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Students' Views on the Nature of Science in an Interdisciplinary First-Year Science Program: Content Analysis of a Weekly Reflection Activity

ABSTRACT

A primary aim of science education is to teach students how to interpret and engage with scientific information. To do so effectively requires an adequate understanding of the nature of science (NOS)—in other words, what science is and how it works. There is a long history of evidence to suggest that many undergraduate students struggle to properly understand NOS. While the specific factors contributing to misinformed views on NOS may be difficult to tease apart, the way in which students learn about science at the undergraduate level is a significant contributor. We implemented a reflection activity in a unique first-year program at a large Canadian university in order to promote student learning of NOS. Through the students' reflections, we identified how certain pedagogical approaches, many of which deviate from traditional teaching methods used throughout undergraduate science education, can positively impact student comprehension of NOS. Our experiences support the use of reflective practices in promoting critical thinking and the development of more nuanced student views of NOS.

KEYWORDS

reflections, nature of science, interdisciplinary teaching, first-year science, program evaluation

INTRODUCTION

An overarching aim of science education is to encourage the development of scientific literacy, or the ability to process, interpret, and engage with scientific information (NRC 1996). Science informs not only individual welfare but also key government policies, and according to the Next Generation Science Standards, "there is a strong consensus about the characteristics of the scientific enterprise that should be understood by an educated citizen" (NRC 2012, 78). Science education at the secondary and post-secondary level, however, is widely discipline-based, with separate fields of science taught independent of one another. In this system, more generalized scientific topics, such as the nature of scientific inquiry or the role science plays in society, can receive little attention (Rowe et al. 2015). In addition, the level of scientific literacy among students is often low: a 20-year study of approximately 10,000 undergraduate students in the United States found they are only slightly more scientifically literate than the general public (Impey et al. 2011). Concern over a lack of scientific literacy among future generations has led educators to highlight the importance of promoting students' abilities to interpret and communicate scientific research (Krajcik and Sutherland 2010).

A major component in the measurement of scientific literacy is a person's views or beliefs about "the Nature of Science" (NOS; NRC 1996). While there is no single agreed-upon definition of NOS (Smith and Scharmann 1999), it may be thought of as the values and assumptions inherent to science (Lederman 1992), or, more simply, "what science is and how it works" (Parker et al. 2008, 1681). Students often hold naïve or moderately uninformed beliefs when it comes to NOS (Abd-El-Khalick 2006; Desaulniers Miller et al. 2010; Parker et al. 2008; Ryder, Leach, and Driver 1999; Vhurumuku 2010), and there is evidence that poorly-informed views of NOS are correlated with lower conceptual understandings (Nufida et al. 2019). Addressing misinformed views of science is an important step towards achieving scientific literacy.

The ways in which science is taught in the classroom is a significant contributor to students' naivety regarding NOS (Lederman 2007; Liu and Tsao 2008). Misconceptions, or beliefs that are in conflict with scientific concepts and theories, have been widely studied in science education and can come in many forms (Vosniadou 2020). Researchers suggest that many misconceptions, such as the belief that science proves irrefutable truths, are consequences of a teaching approach that depicts the advancement of scientific knowledge as unidirectional and entirely objective (Abd-El-Khalick 2006; Desaulniers Miller et al. 2010; Ryder, Leach, and Driver 1999). An emphasis on confirmed discoveries—or as Latour (1987, 4) calls it, "ready-made science"—and limited discussion of the exploratory and tentative nature of scientific research could persuade students to view scientific knowledge as being attained through a constant progression of confirmed truths rather than through a gradual accumulation of evidence.

While student NOS views have been predominantly studied through the use of rigidly structured questionnaires and sometimes follow-up surveys (Abd-El-Khalick 2006; Lederman and Lederman 2014), there are potential benefits to using more open-ended methods such as reflection activities. Questionnaires allow for a comprehensive analysis of students' views on aspects of NOS as defined by the researcher, but they often do not allow for consideration of contextual nuances, and their ability to accurately measure students' understanding of science and the scientific process has been questioned (Elby and Hammer 2001; Matthews 2012). Reflective practice, on the other hand, encourages students to discuss aspects of science that resonate with them the most, such as "proximal knowledge" (Hogan 2000), and gives them the freedom to describe how their beliefs might be affected by context. Metacognition, or reflection on how one learns, helps students develop a deeper understanding of course material (Tanner 2012), and reflection activities have been incorporated in various scientific disciplines (e.g. Dounas-Frazer and Reinholz 2015; Rickey and Stacy 2000; Schussler et al. 2008), sometimes with the explicit aim of helping students better understand NOS (e.g. Bautista and Schussler 2010). In this way, promoting metacognition on NOS not only could be useful in learning about students' views, but could also benefit the development of scientific literacy in undergraduate students.

We integrated reflective practice in a small, first-year science program called Science One at the University of British Columbia (UBC), a large, public university located in Vancouver, Canada. The program differs in many ways from the traditional format of undergraduate science programs (Benbasat and Gass 2002) and provides an excellent opportunity to promote student learning on NOS. The class size is approximately 60–70 students, or one-quarter to one-half that of equivalent first-year science courses at the university, and students take their courses together as a single cohort for a full academic year. The subjects taught are biology, chemistry, math, physics, and scientific thinking and literacy (STL). The curricula focus on interdisciplinarity, with courses aligned so that instructors from different disciplines attend and contribute to one another's classes. A major focus of the program is to encourage students to "think like scientists," which is discussed most explicitly in STL seminars that cover concepts relating to what science is and how it is conducted. STL seminars also introduce term-long projects, including an independent research project in which the students devise and conduct their own experiments. Scientists from varying backgrounds also join the class to provide guest lectures throughout the year, and the students see scientific research first-hand during a four-day visit to a marine sciences research centre.

To promote the program's aims and to stimulate student discussion and reflection on NOS, we assigned a weekly self-reflection activity over an entire academic year. The activity encouraged all Science One students to relate material learned in the previous week to their understanding of science, the scientific process, and the development of scientific knowledge. We analysed their responses to better understand:

1) what aspects of NOS are of most interest to the students (as measured by the frequency in which certain aspects were discussed in the students' responses),
2) whether certain elements of the program's unique structure help inform students' NOS views, and
3) if reflection activities are a useful source of formative feedback (and if so, in what ways) and whether they encourage the students to consider broader topics they are never tested on in quizzes or exams.

METHODS

Participants

The work was conducted at UBC during the 2018/19 academic year (September–April). UBC is a large, research-intensive university, with 8,496 undergraduate students enrolled in the Faculty of Science in 2018/19. We focused on the 65 students registered in Science One. The students were all registered in their first year at university, with ages ranging from 16 to 19 years old at the start of the first term. Female and international students were slightly over-represented: females made up 58% of the class (in comparison to 53% of all undergraduates in the Faculty of Science) and international students made up 22% of the class (in comparison to 19% of all undergraduates in the Faculty of Science). Students accepted to the program tend to be slightly stronger academically than the average student entering the Faculty of Science (as judged by secondary grades and extra-curricular academic achievements). There is also evidence that participation in the program has a positive effect on performance in 2nd- and 3rd-year science courses (Dryden et al. 2012).

Reflection activities

We administered weekly reflection activities through the university learning management system, Canvas. Reflection responses were graded for participation as a small component of the scientific thinking and literacy portion of Science One, accounting for approximately 0.5% of the overall Science One grade. Instructors periodically provided written feedback to responses via Canvas throughout the year. Reflection activities were made available to the students immediately following the final lecture each week and were due by the start of the first lecture the following week. By soliciting the students' reflections on a weekly basis, we were able to relate their perspectives to their learning environment in the program for any given week.

Each weekly reflection activity asked the students to respond to the following two prompts:

1. What emerging theme(s) did you notice this week that relates to past Science One material?
2. What stood out to you this week about the nature of science and/or your learning at university?

At the end of each term, we asked the students to reflect on the entire term rather than the previous week, and included these responses in our results.

Students wrote their responses in free-form text boxes with no restrictions on response format or length. While our aim was to focus on students' views of NOS contained in their responses to the second prompt, responses to the first prompt regularly touched upon relevant NOS concepts, so we pooled the data such that a student's responses to both prompts was classified as one response. The total student response rate was 94% over the 25 weeks when responses were collected.

Analysis

We conducted a thematic analysis of the data, reading through the students' responses to identify common themes. We identified and organised the themes using a subsumption process, i.e. reading the responses until a relevant concept was encountered and either subsuming this under an established theme or, if the theme did not exist, creating a new theme (Schreier 2014). We continued this process until the point of saturation, when no more additional concepts were found. After the themes were established, we used a coding system to assign relevant statements to the themes (Schreier 2014). Each theme was chosen to reflect a specific thought or viewpoint with respect to the nature of science (Table 1). Two authors (NNB and CP) worked in unison to analyse a subset of the data (6 weeks of responses) and ensure uniformity of coding. A single author (NNB) then completed the coding for all 25 weeks.

We tabulated the number of responses falling under each theme for every week and summed these values to identify the total number of responses over the course of the year (Table 1). Some themes appeared relatively consistently throughout the year. Other themes, however, followed pulse-like patterns, appearing in relatively high numbers during one or two weeks but infrequently for the rest of the year. To characterise these pulse-like patterns, we divided the highest number of responses in a single week by the total number of responses. In addition, we identified major program elements that might have influenced students' perceptions and noted responses that explicitly linked a statement on the nature of science with a specific experience gained through Science One.

RESULTS

Nature of Science themes present in student reflections

Despite the open-ended format of the reflection prompts, the students' responses frequently touched upon several common themes (Table 1). We identified 13 themes relating to NOS that were discussed by more than 10 students over the course of the year. Of these 13 themes, six had pulse-like patterns in which responses were concentrated within a single week (Table 2). These pulses were typically elicited, as noted by the students themselves, by unique events that took place during that week, suggesting learning events that occur during a single week or even a single day can influence how students perceive NOS.

Table 1. Themes relating to NOS that were discussed in reflection activity responses, ordered by frequencies. Frequencies describe the total number of responses that discussed that theme. Themes were identified based on the students' responses through a subsumption process. There were a total of 1524 responses, which were registered over 25 weeks from a class of 65 students. All themes discussed by more than 10 students are included in this list.

Theme	Description	Number of responses	Example response
1. Science is interdisciplinary	Conducting science often requires knowledge of multiple scientific disciplines. Responses discuss how different fields of science rely on one another.	150	"I've noticed that it is impossible to truly categorise sciences into distinct disciplines. Each one feeds off of the other, and they work together to generate [our understanding of] the natural world."
2. Science includes different perspectives	Different scientific disciplines view common topics from different perspectives. Responses describe how terminology can change between disciplines when discussing the same topic, or that different disciplines focus on different aspects of the same topic.	56	"There where [sic] rules or concepts that existed in chemistry when working with the idea of thermodynamics but in physics those concepts where [sic] different. This is interesting to me as how a topic is the same in two disciplines but there are different interpretations of it or a different way of explaining it."
3. Science often relies on assumptions or approximations	Precise measurements cannot always be attained, in which case assumptions or approximations are used. Responses discuss the application of approximations or assumptions to further our understanding when precise measurements are not possible or not necessary.	48	"Approximation is a major aspect of all sciences. In chemistry we assume things are 'close enough' standard pressure and temperature in some cases. In physics we often neglect surrounding conditions and just take one value of atmospheric pressure. In biology we assume all members of a population are equally affected by a gene and equally likely to mate in some cases."

4. Science is constantly changing	Scientific knowledge is constantly changing/progressing in light of new research. Responses state that new research alters our previous beliefs, or that new research is constantly expanding our knowledge.	42	"Science is always evolving . . . We learn to question what we know and continue to expand."
5. Science requires communication	Communication is an important component of science. Responses mention that scientists should be able to communicate their findings clearly, and/or that failure to do so can result in misinterpretation of findings.	39	"It can be easy to get isolated and only communicate results to other scientists, but it is just as important to get the message to the lay community, as it is the general population that funds most research, and then uses the results and should make decisions based on science."
6. Science is a method	Science is a method or process through which we learn about the universe. Also, science is iterative, and there is no universal method.	35	"Science is a tool for gaining knowledge and solving problems"
7. Science is not infallible	Science does not provide absolute truths, and scientists are not infallible. Responses state that scientific discoveries or beliefs are not always accurate.	32	"There always exist exceptions to those theories . . . science does not represent absolute truth, but embodies the human endeavor at rationalizing the natural world."
8. Science is collaborative	Scientific research is typically conducted through collaboration. Responses state that research often requires collaboration among scientists.	24	"The scientific community is always learning from each other, and how these new ideas can be applied to current situations."
9. Science is important to society	Scientific knowledge impacts society. Responses discuss how science can be used to influence or address societal issues.	20	"We can creatively apply scientific methodology and knowledge in order to solve complex problems . . . I now have a greater idea of how the power of science can address societal problems"

10. Science is influenced by society	Scientific research is influenced by its social environment. Responses state that societal factors, such social needs, or funding opportunities, can affect the direction of scientific research.	18	"It seems to me that much of science has developed from a human need to help those around them."
11. Science is influenced by diversity	Diversity among scientists can affect scientific research. Responses state that a lack of diversity can restrict scientific progress.	18	"The importance of diverse perspectives in science really stood out to me this week as I had to write an application for a summer research position outlining how I may diversify the scientific community. . . . it's important that as we move forward in science and make decisions on which issues to tackle and/or how to spend money, that a variety of groups are present at the table."
12. Science requires creativity	The scientific process requires creativity. Responses state that generation of hypotheses and application of science to different problems requires creativity.	18	"We can creatively apply scientific methodology and knowledge in order to solve complex problems."
13. Science builds on past discoveries	Scientific progress is achieved by expanding from previous discoveries. Responses state that scientific discoveries build upon past research.	12	"We explored how one theory can be used to prove others. What we take for granted as mathematical facts are constructed upon each other."

Table 2. Themes for which a significant proportion of responses were concentrated within a single week.
This occurred when a specific event elicited similar responses from numerous students. The percentage of total responses reflects the number of responses for that theme occurring during that week relative to the total number of responses registered for that theme over the entire academic year (25 weeks). All themes for which more than 10% of responses occurred within a single week are included in this list.

Theme	Highest number of responses within a single week	Percentage of total responses for that theme	Event that elicited responses in that week
Science is influenced by diversity	13	72%	Scientific thinking and literacy (STL) class focusing on the how demographic diversity of scientists has influenced research questions and experimental protocols
Science is important to society	12	60%	First guest speaker of the academic year. Speaker discussed their own scientific research and its impact on societal issues.
Science is influenced by society	6	33%	Guest speaker who discussed how issues relating to grant applications and funding affected their research path.
Science is a method	11	31%	Scientific thinking and literacy class focusing on preparing students to conduct their own research in their second term projects
	4	11%	Trip to Bamfield Marine Sciences Centre, where students witnessed examples of "discovery-based science" first-hand
Science includes different perspectives	10	18%	Quantum mechanics taught simultaneously in chemistry and physics classes
	9	16%	Thermodynamics taught simultaneously in chemistry and physics classes
Science requires communication	7	18%	1) Scientific thinking and literacy class focusing on presenting science and 2) "Mini conference" in which students presented their first term projects

The two most frequently discussed themes related to the interdisciplinary aspects of NOS, specifically that science relies on interconnectivity between scientific disciplines and that these disciplines are associated with their own unique perspectives on common scientific topics. Other frequently discussed themes related to the exploratory nature of science. Students regularly noted, for example, that science often relies on assumptions or approximations when precise measurements cannot be obtained (or are not necessary) and that scientific knowledge is constantly changing as a consequence of new research findings. In addition, the students reflected on themes relating to the social aspects of science: that science is collaborative, that it requires communication, that it is influenced by society, that it is important to society, and that it is affected by diversity.

Past research has illustrated several student misconceptions relating to NOS, and we identified five aspects of NOS in which the Science One students demonstrated relatively more informed views. The students linked their understanding to unique pedagogical approaches in Science One, making it possible to identify how their learning experience helped promote these views:

Science is interdisciplinary (relevant themes: numbers 1 and 2 in Table 1)

Students often view science as inherently discipline-based, which likely stems from most science courses being restricted to a single scientific discipline (Abd-El-Khalick 2006). Learning about science in this way discourages students from identifying the interdisciplinary nature of scientific research and reinforces false perceptions, such as the misconception that some disciplines are "less scientific" than others (Bezzi 1999). This is a barrier to recent pushes in undergraduate education to cultivate a better understanding of the interdisciplinary nature of science (Tripp and Shortlidge 2019). Responses from students in Science One indicated that learning science in an interdisciplinary format encouraged them to develop a more complete understanding of how the disciplines contribute to one another and to science as a whole. During one week, for example, a single scientific question—relating to the metabolic function of a bear during hibernation—was addressed through the perspectives of biology, chemistry, and physics. Many of the students were unaccustomed to learning science in this way, and their reflections during that week demonstrated that they gained a more informed view of the interdisciplinary nature of scientific research, as demonstrated in the following student statement:

> I found that . . . a single topic could be explored using different aspects of science . . . I have rarely attempted to do so previously and everything in each discipline seemed discrete. The [interdisciplinary] process is more similar to science in reality where a problem may involve different disciplines to solve.

Another major component of Science One's interdisciplinary approach is an emphasis on communication between disciplinary specialists. Instructors from different disciplines aligned their curricula so that complementary topics were taught at the same time. They also attended and contributed to one another's classes, and students often commented on how those interactions encouraged them to identify cross-discipline connections. The effect this had on students' NOS perspectives was particularly evident during two different weeks when a common topic was taught in chemistry and physics. Both instances led to a pulse in the number of responses touching upon the "different perspectives" theme (Table 2), because students recognized the connections between these two disciplines and inferred that connections exist between other fields of scientific research as well:

> I enjoyed seeing thermodynamics in physics and in chemistry. It's interesting to see how some universal laws can be used for very different purposes. I also like how much it can be extrapolated to other subjects—for example, using thermodynamics to determine whether a reaction will occur is vital to biology, as reactions must occur for the cell to survive.

Students who learn a common topic at different times may not realise that the knowledge attained in one scientific discipline can complement the knowledge obtained in another. This gap stems from difficult-to-address issues relating to knowledge transfer, or the movement of information from one individual or group to another (Becheikh et al. 2010). Coordinating the schedules of different science courses such that they address complementary topics could improve students' understanding of interdisciplinary connections.

Science is tentative (relevant themes: numbers 3, 4, and 7 in Table 1)

While most scientists would agree that science is tentative—in other words, that most scientific progress is made through the gradual accumulation of evidence and that scientific beliefs are subject to change in accordance with new findings—there is a common misconception amongst students that science proves irrefutable truths (Lederman 2007). This misconception might occur when science is taught as objective truth, rather than as a method of inquiry. Science One students recognized that they held this misconception in secondary school (for example, one student wrote, "In high school, where everything we learned was presented as 'fact,' it was easy to think that most of the universe had been figured out.").

The experience of Science One appeared to help students appreciate the tentativeness of science, which they demonstrated through the discussion of several themes. First, many students reflected on the theme that science is constantly changing. The historical development of scientific knowledge—identified by Osborne et al. (2003) as a topic that should be included in all science curricula—is highlighted in Science One. Students commented on how classroom discussions informed their perceptions of science:

> I noticed this week that past scientific ideas are superseded with new [ideas]. This theme has been prominent in our study of relativity in physics classes this week. We looked at how classical concepts/understanding of time, distance and momentum begin to fall apart with the assumption that the speed of light is constant. We looked at how in the context of new discoveries (Maxwell's equations) and theories (Einstein's theory that physical laws such as the speed of light hold true for all reference frames), new formulations and conceptual understanding is required . . . Science is a continuous succession and improvement of ideas to better understand our universe.

Second, students reflected on the theme that many scientific principles hinge upon assumptions or approximations that can influence how they are interpreted. For example, to illustrate the importance of approximation, students were tasked with approximating velocity and acceleration using the Euler Method. Students noted that making approximations allows scientists to approach questions that would otherwise be impossible to address:

> In my other years of schooling, the emphasis has always been on finding the exact right solution, however this year the topic of approximation was used extensively by physics (bounding problems, approximating shapes), as well as biology (making assumptions surrounding ecosystems), chemistry (pseudo-first order reactions, and steady state approximations, as well as

> the simplifying assumptions made by the orbital theories), and even math (Taylor polynomials). The profs showed how important it can be to finding an approximate answer to very difficult questions . . . I think that the emphasis on approximations and assumptions was also good for my critical thinking skills, as too many times we simply learn about what past experiments "proved" without thinking about the approximations and assumptions they used that could be influencing the results.

Third, students discussed science as being fallible. Debates within the scientific community or the presence of implicit biases in scientific research were intentionally introduced in classroom discussions to emphasise that science is tentative. These topics also surfaced (unintentionally) during guest lectures. Students mentioned that published scientific research may be irreproducible or represent inferences that exaggerate results. Several students related their views to classroom discussions or to guest speakers, such as the following:

> I think that it is easy to idealize science and think of it as a "pure" field in which it is only the thirst for truth that motivates, and that scientific results should be prized as untouchable "fact." I like that with STL [seminars] and the guest speakers we have been talking about how science can be flawed (such as with under-representation of groups in drug trials), and how what gets publicized is dependent on human politics. I think it is a good reminder that science is human and has flaws.

Addressing these topics explicitly in classroom discussions appeared to have a direct impact on students' views.

Science does not follow a single, universal method (relevant theme: number 6 in Table 1)

Many undergraduate students believe that all scientific research strictly adheres to a single, universal method (Desaulniers Miller 2010; Vhurumuku 2010). This viewpoint could result from students being taught classic experiments that use the traditional, empirical scientific method without also learning the variety of modern scientific research methods. For example, data-intensive science, which occurs in fields such as ecology (Michener and Jones 2012) and astronomy (Bell, Hey, and Szalay 2009), follows a "discovery-based" approach that involves exploring large data sets for novel discoveries. Following classroom discussions in biology about different scientific methods, the students witnessed data-intensive studies first-hand during a multi-day trip to the Bamfield Marine Sciences Centre. This experience led to a pulse in reflections on the topic of scientific methods (Table 2). There was a second pulse of responses on this topic following an STL seminar that focused on research methods within the context of their second term research projects. Students identified alternative methods for conducting science as they carried out these research projects, such as the collection of data that was not empirical:

> Another theme I noticed was that the methods of gathering data vary due to the objective and research area of the experiment. This was evident since my Term II project was about modelling HIV infection, it would be done by a simulation.

Our experiences indicate that providing students with an opportunity to witness different scientific approaches first-hand, or better yet to explore their own research question using a less traditional method, has the potential to create a meaningful impact on students' perceptions of the scientific method and the diversity of approaches that it encapsulates.

Science and society influence one another (relevant themes: numbers 5, 8, 9, 10, and 11 in Table 1)

Many students do not recognize the influence that society and culture have on science (Abd-El-Khalick 2006; Desaulniers Miller et al. 2010; Liu and Tsao 2008; Ryder, Leach, and Driver 1999). In Science One, appreciating the interplay between science and its social environment is a key learning objective. One way we accomplish this is through the inclusion of guest speakers who speak about their experiences in research. Two guest lectures led to pulses in student reflections on the themes that "science is important to society" and "science is influenced by society." In one lecture, the guest speaker described the use of their work as evidence in criminal trials; in another, the speaker discussed the impact of funding agencies on their chosen research path. STL seminars further influenced NOS views in society-related themes through seminars focused on the relationships between science and society: "I noticed [from the guest speaker] how society has somewhat shaped science, which relates to how last week [in the STL seminar] we learned about how our society has allowed there to be bias in scientific research."

Students also identified the influence of society on science through their experiences conducting independent research projects, such as how one's background and experiences affect the research questions they want to pursue:

> Many people had ideas of projects that I never would have thought of, and I think that is the value in having a variety of people and types of people in science. Everyone approached the projects differently, and due to their lives and backgrounds looked into very different areas.

Similar ideas were also discussed following a peer-review activity in which students provided feedback on their peers' research reports:

> After reading many [of my classmates' research reports], science communication turned out to be a very important topic. Simple, well-explained papers gave a much better impression. . . . Science itself is not supposed to be influenced by how we actually communicate it, but it is.

These responses demonstrate that allowing students to directly engage in scientific procedures, such as conducting research and peer-review, can directly impact the development of NOS views.

Science requires creativity (relevant theme: number 12 in Table 1)

Many students believe that science does not require creativity, aside from the process of designing an experiment (Abd-El-Khalick and Lederman 2000; Desaulniers Miller et al. 2010; Parker et al. 2008; Zeidler et al. 2002). Laboratory courses that do not provide opportunities for experimental design encourage this misconception, leading students to describe even experimental design as uncreative (Parker et al. 2008). Students in Science One, however, reflected on encountering creativity in nearly all aspects of the program, including labs, lectures, guest presentations, and research projects.

For example, first-year physics labs at UBC (taken by students throughout the Faculty of Science, including those in Science One) were designed to foster students' abilities to critically assess experimental methods and devise improvements (Holmes, Wieman, and Bonn 2015). These experiences with experimental design influenced students' perceptions of creativity in scientific research:

> [After today's] physics lab, I've realized that science is not just the regimented textbook knowledge that we strive to gain in high school. There is a large emphasis on creativity and exploration. In physics labs I think that is especially prevalent when we are tasked with developing improvements to our simple experiments.

Developing their own research projects allowed students to further appreciate the creativity and imagination needed to develop a research question:

> This week, my partner and I started to try and figure out what to do for our [research] project, and it made me think a lot about both how we learn science versus how it actually is done. Most of school is being taught information, and then applying it to other situations (on projects and tests) . . . However, when trying to come up with the [research] project you have to both come up with the problem and find a way to use the information that you know to then solve it.

Lectures and guest speakers reinforced this appreciation, with students noting the creative ways in which some guests used scientific methods to address complex problems.

DISCUSSION

Reflective practice as a tool for learning NOS

The incorporation of reflective activities in our program's curricula was beneficial in several ways. One of the broadest impacts was that it encouraged students to think critically about science and scientific research through the lens of their own experiences. Making inferences from one's experiences through reflection is considered essential to critical thinking (Davis 2003; Zembal-Saul et al. 2000). Thinking about and monitoring their cognitive processes enables students to take control of their learning environment by helping them evaluate their own learning (Butler and Winne 1995; Winne 2018). This manner of self-regulated learning has been positively associated with academic achievement and satisfaction and is widely considered by educators as a major contributor to effective learning (Zimmerman and Schunk 1989). Many studies on metacognition have used a single intervention (such as a 50-minute activity or presentation) to mixed results (e.g., Cook, Kennedy, and McGuire 2013; Siegesmund 2016; Soicher and Gurung 2017; Zhao et al. 2014). Some have suggested that repeated activities or interventions may be necessary to improve students' use of metacognitive strategies (Langdon et al. 2019). Although we did not measure the effect of our weekly reflection activity on academic performance, it provided a relatively simple method to promote metacognition in a repeated manner without creating a significant burden to the students' cognitive loads.

By guiding the Science One students to reflect on NOS without pointing them to certain aspects of science, the students were able to develop their viewpoints freely. This contrasts to the traditional, structured format of NOS surveys and questionnaires (Lederman 1992; Lederman et al. 2002). Science educators have questioned the efficacy of this method, arguing that a student's ability to identify some number of declarative statements about NOS may not provide an accurate assessment of their learning and understanding (Matthews 2012). By distilling science to a series of statements that purport to represent consensus views, these instruments may misrepresent the heterogeneity of science and fail to capture the diversity and complexities of scientific practices (Van Dijk 2011; Hodson and Wong 2017). Reflection activities that are open-ended, such as the one we used, allow students to contextualise their viewpoints—something that is critical to the understanding of a topic as complex as science (Galili 2019; Tala and Vesterinen 2015).

In addition to promoting critical thinking and encouraging students to develop nuanced and contextualised views of NOS, our reflection activity demonstrated other practical benefits. One benefit is that it prompted the students to think about topics not directly assessed on quizzes of exams. NOS is a critical component of science education (NRC 2012), even though many students are not enrolled in courses that explicitly focus on it. This becomes an issue if we expect students to attain a lasting understanding of NOS not only because students will spend less time studying the topic, but also because numerous studies indicate that students have greater difficulty retaining knowledge of material that they are never tested on (Brame and Biel 2015; Karpicke and Roediger 2008; McDaniel et al. 2007). Reflection activities provide an instrument through which instructors can get students to focus on material that is not on course exams and assignments, such as broader level topics that exceed the course's primary learning objectives. Our reflection activities accomplished this within the Science One program.

A second benefit to our reflection activities is the additional opportunity for the program's instructors to assess students' comprehension of a topic, allowing instructors to identify unanticipated knowledge gaps or misunderstandings. For example, one student treated the tentative nature of science as evidence that scientific findings are unreliable, writing, "Most of what we know [in science] is just theory, and not 'truth,' and despite people accepting many scientific explanations, [they can] very easily be wrong." Misconceptions are ubiquitous in science (Karpudewan, Zain, and Chandrasegaran 2017) but not always easy to catch, and the "essay format" of our reflection activities provided instructors with a better understanding of misconceptions than could be gained by commonly used exam formats, such as multiple-choice questions (Parker et al. 2012). Student comments, such as the one previously described, encouraged us to more carefully provide a balanced discussion of science that discouraged the development of extreme points of view.

Finally, reflective practice within the contexts of multiple science courses, or more specifically in our case an integrated set of different courses, could encourage a better understanding of the contextual nuances of science (Hodson and Wong 2017; Tala and Vesterinen 2015). Although beyond the scope of our work, continued assessment of one's understanding of NOS over the duration of an undergraduate education, and through the lenses of different scientific fields, could prove useful in addressing the Next Generation Science Standard's recommendation that students "reflect on how [scientific] practices contribute to the accumulation of scientific knowledge" (NRC 2012, 78).

Limitations

While we believe our reflective activity was an effective tool for both students and instructors, its ability to assess students' views on NOS comes with limitations. Since the students were asked to describe their own views on NOS, they were less likely to discuss views they disagree with. Indeed, the only times in which such discussions occurred were when students were reflecting on their own past beliefs. As a consequence, our ability to identify instances in which students might disagree with themes discussed by their classmates was restricted. In addition, while the total number of responses on the different themes gives an idea as to how prevalent certain perceptions are, the voluntary nature of these responses means we cannot draw any firm conclusions with respect to how widely-held the beliefs are. Setting a minimum threshold for the number of students who discussed a theme, as we did, ensures that at least a portion of the class holds a similar view, but we cannot make any definitive statements about the proportion of students who share that view. These shortcomings do not detract from the benefits attained by the activity, nor the conclusions that we have drawn, although they do suggest that such an activity is not appropriate for all situations, and its success depends on the instructor's aims.

CONCLUSION

Responses to our reflection survey demonstrated several aspects of NOS that resonated most with students in Science One. These included the importance of interdisciplinary connections, social and cultural themes (communication, collaboration, societal influences), and the tentativeness of science. Many of the students' views could be directly linked to structural components of Science One. In addition to the programs' emphasis on interdisciplinary learning, elements such as the independent research projects, an extended visit to a research facility, and the inclusion of scientist guest lectures—on top of classroom discussions and activities—helped shape the students' views of the nature of science. Self-reflection itself may play a role in the development of these views, as the weekly activity provided the students an opportunity to reflect on a topic important to the program's overall philosophy, but that was not assessed in any formal manner. The degree to which the act of self-reflection might influence students' views of NOS, however, cannot be determined from our work, and is a potential avenue for future studies. As demonstrated through our experiences, students' perceptions of science were enriched through the incorporation of metacognitive reflection activities that encouraged students to think deeply about material that extends beyond examinable learning objectives.

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