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Learning the Nature of Science in a Course-Based Undergraduate Research Chemistry Laboratory

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Abstract

A quantitative study was conducted to investigate the influence of a Course-based Undergraduate Research Experiences (CUREs) chemistry laboratory on students' understanding of the nature of science (NOS) at a Northwest liberal arts college. The CUREs activities were interspersed with NOS activities throughout the semester. The Views of nature of science (VNOS D+), an open-ended NOS questionnaire, was used and rated to provide quantitative data. Descriptive and inferential statistics were used to interpret the data. The results indicated that the majority of students changed their views of the nature of science from mostly naïve and transitional to informed views. Inferential statistics were done using paired sample t-tests. Significant improvements were observed on the whole instrument and individual items. Cohen's d effect size indicated that these changes had practical implications in education settings. These results inform the need for authentic environments for undergraduate students in chemistry and an explicit approach to teaching NOS.

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Introduction

Wilichowski and Saleem (2018) emphasized the importance of science education, noting that it (1) cultivates future professionals in scientific fields, (2) reflects an integral aspect of modern culture, and (3) fosters scientific literacy essential for navigating today's technological world. These authors believe that teaching science must include both the concepts and processes of science, including controversies (e.g., human impact on climate change). Science has also been marked by past controversies (Baron & Herzog, 2020; Haywood et al, 2023; Sherwood, 2011), which students should explore to better understand the nature and development of scientific inquiry. The National Academies of Science (NAS, 2017) have noted that controversies in science usually stem from different sources, including the inconclusive nature of science and ethical and moral beliefs. They went on to say that various conflicting interpretations of scientific phenomena among scientists can present a hurdle to trusting scientific knowledge. Therefore, the National Academies of Science (2017) believe that providing avenues for discussions of scientific controversies can strengthen scientific knowledge.

Nelson et al. (2019) argued that understanding the nature of science can help reduce students' resistance to engaging with topics like evolution, which are sometimes perceived as controversial. These authors advocated for introducing controversial scientific topics through the lens of the nature of science. The process includes discussing the strengths and weaknesses of alternative explanations, using the power of the scientific process, which includes historical inferences and observations, and encouraging teamwork. Other authors have also indicated that explicitly teaching the philosophy and history of science can improve students' views of the nature of science (Khazaei et al., 2018), which in turn can help students delineate authentic science from pseudoscience. According to Crawford (2015), "authentic science is a variation of inquiry teaching that aligns closely with how scientists do their work and differs from traditional school science laboratory exercises (commonly called "laboratories" in the USA)" (p. 113). In an authentic science environment, students think and work like scientists to explore the natural world using logic and evidence. Jordan et al. (2018) encouraged teachers to engage students in authentic science when teaching climate change, arguing that "engagement with authentic science is a means to mediate trust and motivation in those who are learning about climate change" (p. 350). Kerstiens (2019) indicated that teaching the nature of science can fulfill the role of authenticity when time and material constraints affect authentic science.

A course-based undergraduate research laboratory is one way that higher education institutions can provide authentic environments to students because it enables them to "make discoveries by collecting and analyzing novel data and producing results that are new to students and to the scientific community alike" (Dolan, 2016, p. 3). Students in a CUREs laboratory engage in the rigor of research that is both relevant and promotes the spirit of discovery (Auchincloss et al., 2014). Thus, students can experience the process and nature of science, which does not involve ready-made answers. Further, the CUREs environment provides a valuable opportunity for students to explicitly learn about the nature of science. Research has shown that, when explicitly taught, students can understand the nature of science better (Bell et al. 2011). In this research, we combine an authentic environment through CUREs and explicit teaching to improve students' understanding of the nature of science.

Theoretical Framework

Lederman (1992) defines the nature of science as the "epistemology of science, science as a way of knowing, or the values and beliefs of scientific knowledge and its development" (p. 331). They went on to describe science as tentative, empirical, subjective, and a human endeavor. Thus, the scientific endeavor is a creative and imaginative pursuit that requires inference and is influenced by social and cultural factors. Lee (2013) writes that the nature of science "describes the issues addressed by the philosophy, history, sociology, and psychology of science as they apply to and impact science teaching and learning" (p. 554). Thus, NOS is the "fundamental domain for guiding science educators in portraying science to students, and few people doubt that an authentic science curriculum must contain ideas about the nature of science" (Lee, 2013, p. 554). Lederman and Abd-El-Khalick (1998) caution against conflating science itself with the nature of science (NOS). While science refers to a body of knowledge about the natural world, NOS encompasses the underlying processes, assumptions, and epistemological foundations that guide how that knowledge is generated and validated. According to the authors, it is this methodological and conceptual framework that truly distinguishes science from other disciplines. Therefore, understanding the nature of science is essential not only for grasping how scientific knowledge is constructed but also for recognizing what makes science a distinct way of knowing. Another reason for teaching NOS is to create a scientific literary society (American Association for the Advancement of Science [AAAS], 1990, 1993; Lee, 2013, Millar & Osborne, 1998). Understanding NOS can also have value in motivating students' interest in science and equipping them to grasp socio-scientific issues currently facing the world (Driver et al. 1996; Lee, 2013).

Although there are current disagreements about the role of the nature of science, science educators agree that science students should interact with an authentic science environment in their curriculum (Lee, 2013, Lederman & Abd-El-Khalick, 1998; Schwartz, Lederman, & Thompson, 2001). Further, there is an agreement about important aspects of NOS that students should learn (AAAS, 1990, AAAS, 1993, NRC, 1996, NSTA, 2020)According to Lederman and Abd-El-Khalick (1998), teaching the process of science to students, while crucial, is not enough to enable them to understand the nature of science. Students need to be explicitly guided through the NOS activities for effective learning. Therefore, it may be advantageous to concurrently teach the scientific process and the nature of science.

Objectives of a Chemistry Laboratory

Blosser (1983) acknowledged that one of the objectives of a science laboratory is to teach an understanding of the nature of science. These include "scientific enterprise, scientists and how they work, existence of a multiplicity of scientific methods, interrelationships between science and technology, and among the various disciplines of science" (Travers, 1973, p. 1119). In the 21st century, the laboratory has the following roles.

- To arouse and maintain interest, attitude, satisfaction, open-mindedness, and curiosity.
- To develop creative thinking and problem-solving ability.
- To promote aspects of scientific thinking and the scientific method.
- To develop conceptual understanding.

- To develop practical abilities (for example, designing an experiment, recording data, and analyzing and interpreting results obtained from conducting an experiment). (Hofstein & Hugerat, 2021, p. 3)

The above objectives can be realized when students are given an authentic environment where they "manipulate equipment and materials in an environment suitable for them to construct their knowledge of phenomena and related scientific concepts" (Hofsten & Hugaret, 2021, p. 5). Laboratories have been encouraged to mimic scientists as they explore the natural world and develop explanations for their findings (National Research Council [NRC], 1996). This means providing students with an opportunity to go through the scientific process, where they ask questions, conduct literature reviews, make hypotheses, conduct experiments, experience setbacks while interacting with other lab members and the instructor (Hofstein, 2004). The current laboratory must emphasize the following objectives.

- Understanding of scientific concepts.
- Interest and motivation.
- Attitude toward science.
- Practical scientific skills and problem-solving abilities.
- Scientific habits of mind.
- Understanding the nature of science (NOS).
- The opportunity to do science. (Hofsten & Hugaret, 2021, p. 6)

Some authors (Carnduff & Reid, 2003; Reid & Shah, 2007) proposed three broad objectives for a chemistry laboratory: Practical skills, Transferrable skills, and Intellectual stimulation. Practical skills involve the ability to carry out research using the available instruments while acknowledging the hazards. Transferable skills include working in teams, planning your research activities, organizing activities, and disseminating the results of your activities. Intellectual stimulation emphasizes the relevance of the activity, which motivates the students to get involved. Reid and Shah (2007) propose to "make chemistry real, expose ideas to empirical testing, develop skills of observation, deduction and interpretation, and develop general practical skills (e.g., team working)" (p. 183).

The Need for Understanding the Nature of Science

Schussler et al. (2012) and Agustian (2020) advocate for higher education to increase the role of understanding the nature of science. However, it is not clear to what extent institutions of higher learning incorporate the nature of science in their laboratory curriculum (Agustian, 2020). Abd-El-Khalick (2012) observed that it is mostly non-practicing scientists who focus on learning about the nature of science. Schwartz (2012) revealed that science educators emphasize the importance of the nature of science while practicing scientists do not. Schwartz and Crawford (2004) and Schwartz et al. (2004) note that practicing scientists do not put much effort into the question of science and how it is done. A study by Aydeniz and Bilican (2014) echoed these sentiments when they found that graduate research assistants did not fully grasp NOS related to "the argumentative nature of science, the process of modeling in science, scientists' treatment of unexpected results, collaborative nature of science, and the process of theory formation" (p. 1083). It is no wonder that Schussler and Bautista (2012) also found that undergraduate students had a naïve view of the nature of science. This was mainly because college laboratories do not emphasize process understanding, instead focusing on procedural and conceptual learning. Even inquiry laboratories focus on investigations that have a pre-determined result, thus negating the true process of science. A study by Agustian (2020) found that undergraduate students had a better understanding of the nature of science than reported by Schussler and Bautista (2012). In this case, the students had a transitional view of the nature of science. However, the students in Agustian's study held naïve views about theories and laws, where students believed that a law is just a proven scientific theory. The study also found that students had informed views about imagination and creativity in science.

The Role of CUREs

The CUREs lab accomplishes the objectives stated above because students deal with an authentic environment. This authentic environment includes the challenges involved in conducting authentic research activities. Students have no idea what the result of their investigation will be. Sometimes, students have to do iterations of different experiments to come up with viable solutions. Moreover, one characteristic of CUREs classes is the encouragement of teamwork and collaboration (reference). Students collaborate to develop a research topic and work together throughout the lab activities, up to developing an appropriate research dissemination procedure. All these provide a favorable environment for accomplishing the objectives of a modern chemistry laboratory in higher education. For instance, a study by Ruth et al. (2023) showed that CUREs improved students' ability in "skill in the interpretation of results, ability to integrate theory and practice, and understanding how scientists work on real problems" (p. 49).

Another study by Flaherty et al. (2017) found that students in CUREs improved their understanding of the scientific process and their confidence in perceived scientific knowledge. The students also indicated that the course improved their perceived professional skills as wildlife biologists. They observed that CUREs provide similar opportunities to those in traditional undergraduate research, but CUREs reach a larger number of students. Auchincloss et al. (2014) observed that since CUREs class has fewer experienced researchers who can interact with a larger number of students on a one-to-one basis, students do not fully understand the nature of science or their scientific identity.

This Study

NOS is essential to students' scientific literacy and so must be included as a part of authentic science (AAAS], 1990, 1993; Lee, 2013, Millar & Osborne, 1998). CUREs alone may not help students to fully understand the nature of science (Khazaei et al., 2018; Lederman and Abd-El-Khalick, 1998), but can provide an environment favorable for the understanding of the nature of science. However, combining CUREs and the explicit teaching of NOS may have an impact. In this study, therefore, we investigated the impact of combining CUREs and explicit teaching of NOS on students' understanding of the nature of science by answering the research question:

- To what extent did participation in the CUREs course with explicit teaching of NOS impact chemistry undergraduate students' understanding of the nature of science?

Method

The CUREs Classroom

This is a semester-long organic chemistry laboratory with a focus on authentic chemistry research. During the first week of lab, students read a research article to familiarize themselves with chemistry research. They write out information about research questions the article addresses, and the methodologies used, especially instrumentation. During the second week of lab, students select groups of 3 or 4 to partner in the lab work. The instructor provides a broad topic that students need to work on and asks students to use Google research and identify at least 6 articles per group, dealing with that broad topic. The students are then asked to peruse the six articles, brainstorm in their groups, and write down their thoughts on a shared online Word document. The thoughts could be in the form of statements or research questions. The whole class discusses different brainstorming statements from various groups. In the next phase, students are asked to come up with three research questions from their statements, from which they will choose one as their research topic. The first nature of science activity is introduced during this week, which deals with the difference between theory and laws. During the third week, students learn about and start writing their research proposals. The nature of science activity this week involves inferences and observations. In the fourth week, some groups are still designing their experiments while others are starting their trial runs. The nature of science activity this week involves creativity and subjectivity. Weeks 5 to 9 involve carrying out their experiments while completing lab notebooks each week. During week 10, students write their abstract for the campus symposium submission. Students learn about science as a human endeavor involving social and cultural aspects. They start creating posters for presentations during week 11 while finishing up any outstanding experiments. By week 14, students have their final posters ready for presentation. Spring 2024 students investigated biodiesel synthesis, and spring 2025 students investigated flavonoids and their properties in various natural products.

Participants

A convenience sample was used because to be included in this study, a student would have to take organic chemistry II lab and consent to data being used for research purposes. We collected data from the spring 2024 semester (10 participants) and the spring 2025 semester (9 participants). The participants had already taken at least 3 chemistry courses: general chemistry I & II, and organic chemistry I & lab. The students were also concurrently in the organic chemistry II lecture section. We sought human subject review board approval and carried out the consent process with the participants.

The Instrument

The Views of Nature of Science questionnaire (VNOS D+), developed by Lederman et al. (2002), was used as both a pre- and post-test instrument. Widely validated and frequently cited in NOS research (Ayala-Villamil & García-Martínez, 2021; Mesci, 2020; Narbona et al., 2022), the VNOS D+ consists of 10 open-ended questions (14 items in total) designed to assess key aspects of the nature of science. These include the distinction between observation and inference, the empirical basis of science, the role of creativity and imagination, subjectivity in science, its social and cultural embeddedness, the tentative nature of scientific knowledge, and the distinction between scientific laws and theories.

Data Collection and Analysis

Participants completed the VNOS D+ survey twice: once during the first week of the semester as a pretest, and again in the final week before exams as a post-test. The first and second authors independently evaluated the responses, categorizing each according to the level of understanding demonstrated: 1 for naïve views, 2 for transitional views, and 3 for informed views. For example, on the aspect of the tentativeness of science:

- A naïve view might be: *"Scientific facts never change."*
- A transitional view might be: *"Sometimes science changes, but mostly it stays the same."*
- An informed view might be: *"Scientific knowledge is tentative and can change with new evidence, but it is reliable because it is based on careful testing."*

The interrater reliability between the two authors exceeded 85%. Any discrepancies in ratings were resolved through discussion until consensus was reached. These numerical ratings were then used to quantitatively analyze and report students' understanding of the nature of science based on their VNOS D+ responses. Table 1 shows sample ratings from two participants.

Table 1. Sample Rating for two NOS Targets from Two Participants

Target	Test	Participants Statements	Rating
Empirical nature of science	Pre	Science is disciplined by natural, provable forces, while art and philosophy are moved by passion and hopes or dreams; it's all in the eye of the beholder.	1
	Post	Science is a unique discipline because it relies on different methods of knowledge, including observation, experimentation, and evidence. Unlike other subjects like art and history, it's grounded in scientific methods involving forming hypotheses, conducting experiments, and analyzing data to draw conclusions about the process. This allows scientists to test ideas in ways that are repeatable and measurable, which can lead to results that can be verified by others.	3
Inferential nature of science	Pre	I think they only are to a point because computers can make errors even if they are programmed not to. A glitch in the system or a virus can affect how the system reads the weather. On the other hand, I think they are mostly certain because the computer models have been correct a majority of the time.	2
	Post	I think that meteorologists are certain about their computer models to a certain extent, and a lot of their models are run on probability. This is why when they suggest there will be rain, they always say "there is a chance for rain." They are not 100% certain that it will rain, but there is a chance based on the models they use.	3

Descriptive and inferential statistics were used to analyze the data. A data table and a bar graph were used to describe the data. Paired sample t-tests were used to test the significance of the mean pre and post-test scores for the whole questionnaire and individual questions. Cohen's d was used to test the practicality of significance tests.

Results

Table 2 shows changes in the number of participants whose views were naïve (N), transitional (T), or informed (I) for each item during the pre and post-tests. According to the VNOS D+ key, naïve response is not consistent with any part of the NOS aspect, transitional response is consistent with some, but not all, parts of the NOS aspect, and informed response is consistent and addresses all parts of the NOS aspect. The results show that most students had naïve views on items 2 and 8, had transitional views on items 1, 4c, and 5b, and had informed views on items 3, 14, and 16 during the pretest. During the post-test, a majority of participants had informed views on all items.

Table 2. Students Count Changes by Epistemological View Type in Pre and Post-Tests

		Pretest			Posttest		
Science is	Item	N	T	I	N	T	I
Tentative and objective	1	3	13	3	1	5	13
Creative, empirical, and subjective	2	9	6	4	1	5	13
Tentative, observational, inferential, and subjective	3	1	2	16	2	1	16
Observational and inferential	4a	2	8	9	0	5	14
Tentative and inferential	4b	4	6	9	2	3	14
Inferential and subjective	4c	5	9	5	0	3	16
Empirical	4d	4	8	7	0	5	14
Tentative, observational, and inferential	5b	3	10	6	2	5	12
Observational and inferential	6	3	7	9	3	3	13
Creative and subjective	7	6	6	7	1	4	14
Based on theories and laws	8	9	6	4	4	1	14
Tentative	9	2	3	14	0	2	17
Socially and culturally embedded	10	0	3	16	1	1	17

The table shows a clear overall shift in students' understanding of various aspects of the nature of science (NOS), with a noticeable decrease in naïve views and a corresponding increase in informed views from pretest to posttest. For instance, in Item 2 (creative, empirical, and subjective), the number of students with naïve views dropped from 9 to 1, while those with informed views rose from 4 to 13. Similarly, in Item 4c (inferential and subjective), naïve views decreased from 5 to 0, and informed views increased from 5 to 16. This trend suggests that after instruction, students developed a more informed and nuanced understanding of NOS aspects such as subjectivity, inference, and tentativeness

Figure 1 shows a substantial decrease in the percentage of total naïve views from 21 to 7, transitional views from 35 to 17, and an increase in informed views from 44 to 76% between pre and posttests.

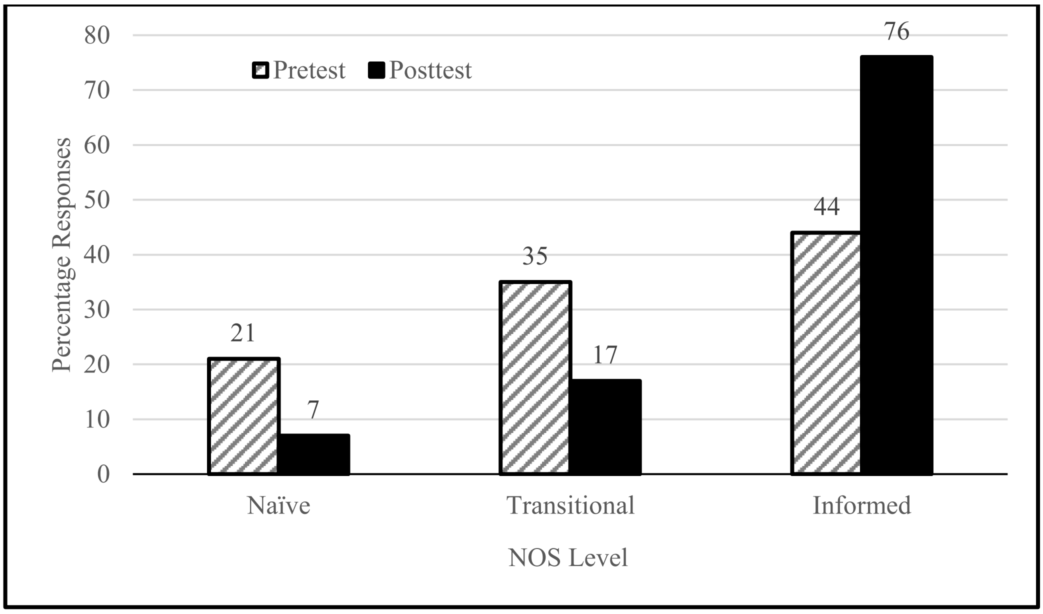

Figure 1. NOS Percentage Changes between Pretest and Posttest

The Kolmogorov-Smirnov (KS) test was used to check the distribution of pre and post-tests. The pretest had a KS value of 0.12 ($p = 0.62$) and the post-test had a KS value of 0.15 ($p = 0.27$), indicating normal distribution of data both in the pre and post-test ($p > 0.05$). Then we used a paired sample t-test to compare the sample means of pre- and post-VNOS D+ scores. The t-test was used to answer the research question, "*To what extent did participation in the CUREs course impact chemistry undergraduate students' understanding of the nature of science?*" Table 3 shows the results of the significance test between pre and post-test mean scores. The table shows that the post-test mean score is significantly higher than the pretest mean score ($t = 9.25$, $p = 0.000$). A large Cohen's d ($d = 1.62$) indicates that significance is large enough to have practical utility (Cohen, 1988**)**

Table 3. Pre and Posttest NOS Rated Scores Inferential Statistics

Test	N	Mean (out of 3)	SD	t	p	d
Pretest	19	2.24	0.30	9.25	0.000	1.62
Posttest	19	2.69	0.25			

Table 4 shows the mean pre and post-test scores of individual items. The participants had a significant improvement in most of the items except items 3, 4a, 9, and 10.

Table 4. Mean Pre and Post-Test Scores of Individual Items

Item	Pretest	Posttest
1	2.00±0.58	2.63±0.60**
2	1.74±0.80	2.63±0.60**
3	2.78±0.54	2.73±0.65
4a	2.42±0.60	2.74±0.45
4b	2.26±0.80	2.63±0.68*

Item	Pretest	Posttest
4c	2.00±0.74	2.84±0.37**
4d	2.16±0.76	2.74±0.45**
5	2.16±0.69	2.52±0.70*
6	2.31±0.75	2.53±0.77*
7	2.05±0.85	2.68±0.58**
8	1.74±0.81	2.53±0.84**
9	2.63±0.68	2.89±0.31
10	2.84±0.37	2.84±0.50

*p < 0.05; **P < 0.01

Discussion

This study showed that adding NOS activities to the course-based undergraduate research chemistry lab improved students' understanding of the nature of science (Table 2). We observed a decrease in naive understanding of NOS from 21% during the pretest to just 7% in the post-test. Transitional understanding of NOS decreased from 35% during the pretest to 17% in the post-test. A large increase in informed NOS was observed from 44% during the pretest to 76 % in the post-test. Inferential statistics (see Table 3) showed a significant increase between pre- and post-tests ($p = 0.000$), with practical significance at Cohen's $d = 1.61$. According to Wierzchowski and Wink (2023), "One important purpose for learning in a research setting is to let students learn about the research process and nature of science (NOS) outside of simple knowledge of facts and practices in science" (p. 2874). Schwartz et al. (2004) found that understanding the NOS is enhanced when college labs combine authentic science environments with explicit reflection of the nature of science. Therefore, the improvement in our study makes sense because the students had two opportunities to learn the NOS. First, they had to go through the activities mimicking real-life scientists by researching real-life problems. Second, the nature of science was explicitly taught to them. Khazaei et al. (2018) stated that students should be explicitly taught the philosophy and history of science to improve their views of NOS. Kerstiens (2019) promoted the explicit teaching of NOS to enhance authentic science, specifically when resources are scarce. We argue that even when resources are present, the nature of science activities must be taught explicitly. Combining authentic science research activities and the explicit teaching of NOS provides a double advantage to the students. In CUREs labs, students follow the scientific process, which goes through all the rigors of science (Auchincloss et al., 2014; Dolan, 2016). In this case, students will understand the processes involved in conducting science and thus, the nature of science. A study by Russell and Weaver (2011) found that CUREs labs bring authenticity by discussing important processes that scientists value and how scientists conduct their work. Wierzchowski and Wink (2023) also observed an improved nature of science in a CUREs class, attributing their results to the comfort that group work in the research activities provided. These authors believed that the CUREs offered an environment where students could discover themselves as scientists.

Results from this research are important because understanding the nature of science will prepare current and future scientists to deal with controversies in science (Agustian, 2020; Baron & Herzog, 2020; Haywood et al, 2023, Schussler et al., 2013), which can present hurdles to trusting science (NAS, 2017). Further, with the observation by Abd-El-Khalick (2012) and Schwartz (2012) that it is usually nonpracticing scientists (e.g., science educators) who focus on the nature of science, this study redirects NOS learning to practicing scientists. The undergraduate students involved in this study were all in the scientific career pipelines, developing as future scientists, and this is an opportunity to introduce them to the understanding of NOS. Results from this study also align with Schussler and Bautista (2012), who found that undergraduate students had naïve NOS due to the emphasis on procedural and conceptual learning in the college laboratory. On the other hand, Agustin (2020) found that undergraduate students had transitional views of NOS. This agrees with our study, where the average pretest scores display the transitional views of the nature of science. Our results indicate that CUREs combined with explicit NOS teaching can teach future scientists about the nature of science. This is the case because, as the students conducted scientific research, we connected their activities to the nature of science. We taught them the (1) use of observations and inferences, (2) subjectivity and objectivity in science as they interpreted their results, (3) tentativeness of science through changes to the previous understanding of science, and (4) the importance of social aspects to science.

When looking at the responses to individual items (Table 4), we found that students had the most naïve NOS on their understanding of theory and laws (question 8) during the pretest. This is not surprising because Agustin (2020) found that although undergraduate students had transitional views, they still had naïve views about theories and laws. In our study, only 4 students out of 19 had informed views about theories and laws during the pretest. Most of the students during the pretest used the hierarchical view of the nature of science (Lederman et al., 2002), which puts theories inferior to laws. The students believed that theories became laws after exhaustive testing. This view changed during the post-test (14 students had informed views), where students mentioned the explanatory role of theories and the descriptive role of laws. No significant differences were observed on questions 3, 4a, 9, and 10, with mostly minimal positive gains, except for one item showing a slight negative change. Question 3 addresses the tentative, observational, inferential, and subjective nature of science; Question 4a focuses on the observational and inferential nature; Question 9 concerns the tentative nature; and Question 10 relates to the social and cultural aspects of science. Students in this study already held mostly informed views on these NOS aspects, which may have limited the scope for substantial improvement.

Conclusion

This study has shown that providing undergraduate chemistry students with authentic research experience while explicitly teaching NOS can improve their understanding of the nature of science. This is important because students, even at the graduate level, do not yet have a fully informed understanding of the NOS when they are not properly guided. In this study, we agree with the recommendation that students should interact with an authentic science environment (Lee, 2013, Lederman & Abd-El-Khalick, 1998; Schwartz, Lederman, & Thompson, 2001). We also agree with the recommendation that the teaching of the nature of science must accompany the teaching of the process (Lederman and Abd-El-Khalick, 2005). Therefore, science educators must create environments that improve both the process and the nature of science.

Limitations and Future Studies

Further study must involve a comparison group, which was not included in this case. More research also needs to be done with a bigger sample size to increase the strength of these results. However, literature has supported the need for an authentic science environment and an explicit approach to teaching NOS. Therefore, we believe that our study provides crucial information to science educators on what to focus on as they create future scientists.

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