ($p < .01$)

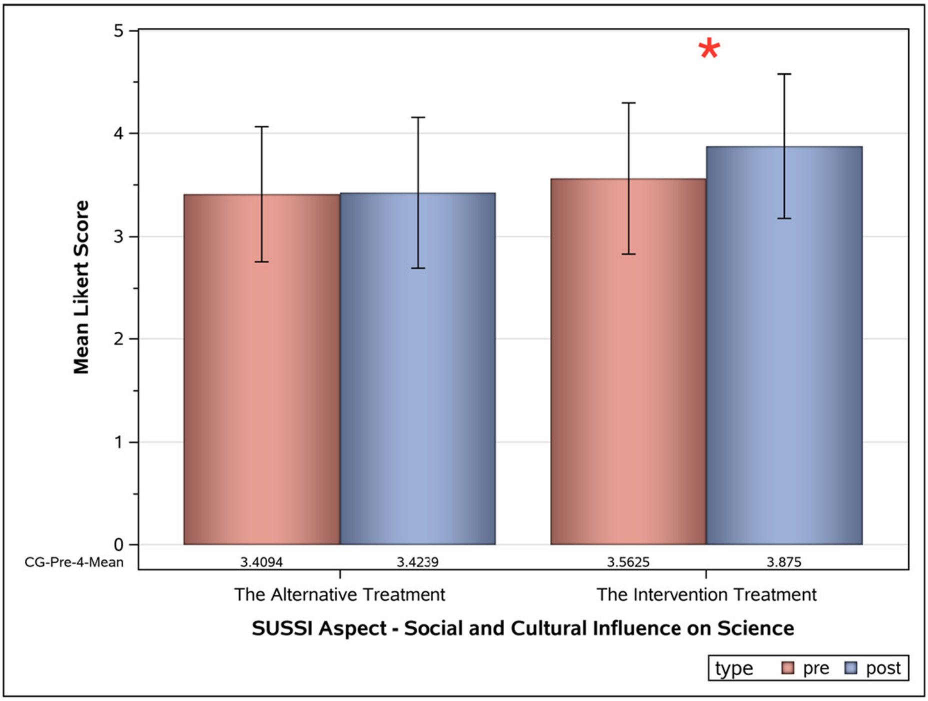

Fig. 2 SUSSI mean Likert scores for the social and cultural aspect of NOS in the alternative treatment and the intervention treatment. Error bars represent standard deviation. The asterisk (*) indicates significant increase from pre- to post-SUSSI ($p < .05$)

alternative treatment had a better understanding of the creativity and imagination aspect of NOS.

For the intervention treatment, the results showed that students' mean scores for the creativity and imagination aspect increased from 2.98 (SD = 1.089) on the pre-SUSSI to 3.78 (SD = .849) on the post-SUSSI assessments. The p value (= .000) was less than .01, which suggested students got significant improvement in their understanding of the creativity and imagination aspect of NOS after the intervention. Moreover, students' mean scores for the social and cultural influences increased from 3.56 (SD = .732) on the pre-SUSSI to 3.88 (SD = .699) on the post-SUSSI assessments. The p value (= .021) was less than .05, indicating a statistically significant increase in understanding the social and cultural aspect of NOS with the help of the intervention. In general, students had a better understanding of the two targeted aspects of NOS (the role of creativity and imagination in science and social and cultural

Table 4 Effect size (Cohen's *d*) of the comparisons of treatments

SUSSI NOS aspect	Cohen's *d*	Effect size (ES)
1. Observations and inferences	.303	.585
2. Tentativeness	.042	.512
3. Scientific laws and theories	.661	.680
4. Social and cultural influence	.225	.563
5. Creativity and imagination	.227	.564
6. Scientific methodology	.228	.564

influences on science) in the intervention treatment. The possible reasons for the positive changes in understanding NOS were revealed and explained by the following interview data.

6.2 Results from Qualitative Data

6.2.1 Imagination and Creativity

The primary purpose of the qualitative data analysis was to gain a deep understanding of the reasons for the changes students made from pre- to post-SUSSI responses. During the interview, participants were provided with their completed NOS surveys and asked to explain if there were any changes from their pre- to post-SUSSI responses. In the alternative treatment, the majority of participants (ten out of thirteen) held the misconception that science should not involve any imagination and creativity. These participants failed to recognize the role of imagination and creativity in scientific investigations. They seemed to believe that science is mainly based on facts as well as scientists are objective in their experiments:

> "S: I don't think scientists should use their creative skills. Science is based on facts and research. I don't see where using your imagination is acceptable and appropriate. They have to be factual and objective in their studies, otherwise, they'll be wrong and produce faulty thoughts." (Student 12 interview from the alternative treatment)

Moreover, for those participants who agreed that science involves the imagination and creativity, they were not able to realize that scientists use imagination and creativity throughout the whole scientific process, including experimental design, data collection, and data analyzation and interpretation.

> "S: Just the way you interpret what you find, you interpret it in a bunch of different ways if you want. But, the actual process... getting your results, I don't think is a really creative part of the experiments and stuff. Because I also feel like it's a pretty step-by-step procedure." (Student 1 interview from the alternative treatment)

Only three out of thirteen students interviewed in the alternative treatment made positive changes on the Likert scores for the imagination and creativity aspect of NOS from pre- to post-SUSSI assessments. However, neither of the three interviewees who indicated an improved understanding could make a sophisticated explanation for their changes nor provide specific examples from class. For example, student 6 said that he did not know why he made changes from pre- to post-assessment. He explained that he might not have read the question very well the first time. In addition, student 1 noted that the reason for the changes in the imagination and creativity response was because of the lab experience from another course, which is unrelated to the current biology class.

> "… But, I don't know why I disagreed with it. Like I think this one is more of like what I would be thinking because scientists do have to use their, like, creativity when deciphering different aspects of science, in a sense." (Student 1 interview from the alternative treatment)

> "I guess it [positive change on the imagination and creativity statement from pre- to post-SUSSI] stems from being in my lab, which is doing experiments and stuff. I guess because everything is like in file and organized and there's just a lot of things that you could use imagination and creativity, it's like just a procedure that you just go through. So, I think it comes from that." (Student 6 interview from the alternative treatment)

However, in the intervention treatment, eight out of fourteen participants exhibited an improved understanding of the imagination and creativity aspect of NOS. Of these eight, six students specifically mentioned the historical narrative associated with the discovery of the structure of DNA as an example to express the reasons for the change of the targeted NOS responses. For example, student 11 mentioned that she thought imagination and creativity should not be related to science on the pre-SUSSI. After learning the narrative about how James Watson and Francis Crick insightfully discovered the structure of DNA, she changed her answers on the post-assessment:

> "in the pre-assessment… I'm like imagination and creativity, like, in science, that doesn't sound good… But then, later on, when he explained how they [James Watson and Francis Crick] used creativity to create the DNA basically … showing how to create the structure like that, that changed my answers to being strongly agree, because you have to use your imagination to create certain things for experiments." (Student 11 interview from the intervention treatment)

Student 6 mentioned that the historical narrative describing how James Watson and Francis Crick creatively construct the structure of DNA with various materials made him recognize science could be a creative process:

> "With the DNA structures, they [James Watson and Francis Crick] used creativity when making the structure, like the materials they used and things like that, and I know one of them was made out of cardboard or paper or something like that I feel like you have to be creative in that aspect and, I mean, you could have made the structure with anything, any kind of material, wood, paper, plastic, whatever, and so I feel like that's a creative aspect." (Student 6 interview from the intervention treatment)

6.2.2 Social and Cultural Influences on Science

In the alternative treatment, five out of thirteen participants made negative changes, five made positive changes, and three made no changes on the Likert scores for the social and cultural aspect of NOS from pre- to post-SUSSI assessments. Some of the participants held the misconception that scientific research should not be influenced by society and culture. Scientists should remain objective instead of bringing their bias into science. Besides, scientists have to follow the same method when conducting scientific research:

> "When scientists do experiments, they have to follow the scientific method and they shouldn't have society influence them… they should think on their own, and figure it out on their own so when they open it up to the world then the society cannot influence it." (Student 13 interview from the alternative treatment)

For those participants who indicated an improved understanding of the social and cultural aspects of NOS, most of them could not make a sophisticated explanation of their positive changes or provide specific examples. Student 8 was one of the exceptions who demonstrated an informed view of the role of society and culture in science by providing an example from outside coursework, McDonald's food research, to make the explanation:

> "… I was like, yeah, cultural values would probably determine what scientists have conducted because different cultures have different interests. So, whereas like here they might research like McDonalds and like the effect the food has on Americans here, but like in a country has like healthier food, they might research like the benefits of eating healthy compared to eating McDonald's in America."(Student 8 interview from the alternative treatment)

However, in the intervention treatment, nine out of fourteen students exhibited an improved understanding of this NOS concept. Of these nine, four specifically mentioned the historical narrative associated with the discovery of the structure of DNA as an example to make the explanation for changes. For example, student 2 expressed that the stories about Rosalind Franklin and her neglected role on the discovery of the structure of DNA made her emotionally connected, so she got the idea that social and cultural factors have an impact on science:

> "The pre-assessment was more like… it shouldn't determine how it's conducted, just like thinking about it again and for the post-assessment, I was just like thinking about the whole Rosalind Franklin thing again just, yeah, made me a little bit touchy on that subject. Of like how you should treat people …" (Student 2 interview from the intervention treatment)

In general, most participants recognized that science always occurs within a specific social and cultural context. Additionally, many of these participants mentioned that the historical narrative of Rosalind Franklin facilitated change in their misconceptions about whether the social and cultural factor influences in science.

> "because what she [Rosalind Franklin] did was, or how she was credited was just potentially social and cultural influences, affected how much she was credited with that. So, that would, yeah, it helped." (Student 13 interview from the intervention treatment)

6.3 Gender Differences in Understanding the Social and Cultural Aspect of NOS

6.3.1 Results from Quantitative Data

In our study, we examined whether gender differences exist in students' perception of different aspects of NOS. For both treatments, a one-way between-subjects ANOVA was used to determine whether there is a significant difference between male and female students on their view changes of all six aspects of NOS from pre- to post-SUSSI assessments. Among all the six aspects of NOS for both treatments, the p value (= .036) for mean differences between male and female students on understanding of the social and cultural aspect of NOS was less than .05, which revealed that there was a statistically significant difference between male and female students' views of the social and cultural aspect of NOS (Fig. 3). The effect size using partial eta squared was .143, which indicated a large effect size for groups-differences between pre- and post-intervention. However, the difference between male and female students on understanding other aspects of NOS was not significant (p value is larger than .05). These results revealed that, in the intervention treatment, there was no difference in students' view changes of most aspects of NOS except the social and cultural influences on science. Analysis of the social and cultural aspect of NOS showed that female students were able to better improve their understanding of the social and cultural factors in science with the help of the intervention.

6.3.2 Results from Qualitative Data

In the intervention treatment, female participants had higher frequency counts of referring to the historical narrative associated with Rosalind Franklin as an example when making explanations of the changes in the social and cultural aspect of NOS. Three of five female participants who made positive changes in the understanding of the social and cultural aspect

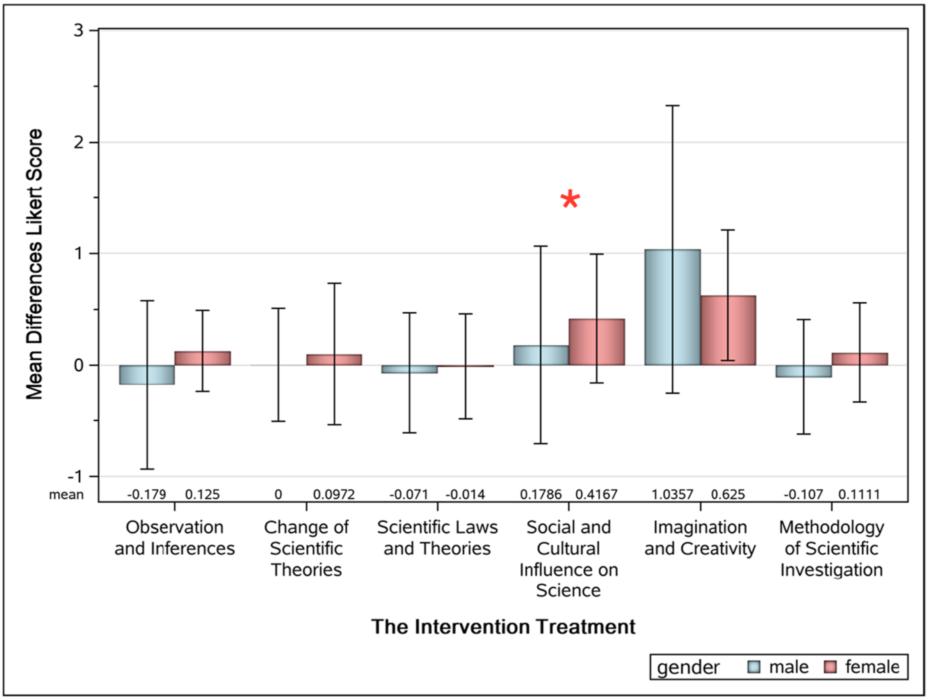

Fig. 3 SUSSI mean differences Likert scores for the intervention treatment. Error bars represent standard deviation. The asterisk (*) indicates a significant the mean difference between male and female changing from pre- to post-SUSSI ($p < .05$)

mentioned the story of Rosalind Franklin while providing the reasons for their improvement. For example, one female interviewee recognized the unfairness towards women in science from the Rosalind Franklin story:

> "I guess it was just like thinking about the whole Rosalind Franklin thing made me a little bit touchy on that subject. It was very much the same, just hoping, hey, science should be objective in an ideal world, but, there is no circumstances where our culture and social pressures don't affect us." – (Student 3 interview from the intervention treatment)

However, only one out of four male participants mentioned the narrative of Rosalind Franklin helped their understanding of the social and cultural aspect of NOS. The other three male participants provided reasons that were related to other activities of the course or external factors. For example, one male participant mentioned:

> "You're going to do a science experiment what people actually care about, like cancer. If cancer wasn't a big deal, nobody would be doing experiments about it, but culture really cares about it and our society really cares about it, so there's tons of people out there trying to make something happen and doing as many tests as they can and trying to find a cure. But if cancer wasn't a big deal, then it wouldn't like nobody would really care about it." – (Student 8 interview from the intervention treatment)

One reason for this difference is likely the fact that the Rosalind Franklin story included a female scientist as its protagonist. Female students may identify more with this story. During the interviews in the intervention treatment, participants were asked about whether they think men and women scientists are equally treated in current society. The intent of this interview question was to find out whether male and female participants differ in their opinion of gender equality in science. Surprisingly, all seven female interviewees believed that women scientists still do not have equal rights, even in current society. Many of them related the Rosalind Franklin's example to their work experiences, own family issues, and male-only stereotype in society. For example, a female participant said that society stereotypes provide females a lower sense of belonging and less desire to participate in the science field:

> "Guys just think they're more dominant than women and I think they're a little more confident too, which society probably made them that way, but I'll be like, oh, you're better and so women are just thought of as like having the children and like staying at home and cooking and stuff." – (Student 7 interview from the intervention treatment)

In sharp contrast, three of seven male interviewees indicated they believed the gender issue had declined dramatically since the 1950s, and that men and women scientists nowadays are generally treated as equals. For example, a male participant expressed that the gender issues have been changed in current society because women were allowed to vote for president:

> "I think they [men and women] are being equal because the main opportunities, back then wasn't the same, like for the woman, they didn't get that much, so, you know, back then, women weren't allowed to vote. Now, women can vote now and women can run for president." – (Student 12 interview from the intervention treatment)

However, four of seven male interviewees disagreed that men and women are currently equal. For example, a male participant referred to the example that women still do not get paid as much as men:

> "I feel like, it kind of does, because like still women don't get paid as much as men today… there are still some people out there, it's like, women can't do the same stuff as men." – (Student 9 interview from the intervention treatment)

The results of this study reveal that compared to the alternative treatment, students in the intervention treatment made significant changes between pre- and post-intervention in their understanding of two targeted aspects of NOS including scientists' use of creativity and imagination, and social and cultural influences on science. Most interviewees in the intervention treatment specifically mentioned that the historical stories regarding the discovery of the structure of DNA helped them make positive changes in understanding of the two targeted aspects of NOS. In addition, our study indicates that female students perceived better understanding of the social and cultural aspect of NOS with the help of Rosalind Franklin story compared with male students. Our study suggests that the story regarding Rosalind Franklin's neglected contributions may get more attention and recognition from female students. One reason might be that female students have a better connection with the historical narrative describing female participation in science.

7 Discussion

The focus in the current study was to address the extent to which historical narratives based on the history of the discovery of the structure of DNA impact students' understanding of the two targeted aspects of NOS. Not surprisingly, the results from both groups showed that most non-major undergraduates had a limited understanding of NOS before the intervention, which was also consistent with the findings from other studies (e.g., Rudge et al. 2014; Williams & Rudge 2016; García-Carmona 2018). This is to be expected considering textbooks, as one of the primary resources that students used to learn science, rarely convey the concepts of NOS or the work of scientists (Clough 2006).

Analysis of participants' responses to the Likert scale questions on the SUSSI and follow-up interviews with a subset reveals that the majority of participants from the intervention treatment were able to better articulate and understand two targeted aspects of NOS, including creativity and imagination and social and cultural influences on science. During the interviews, many participants particularly noted that the historical stories introduced in the class were most helpful in understanding NOS. Interviews indicated that the story describing how James Watson and Francis Crick first discovered the structure of DNA was particularly helpful in helping students appreciate the role of creativity and imagination in science. Our analysis of interview data also suggests that the historical narrative describing Rosalind Franklin's neglected contribution had a positive effect on students' understanding of the importance of the social and cultural influences in science.

Our findings align with a previous similar study by García-Carmona (2018) that also studied how readings based on the history of the discovery of DNA could affect pre-service elementary teachers' (PETs') understandings of the nature of science. Their results showed that PETs improved their understanding of non-epistemic factors more than epistemic factors of NOS after a historical case shared with a critical reflective teaching technique. The non-epistemic aspects of science are generally referred to as the social and cultural values related to science and scientists (Acevedo & García-Carmona 2017). With respect to the epistemic factors, the most cited factors from the historical case were "Different research Methodologies" and "Creativity of Watson and Crick." With respect to the non-epistemic factors, PETS most often referenced "Lack of Ethics of Watson and Crick" and "Tensions between Franklin and Wilkins" (García-Carmona 2018). Similar to our study results, the most cited aspects of NOS by PETs are related to the creativity and imagination and social and cultural influences on science. This suggests that these historical narratives based on the history of research on the structure of DNA were helpful for improving some aspects of NOS for both pre-service teachers and undergraduate students more generally.

The present study has drawn particular attention to gender differences in participant understandings of social and cultural aspects of NOS. Our findings demonstrate that the narrative emphasizing Rosalind Franklin's heretofore neglected role in the discovery was effective in raising female participants' conscious awareness of cultural issues related to science. The historical narrative describing Rosalind Franklin's challenges as an isolated female scientist during the early 1950s when science was largely male dominated were particularly influential in drawing female students' attention to topics related to gender equity in science. One possible reason for this gap indicated by some evidence from the interviews is that female students might have more emotional connections with the stories that emphasize women scientists (Cheryan et al. 2011). It is worth noting that multiple female participants mentioned the difficulties they faced as girls or women in science classes or labs because of male-only stereotypes in society. One female student specifically mentioned how she was treated unfairly in her family. These references indicate that gender bias still remains and affects women and girls and their perceptions of how easy it is for women to succeed in science today.

Science education researchers have rarely studied whether and to what extent gender gaps exist in student understanding of NOS. Moreover, the reasons for the existence of this gap are poorly recognized. Our study results show there is a gender gap in students' perceptions of the social and cultural aspects of NOS targeted in the narrative we developed surrounding Rosalind Franklin's role in the discovery of the structure of DNA. As previously mentioned, female participants in our study reported a higher understanding of the gender issues in science than male students. Nevertheless, some of the male participants did acknowledge the importance of discussing Rosalind Franklin's role in the discovery, specifically noting they had previously been unaware of it. Knowing this history makes them better aware that gender bias has and continues to play in science.

8 Conclusions

Previous empirical studies have confirmed the effectiveness of highly contextualized NOS instruction techniques on student understanding of NOS (Clough 2006; Klassen 2009; Rudge and Howe 2009). The use of historical narratives and an explicit and reflective approaches to the teaching of NOS has been advocated by many researchers as particularly effective (Clough 2011; García-Carmona 2018; Tybulsky 2018; Rudge and Howe 2019). Williams and Rudge (2019) emphasize the process of restructuring the essential schema to minimize conflict between preconceptions and new knowledge is crucial for the improvement in understanding of NOS (Ausubel 1960; Posner et al. 1982; Appleton 1997). It is important to note that most research on NOS has focused on all aspects of NOS, without regard to the fact that it is unlikely a single story can illustrate all of them (García-Carmona 2018; Tybulsky 2018; Williams and Rudge 2019). We accordingly advocate focused research on targeted NOS issues.

We think our second narrative was particularly effective because it drew attention to not only the fact that Rosalind Franklin's contributions were unrecognized at the time of the discovery, but also why this was the case, namely she worked at a time when men dominated science. The design of this narrative was aimed at drawing students' attention to the social and cultural aspects of NOS, specifically, the influence of gender in science. Women were ignored in science for many years. While most people believe that gender bias in science has made enormous progress in recent decades, some studies published in recent years show that gender inequality or male overrepresentation still exists in many fields in job hiring and salary differences (Cheryan et al. 2011; Thomas 2017). Moreover, the fact that the number of females in science majors still represents a minority, and this gender gap is still existing in the future years raises broad attention in the USA (Wang & Degol 2017). Social stereotypes have been proposed as one of the primary reasons for female students not to select or pursue a science major (Merrick 2012). It is essential to note that female generations are more likely to avoid science fields in the lack of role models of female scientists (Cheryan et al. 2011; Thomas 2017). Wang & Degol (2017) proposed that it is important to highlight the achievements of women and girls in STEM areas to increase female students' interest in those fields and provide them a sense of belongs.

Among research studies on HOS and NOS in science education, only a few science stories focus on women's representation in science that educators used to teach NOS concepts. In recent years, most contextualized and historical-based science stories that educators developed to help students learn NOS concepts are primarily male-dominated such as the Origins of Elements, Mendel's genetics, and Darwin's theory of evolution (Clough 2011; Williams & Rudge 2016). It should be noted that incorporating all male-leading stories in science class might implicitly mislead students to associate science with masculinity, which potentially hinders female students from choosing a science major or to learn science (Thomas 2017).

This results of this study and García-Carmona's aforementioned previous study indicate that stories describing Rosalind Franklin's neglected contributions can be of significant value in raising student understanding of gender inequities in science and how the history of science is often (mis-)represented. We suggest the inclusion of more stories about the contributions of women scientists has the potential to encourage more female students participate in the course activities, enhancing more female students' motivation of learning, encouraging more female students go for a career in STEM in the long term.

9 Limitations and Future Work

Our study has some potential limitations. First, the SUSSI instrument may not fully reflect student NOS views for reasons such as limited time for the questionnaire and variable reading and writing skills. However, this deficiency was mainly mitigated by the use of semi-structured interviews, which provided students opportunities to further interpret their responses on the SUSSI and elaborate on reasons for their changes of understanding from pre- to post-assessment. Second, our study was limited in terms of the small number of total participants, which was drawn based upon the convenience sampling strategy. Therefore, the generalizability of results to the entire population might be limited. One of the future directions can be the extension of the pilot study to a larger population with particular emphasis on the effectiveness of the historical narratives on different characteristics of the population, such as age, gender, race, and academic background.

Next, our study could be criticized for the effectiveness of the short-term intervention on student NOS understanding. Previous, empirical studies published in recent years show that short-term intervention can positively affect students' NOS views (Kim and Irving 2010; Rudge et al. 2014; Williams and Rudge 2016, 2019). However, Clough (2006) noted that the development of NOS views is a long-term process with continuous exposure to NOS instruction through a whole course. This limitation leads us to the development of a future study where we will create a series of historical narratives. Each of the narratives will be associated with one or more aspects of NOS. We anticipate examining the effectiveness of NOS instruction with multiple exposures to NOS content through a series of historical narratives to promote students' NOS views.

Last, given that the two historical narratives (James Watson and Francis Crick story and Rosalind Franklin story) were shared in one intervention unit, it was unclear which narratives were indexed for which targeted aspect of NOS. There might be an interaction between the effectiveness of both narratives. However, the interviews were particularly helpful for developing a more in-depth understanding of how the use of historical narratives influenced student NOS concepts in order to disaggregate effects by two narratives work further.

Previous studies have suggested that there might be relationships between students' NOS understanding, their attitudes of learning science, contextualized learning method, and students' motivation for learning science (Darner 2014). Hence, another potential research direction may focus on the relationship between students' NOS understanding, attitudes, and motivation for learning science. Potential future studies to explore the improvement of both female and male students' realization and reflection on gender issues in science are needed, considering the fact that the Rosalind Franklin story increased female students' recognition of gender issues in science more than male students in this study. There are a couple of follow-up questions that could be asked during interviews. For example, why is it essential to have an inclusive workplace for scientists? How can we develop a more inclusive work environment for women scientists? What are the potential benefits of having a more inclusive work environment?

The recent research findings have shown that incorporating historical narratives into the class is useful for improving students' engagement, learning science content, and NOS (Klassen 2014; Williams and Rudge 2016, 2019). However, there is no agreement on how to create historical narratives that are effective to foster student learning the targeted aspects of NOS. In our study, historical narratives were developed with reference to Klassen's narrative framework (2009), which has received the most attention from science education researchers. More empirical research should be focused on whether the ten elements of the narrative framework are suitable to create compelling historical stories for teachers and educators.

Author's Contributions All authors contributed to the study conception and design. Author 1 (Peng Dai) is the corresponding author who has major contribution to study design, material preparation, data collection, and analysis. She also wrote the first draft of the manuscript. Author 2 (Cody Tyler Williams), Author 3 (Allison Michelle Witucki), Author 4 (David Wÿss Rudge) assisted with the design and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The data that support the findings of this study are available on request from the corresponding author, [PD]. The data are not publicly available due to [the privacy/ethical restrictions e.g., their containing information that could compromise the privacy of research participants].

Compliance with Ethical Standards

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

Code Availability The software application and custom code described in this manuscript are available for testing by reviewers. It is also available on request from the corresponding author, [PD], when published.

Appendix 1

Table 5 Klassen's (2009) narrative elements, characteristics, and examples included in the intervention treatment

Narrative element	Narrative characteristic	Example from the intervention
1. Event-tokens	The narrative is comprised of related events introduced in chronological sequence.	Watson and Crick did no experiment but speculation on the structure of DNA—Wilkins gave Watson direct access to Franklin's data without her permission—Watson and Crick published their finding and won the Noble Prize in 1962.
2. The narrator	The narrator decides the purpose and events of the story, as well as the sequence of those events. The narrator can be a participant or an observer.	The narrator of the story is an observer and a story-teller introducing the story in chronological order objectively.
3. Narrative appetite	The narrative uses elements to inspire listeners to know what will happen next.	The author foreshadows in several ways through presenting the difficulties that Franklin has as a female scientist due to gender inequality in London.
4. Past time	The described events will already have taken place and have a historical context.	The narratives take place from the year 1950s to 1968.
5. The structure	The narrative has an "initial state—event—final state" sequence of events in the story.	Watson and Crick planned to build a DNA structural model–Franklin produced the clearest picture of the B form of DNA (The Photo 51)—Wilkins shared Rosalind Franklin's data with Watson without her permission—Watson and Crick created the DNA successfully—Watson, Crick, and Wilkins were awarded the Nobel Prize in 1962 without mentioning Franklin.
6. Agency	The narrative has characters usually recognized as moral agents.	Watson and Crick chose to create a model of DNA structure. The result is that Watson and Crick got success and won the Nobel Price because of discovering the secret of life.
7. The purpose	The narrative generally has a "moral" that raises listeners' sense of empathy for the characters.	The purpose for the narratives is to help listeners learn the facts and information through the history of discovering the structure of DNA. The additional purpose of the narratives is to help listeners understand the two targeted aspects of NOS.
8. The role of the reader or listener	The narrative inspires listeners to have certain responses such as forming questions.	The narratives are developed for listeners to understand and interpret what is being said within the context of the story.
9. The effect of the untold	The narrative "gaps" between each event are used to inspire listeners to engage.	Some details in the narratives are intentionally left out in order to engage listeners. For example, the detailed description of Franklin's work office.
10. Irony	The narrative usually involves different results than what the listeners expected before.	Franklin has expertise in X-ray diffraction and produced the clearest picture of the B form of DNA. However, her contribution was ignored for many years because of the gender inequality environment.

Appendix 2

Historical Background—Day 1

James Watson was born in Chicago in 1928. He received his bachelor's degree in zoology from the University of Chicago when he was only 19 years old and received his Ph.D. degree from Indiana University when he was 21 years old. Then Watson was awarded a Postdoctoral Fellowship doing his postdoctoral research at Cavendish Laboratory at Cambridge University in London because he was convinced that DNA was the genetic material. Francis Crick was born in 1916 in England. After he had got his Bachelor of Science degree in physics, he was planning to continue his Ph.D. However, his study was interrupted by World War II. In 1947, Crick was back to school, working on his Ph.D. degree at Cambridge University when he was 31 years old. He also worked in the Cavendish Laboratory (Gibbons 2012).

Around that time, most scientists still believed that compared with the simple molecule DNA, protein should have more possibilities to be responsible for the diversity of life. But some scientists believed that discovering the structure of DNA could help understanding whether DNA is the genetic material. When James Watson and Francis Crick met each other at the Cavendish Laboratory, they found that they had the same interests in discovering the structure of DNA. At the same time, the Cavendish Laboratory at Cambridge University was in a significant competition with the Biophysics Research Laboratory at King's College in London. Scientists in this lab also believed that DNA was the key to discovering the secret of life and started to transfer their focus from protein to DNA research. This research group used X-ray crystallography to investigate the structure of DNA. This technique can identify the atomic and molecular structure in its crystalline form through the X-rays (Gibbons 2012).

For Watson and Crick, the most likely competitors were Maurice Wilkins and Rosalind Franklin, the British scientists who worked in the Biophysics Research laboratory at King's College. Wilkins produced the first X-ray clear diffraction images of DNA. And Franklin probably knew the most about the shape of the DNA molecule based on her X-ray diffraction studies. However, the methodological approach used by Franklin and Wilkins was slow. Different from the approach that Wilkins and Franklin used, Watson and Crick did no experiments in the ordinary sense of the word. Instead, they spent their time trying to construct a DNA structural model that made sense and fit the data. Because Wilkins was an old friend of Watson and Crick, they often invited him to come over to talk to them about his DNA research. Wilkins also shared Franklin's data with them. Therefore, Watson and Crick were familiar with the X-ray information relating to DNA (Maddox 2002).

Based on the information they assembled, Watson and Crick constructed their first DNA model. However, the model was not correct. But Watson and Crick did not give up, and kept thinking about this work. Meanwhile, another potential contender, Linus Pauling got into this competition. He was a famous American chemist and also moved his research into the structure of DNA. His younger son, Peter Pauling, worked in the same laboratory as Watson and Crick. On 28, January 1953, Linus Pauling sent his son a paper in which he proposed the structure of DNA. When Watson and Crick found out about the paper, they were driven by the fear that he would beat them to the structure of DNA. But when they saw the paper, they found Pauling made some similar mistakes on the model just like Watson and Crick had built before. Pauling's model had a triple-stranded helix with the phosphates at the center and bases on the outside. But they also knew that Pauling would realize his mistakes and make a corrected model very soon. Watson felt that he and Crick needed to speed up to solve the problem (Maddox 2002; Elkin 2003; Gibbons 2012).

When Watson talked with Wilkins about the DNA structure, Wilkins showed him the Photo 51, the clearest picture of B form DNA that Franklin had taken. The amount of tilting and spacing shown on Photo 51 provided the basic parameters of the structure of DNA. It suggested that the molecule was a right-handed double helix. Wilkins and Franklin's data on the X-ray diffraction of DNA also indicated that the sugar-phosphate backbone of each chain was on the outside of the DNA molecule, and the bases were facing the inside as shown in the Photo 51. Watson and Crick also noted from Franklin's own notes that the two chains should run in opposite directions. So far, Watson and Crick already got most of the crucial facts to build the DNA model. But they still had one stumbling block in the bases combinations problem. According to Chargaff's Rules, the amount of adenosine was always equal to the amount of thymidine, and the amount of cytosine was always equal to the amount of guanine. But how could specific pairs of bases (A with T, and G with C) form interchain hydrogen bonds (Maddox 2002)?

Watson tried different bases combinations using cardboards with great creativity. After spending time rearranging the cardboards bases to help him imagine possible structures, Watson finally mated the bases (A pairs with T, G pairs with C) in the double helix. On 28, February 1953, Watson and Crick went to have lunch at Eagle Pub, and Crick told everybody "We had found the secret of life." Very soon, Watson and Crick published their results in Nature (Watson 2012 [1968]). They proposed that the DNA structure consisted of two antiparallel helical strands; the nitrogenous bases were on the inside of the helix, while the phosphate-sugar structure disposed towards the outside; and most importantly, when the two strands separate apart, each strand of double helix can be used as a template to copy a new strand. This process explained how the genetic material passed from generation to generation (Watson and Crick 1953). At the same time, Wilkins and Franklin also published their results separately to confirm Watson and Crick's DNA structure (Franklin and Gosling 1953).

In 1962, James Watson, Francis Crick, and Maurice Wilkins shared the Nobel Prize in Physiology or Medicine for their remarkable discovery of the structure of DNA. Rosalind Franklin was not mentioned because she had passed away 4 years ago from ovarian cancer. The Nobel Prize committee rules prohibited the awarding of the prize posthumously (Maddox 2002; Elkin 2003; Gibbons 2012).

Historical Background—Day 2

Rosalind Franklin was a X-ray crystallographer and chemist who had been working on the structure of complex chemicals in Paris, France. In 1951, known for her expertise in the field of X-ray crystallography, Franklin was offered a fellowship as a DNA researcher in the Biophysics Research Laboratory at the King's College in London. The other crystallographer, Maurice Wilkins, had been working in that group for several years. He was the assistant director of the biophysics unit and also worked on the X-ray diffraction of DNA. At the time of Franklin's arrival, Wilkins was on holiday. The head of the Biophysics Research Laboratory called a meeting to introduce Franklin and mentioned that her first task was to adjust the limitations of the laboratory. When Wilkins got back, he found that Franklin had already improved his lab without his permission. Franklin thought she was an independent researcher, but Wilkins thought that Franklin was his assistant. Because of the confusion about who was in charge in the lab, the conflict between Franklin and Wilkins became intense (Glynn 2012).

The situation continued getting worse because of their different personalities. Franklin was articulate, passionate, and good at debate, but Wilkins, on the opposite, was expressionless, shy, and quiet. Wilkins felt it was very hard to communicate with her, and she had a peremptory manner and rebuked him (Maddox 2002). On the other hand, due to the particular cultural environment in London around that time, science was heavily dominated by men, and indeed women scientists were looked down upon. Franklin was in a unique and difficult position as a female pursuing excellence in an overwhelmingly male environment. She felt angry and excluded. She even was not allowed to dine in the same lunchroom with the male scientists at King's College. Even worse, she was given the sarcastic nickname "Rosy" from her colleagues behind her back (Maddox 2002; Gibbons 2012).

When Wilkins came over to talk with Watson and Crick about his DNA research, he also told them about his tense relationship with a woman scientist named "Rosy" Franklin. He felt that she had shut him out of his research and did not want to share her experimental results with her group. Around that time, Wilkins also passed a lot of information from Franklin to Watson and Crick. Although Franklin was staying in a negative environment at King's College, she still produced amazing results, including the best X-ray diffraction photos of DNA. She found that DNA has two distinct forms, the A form, and the B form, and there is a transition between them. Besides, she noted that both forms might have helical properties based on her calculation of X-ray diffraction of DNA. In November of 1951, Rosalind Franklin gave a presentation on her startling and revolutionary discovery that DNA's backbone stands on the outside of the molecule, and its basic structure is helical. Watson attended her talk, but he was not trained in X-ray diffraction and was not able to understand all of the details. Meanwhile, he had a supreme curiosity about the woman scientist "Rosy" mentioned by Wilkins. Watson assessed that Franklin had bad taste in dressing up that went against the standard of feminine beauty (Maddox 2002; Gibbons 2012; Glynn 2012).

Soon after, when Watson returned to his lab in Cambridge, he and Crick built a model of the DNA molecule with its backbone on the inside based on the misunderstanding about what Franklin had presented. When he proudly showed this incorrect model to Franklin, she curtly informed them of their errors. As a result, the meeting turned into an embarrassment for Watson and Crick. When news of Watson and Crick's failure reached the head of Cavendish Laboratory, he ordered them to leave the study of the structure of DNA to the researchers at King's College.

Instead of using the speculation that Watson and Crick engaged in, Franklin believed that only the correct data and evidence could prove the structure of DNA. She felt Watson and Crick's model-building of the DNA molecule was not professional. Franklin was continuously taking X-ray photographs on DNA, collecting the information, calculating the data, and analyzing results. In May 1952, she produced the clearest picture of the B form of DNA. Franklin named it as "photo 51." The "X"-shaped diffraction pattern crossed over in the center of the photo of B forms of DNA significantly represented a helical structure. Then she put the Photo 51 aside and kept working on the A form pattern. But around this time, Franklin acquired another nickname, "The Dark Lady." Her unhappiness at King's College left a legacy of a "face like a thundercloud." She did not want to keep staying in this unpleasant atmosphere. In early July 1952, Franklin told the leader in the Biophysics Research Laboratory that she was planning to leave King's College. The personnel committee accepted her resignation, but on the condition, she would finish her analysis of her DNA findings and publish her results. As a result of her decision, Wilkins took over her lab. In the process of the transition, Wilkins obtained the Photo 51 (Maddox 2002; Gibbons 2012).

In January 1953, having kept in touch with Wilkins after the disastrous meeting that revealed their incorrect model, Watson came to King's College to visit him. At the time, they were feverishly trying to find the structure of DNA before their most famous rival, Linus Pauling (Maddox 2002). When Watson talked with Wilkins about the DNA structure, Wilkins showed Watson the Photo 51, the best picture of B form pattern, that Franklin had taken 8 months earlier. Watson said in The Double Helix "The instant I saw the picture my mouth fell open and my pulse began to race." It was clear evidence of a helix with its clear "X" in its center and crucial information for Watson to build the DNA model. Watson said in The Double Helix, "Rosy, of course, did not directly give us her data. For that matter, no one at King's realized they were in our hands race (Watson 2012 [1968])." Watson drew the pattern of Photo 51 on his newspaper on the train back to Cambridge and prepared to talk with Crick about the significant information. After Crick and Watson had discussed it, they rushed to build the DNA model again.

Watson and Crick were sufficiently convinced that DNA is a double helix with Photo 51. Besides, they also received more valuable information from John Randall, who worked in the medical research council (MRC) committee. He distributed a report describing the most recent work done in the laboratory, which included a summary of Franklin and Gosling's work about DNA structure. On Franklin's notebook, a simple drawing illustrated that the two strands of the double helix should run in opposite direction. In other words, one strand ran up and the other strand ran down. Crick immediately realized that DNA had an anti-parallel structure. And in February 1953, Watson and Crick announced their discovery of the structure of DNA. Their model of its structure so perfectly fit the experimental data that it was almost immediately accepted by the scientific community, including Franklin. But at the time Franklin was unaware of the important role her photograph had played in allowing them to build their model (Maddox 2002; Gibbons 2012).

For Watson and Crick, once they discovered the DNA model, they needed to publish quickly. But the problem is that they could not cite Rosalind Franklin's data because she had not published yet. They also could not refer to the MRC report, which is still officially unpublished. In this event, the heads of Cavendish Laboratory, at Cambridge University, and the head of the Biophysics Research Laboratory at King's College approached the editors of Nature to agree to publish three articles together. Partly as a consequence of the third placement, Franklin's paper seemed merely to support Watson and Crick's work. But her data played far more than just a supporting role. It provided the essential evidence for Watson and Crick to build the correct DNA model (Maddox 2002; Gibbons 2012).

In 1953, Franklin had taken her new position at Birkbeck College. Three year later, she was diagnosed with ovarian cancer. Because working in X-ray labs has some potential risk to people's health, there is a speculation that the overexposure to X-rays caused her disease. Franklin died in 1958 at the age of 37. In 1962, James Watson, Francis Crick, and Maurice Wilkins shared the Nobel Prize in Physiology or Medicine for their remarkable discovery of the structure of DNA. But the Nobel Committee did not mention Rosalind Franklin's contributions. Indeed, Franklin's contributions to Watson and Crick's discovery did not become widely known until Watson published The Double Helix, by which point Franklin was dead. Thereafter, her role in the discovery of DNA's structure gradually gained wider recognition, raising questions about whether or not she was properly credited, and Franklin eventually became a symbol of sexism in science (Maddox 2002; Crease 2003; Gibbons 2012; Glynn 2012).

Appendix 3

Semi-structured Interview Protocol[1]

1. What is your overall impression of the format of the course?

- Did you enjoy taking a course that featured a "flipped classroom"? Please explain your answer.

2. On a regular basis your instructor made a point of raising questions about new material before you viewed the on-line lecture, read the chapter, completed the homework and completed a quiz.

- Was this procedure of raising questions before you had a chance to review the new materials helpful to you or not helpful to you? Why or why not?

3. The introduction of new material was often accompanied by the use of pre-assessment instruments, such as surveys and short writing assignments.

- Was the process of coming up with your own answers to questions in a non-evaluative context prior to studying the chapter helpful to you? Why or why not?

4. The introduction of new material was also often accompanied by themes or stories from the history of biology.

- Do you think your instructor use the themes or stories to teach in your class? If yes, which approach do you perceive your instructor relied upon to teach?
- What do you mean by themes or stories? Can you give an example of the themes or stories from class?
- Was it helpful to you? Why or why not?

5. In your opinion, would it be helpful or unhelpful for your instructor to use stories in class?

- What do you see as the advantages or disadvantages of using stories in science classes?

6. Did the way your instructor introduced course content by means of broad themes and/or stories give you any insights into the practice of science?

- Please explain your answer with an example.

7. Did the way your instructor introduced course content by means of broad themes and/or stories help you understand the content of the course?

- Please explain your answer with an example.

[1] The questions in this interview script have been developed with reference to Norris et al. (2005). A Theoretical framework for narrative explanation in science. *Science Education* 89(4): 535–554.

8. Did the way your instructor introduced course content by means of broad themes and/or stories make you more or less comfortable learning science?

- Please explain your answer with an example.

Possible prompts

- Could you expand on that?
- Could you tell me more about that?

Next go over differences in student responses to the Pre and Post SUSSI.

9. I'd like to ask you some questions about a specific class devoted to the discovery of the structure of DNA. Can you tell me what you thought about this particular class?

- Did your instructor introduce the process of discovering the structure of DNA? If so, how did your instructor introduce this topic?
- Was it helpful for you to learn the content? Why or why not?
- Was it by themes or stories?
- What do you mean by "themes"/ "stories"?

10. Does the process of science involve creativity and/or imagination?

- What do creativity and imagination in science mean to you?
- If yes, explain and provide examples. If no, explain why not.
- Did what you learned about the discovery of the structure of DNA help you learn how creativity and imagination are involved in science? Explain.

11. Does the process of science involve social and cultural factors?

- What do social and cultural factors mean to you?
- Is science affected by society and/or cultural factors? If yes, explain and provide examples. If no, explain why not.
- Is science today affected by social and cultural factors? Why or why not? If yes, explain and provide examples. If no, explain why not.
- Did what you learned about the discovery of the structure of DNA help you learn how social and cultural factors are involved in science?
- In your opinion, do you think men and women are treated equally in current society?

13. Do you think there are any connections between the class questions and activities for the discovery of the structure of DNA and the assessment we just discussed? If so, what connections do you see?

[1]The questions in the interview script are based on ideas from Norris et al. (2005). A Theoretical framework for narrative explanation in science. *Science Education* 89(4): 535–554.

Appendix 4

Table 6 SUSSI Likert items comprising NOS components developed from Liang et al. (2008)

NOS Component	Items (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. (+)
Tentativeness	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 and 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 influence	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. (−)
Creativity and imagination	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. (−)
Scientific methodology	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. (+)

Note. Items marked (+) are scored positively from strongly disagree (1) to strongly agree (5). Items marked (−) are scored negatively from strongly agree (1) to strongly disagree (5)

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