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Developing Connections Between Integrated Laboratory Practices and First-Year Undergraduate Nature of Science (NOS) Understanding

Margery A. Gardner[a]

[a]Colgate University, New-York, USA

ABSTRACT

This study featured findings from a three-year National Science Foundation (NSF) funded research project at a STEM focused college. 'Project Synapse' was developed to build relevance between disciplines through authentic collaborations between biology and chemistry content. Integrated science practices were explicitly addressed during investigations of interdisciplinary topics such as microscopy and redox reactions. This study focused on the impact of one integrated laboratory-based intervention on student nature of science (NOS) understanding. Using a previously validated survey, Views on Nature of Science (VNOS), student NOS knowledge was assessed at the beginning and end of the academic school year. Structured interviews were conducted to gather a more in-depth understanding of student thinking. Additional qualitative data sets included participant observations of labs, interviews with in instructors, and focus groups with students. Project Synapse students performed better on both the pre and post assessments of NOS understanding. At the close of the academic year, Project Synapse students scored higher in the domains of inference and theoretical entities in science and nature of scientific theories as compared to students not exposed to the model. Students in both the control and experimental group struggled to discriminate between theories and laws or provide specific examples. his integrated model offered a more authentic look at the actual practices of science through investigations that extended beyond a single subject area. Findings suggest that this collaborative instructional model may provide greater opportunities to address NOS content throughout the school year.

KEYWORDS
science teaching, integrated STEM education, Nature of Science (NOS), curriculum development, higher education

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Introduction

Zeidler and Kahn (2014) define functional scientific literacy as the capacity to apply scientific reasoning to real-life situations through conducting of research, weighting ethical ramifications of decisions, and deliberation given

CORRESPONDENCE Margery A. Gardner mgardner@colgate.edu

that evidence is tentative in nature. Nature of science (NOS) is a critical element in science learning because it contextualizes the processes of science through a socio-cultural lens. NOS was defined as "the epistemology and sociology of science, science as a way of knowing, or the values and beliefs inherent to scientific knowledge and its development" (Lederman, 1992; Lederman, Abd El-Khalick, Bell, and Schwartz, 2002, p. 498). NOS addresses the values and assumptions that is part of the process of scientific discovery. The strengths and limitations of science must be well articulated in schools in order to expose students to the authentic work of scientists.

While the science education community has long reached consensus that NOS principles are a critical component to science teaching; they are often overlooked when science curriculum is enacted. Many teachers do not fully understand the utility of NOS principles nor have the capacity to develop content-embedded student experiences. This trend is found in science teaching in both secondary and higher education. McComas and Olson (1998) investigated the degree to which NOS was integrated into standards of eight countries including the US. The research team found that subjectivity and creativity in science were topics not broached in any of the standards studied. Furthermore, some NOS related aspects were referenced but without adequate definitions. Sardag, Aydin, Kalender, Tortumlu, Ciftci, and Perihanoglu (2014) conducted a similar document analysis investigation using Turkish curricular materials for secondary science disciplines. The number of NOS objectives for biology, chemistry, and physics ranged from three to nine percent of the overall. Creativity, subjectivity and socio-cultural embeddedness of science were completely devoid in the curricular documents investigated by the team. Lack of NOS priority in standards and curriculum attributes to a trend of stagnation in student understanding of the actual practices of science.

A plethora of naïve understandings regarding the generation of science knowledge continue to be perpetuated within our current system of education. McComas (1998) identified fifteen common science myths that still pervade science teaching. The notion that laws and theories are hierarchical in nature and that 'the' scientific method is a linear process are two such common misunderstandings. The work of Ryan and Aikenhead (1992) further substantiated McComas' findings through direct investigations of student misconceptions of NOS principles.

The crux of the matter is that at all levels science teaching and textbooks emphasize the factual recall of science content to the near total exclusion of the knowledge-generation process. Science teachers rarely have opportunities to learn how science functions in their own studies and, not surprisingly, fail to emphasize that aspect of science to their students (McComas, 1998, p. 4).

Among these misconceptions, is the common myth that science is a solitary endeavor (Harwood, 2004; McComas, 2002). Harwood (2004) outlines a new model of inquiry that places questions at the center with non-linear paths to additional elements such as observing, determining the known, and communicating with others.

Throughout the course of an inquiry, scientists communicate with peers in their lab and colleagues elsewhere. Many inquiries involve collaborative efforts of good scientists. Good communication among them is an essential feature of inquiry. When a study is completed, the last activity will be formal communication through oral or written presentations (p. 31).

Conceptual Change as Theoretical Frame

The framework that was adopted as part of this study is rooted in conceptual change.

The conceptual change model posits that new information is assimilated and eventually accommodated given direct engagement with content. Posner, Strike, Hewson, and Gertzog, (1982) in their seminal work describe four conditions that must be fulfilled in order for conceptual change to occur: (1) dissatisfaction with existing conceptions, (2) a new conception must be intelligible, (3) a new conception must appear at least initially plausible, (4) a new concept should suggest the possibility of a fruitful research program (pg. 214). Student learning opportunities that provide sufficient levels of cognitive dissonance are necessary to achieve accommodation. The conceptual change framework is well suited for this study considering its primary focus centers on student ability to internalize and apply NOS principles.

Purpose and Research Questions

The purpose of this case study was to explore NOS understanding for first-year undergraduate science majors at a STEM focused doctoral accrediting institution. Participants were divided into two groups; the treatment was exposed to an interdisciplinary model of instruction while the control underwent a more conventional first-year science experience. The study sought to compare the results between the two student groups as a way to assess the effectiveness of integrated instruction to convey NOS principles. NOS understanding was evaluated using a standardized open-ended survey instrument. Student understanding was based on their ability to provide responses that align with contemporary views on the following NOS aspects: empirical nature of scientific knowledge, inference and theoretical entities in science, nature of scientific theories, scientific theories versus laws, creativity in science, subjectivity in science, and social and cultural influences.

The research question central to the investigation was: How is NOS understanding affected by integrated knowledge-based laboratory experiences for first-year biology and chemistry majors?

Project Synapse

This study centered on an integrated curriculum and teaching model that was developed directly by the biology and chemistry laboratory instructors, Jim and Nick, in an effort to build relevance across these disciplines. At the time of the study, the university required that all science majors take a year-long chemistry and biology course with laboratory components. The instructors encountered student resistance with many biology majors not viewing chemistry as critical to their studies and vice versa. Based on student feedback, the instructors sought to create an integrated curriculum that explicitly demonstrates connections between biology and chemistry in the laboratory setting. The primary vehicle to address this student need was through biological field investigations that involved chemistry-based analysis. In addition to integrated biology and chemistry laboratory experiences, the model also included a science communication component. Science communication coursework focused on technical writing skills and public presentations to a wide array of audiences. The goals of Synapse were three-fold: (1) Improve student understanding of the interconnectedness of biology and chemistry, (2) Elevate interest and attitudes towards both science disciplines, and (3) Equip students with necessary laboratory and writing skills that are required for advanced coursework.

> *Jim (biology laboratory instructor): We realized that there were opportunities to integrate some activities to try to give students some experiences that would be enriching for them and try to build some interest and build some, context as to why they are learning skills and content in the two different disciplines (Interview, 10-20-2014).*

Three integrated investigations were developed and enacted by, Jim, biology lab instructor, and Nick, chemistry lab instructor. In the first few weeks of school, students explored differences in herbaceous plant life in primary and secondary forests. Students were encouraged to develop their own methodological process and complete soil analyses. In subsequent inquiries, students learned about photosynthesis and chemical energy transformations, and analyzed pigments using paper chromatography and resin columns as part of a larger understanding of plant spectra absorption patterns. Students are taught communication skills that range from laboratory report writing to public speaking. As part of the English course, students read and discuss texts that relate to the socio-cultural elements of scientific discovery. Students are asked to challenge their notions of objectivity through assigned readings, panel discussions with experts, and debriefing sessions that emulate peer review. All three instructors are involved in collaborative planning and execution of learning objectives.

The Synapse project was selected as a case study for this research because of its attention to interdisciplinary connection. This model intersects with NOS principles due to its emphasis on authentic practices of science and collaborative spirit. The Synapse model of instruction forges explicit bonds between the work of biologists and chemists while highlighting the need for various forms of communication in both fields of study.

Study participants: Instructors

The instructors featured in this study both were in their fifth year of teaching at the institution at the start of the study in 2014. As part of their role, both supervise multiple laboratory sections and coordinate several teaching assistants. Nick received his Ph.D. in 2005 and completed postdoctoral research on fuel cell and solid-state chemistry before accepting his current position. As an undergraduate he minored in education and completed a student teaching placement. He currently is very active in university sponsored community outreach programs. He conducts on-going professional development for science teachers in renewable energies.

STEM education for me started as a student in that I really enjoyed science and learning about science, and really just wanted to continue to I guess, give back and share back that how I learned it with other people, being that science is where I found my focus, the education came to me in the sciences (Nick, interview, 10-22-2014).

Jim has a background in environmental science and forest ecology and worked for an education and lobbying group that focused on the Clean Water Act and waste management reforms. His research interests centered on the influence of forest management on biodiversity.

He conducted granted-funded research for the institution prior to accepting his current position as introductory biology laboratory instructor. He was responsible for advising both graduate and doctoral students at the university. When asked about his teaching philosophy he said, "At every opportunity, I try to teach in a way that the material, that content and process is revealed to students by their observations" (Jim, Interview, 10-20-2014).

Study participants: Students

Students were selected from a freshman class at a doctoral granting public state institution that offers specialized science majors in the United States. Eligibility for participation was based on declared major. Only students that declared biology, chemistry, or environmental science as incoming freshman were considered. Students in these majors are required to take both biology and chemistry for both semesters in their first year of study as an undergraduate. Therefore, the instructors could gather a sense of student understanding over the course of an entire academic year (See Table 1).

Table 1. Student participants

Name	Gender	Group	Major
Alison	Female	Synapse	Biotechnology
Alana	Female	Synapse	Environmental biology
Anne	Female	Synapse	Environmental science
Billy	Male	Synapse	Environmental biology
Dave	Male	Synapse	Conservation biology
Erin	Female	Synapse	Environmental biology
Harry	Male	Synapse	Conservation biology
Kevin	Male	Synapse	Wildlife science
Tyler	Male	Synapse	Biotechnology
Deb	Female	Non-Synapse	Environmental biology
Diane	Female	Non-Synapse	Forest ecosystem science
Jade	Female	Non-Synapse	Chemistry
Logan	Male	Non-Synapse	Chemistry
Rachel	Female	Non-Synapse	Aquatics and fisheries science
Renee	Female	Non-Synapse	Construction management
Rick	Male	Non-Synapse	Wildlife science
Sylvia	Female	Non-Synapse	Conservation biology
Tim	Male	Non-Synapse	

Researcher role

I became involved in this study during the third and final year of the implementation phase. While familiar with the institution and it's programming, I had no direct role in the project design, development or evaluation. The instructors provided access to students and agreed to be interviewed for the project but were not involved in the data analysis phase. At the time of the study, I was a Ph. D. student in science education from another institution in the Northeast. In an effort to maintain consistency in pre and post assessment evaluation, I analyzed all data sets.

Methods

Instrumentation

This study employed the Views of Nature of Science (VNOS) survey created by Lederman et al. (2002). The VNOS was selected because its content had been previous validated. Furthermore, other science education researchers have used the VNOS survey or variations of it and therefore comparisons could be potentially formulated based on other's work. VNOS Form B was selected as the pre-assessment and post assessment based on its well-established construct validity. The survey is open ended in nature with seven questions and took students roughly twenty to sixty minutes to complete. The survey uncovered student understanding in the following domains: (1) Empirical nature of science knowledge, (2) Inference and theoretical entities in science, (3) Nature of scientific theories, (4) Scientific theories vs. laws, (5) Creativity in science, (6) Subjectivity in science, and (7) Social and cultural influences. Each domain contained a range of one to five clarifying indicators that were used for coding purposes. For instance in Domain 1, empirical nature of scientific knowledge, an example of one indicator was that evidence "supports rather than proves scientific claims."

During the structured interview process, students were asked to re-read their original answers, and justify their responses including examples. Students were asked to complete the survey at the very beginning of the school year in August and once again in April of their second semester. I wanted to specifically investigate patterns of thinking and how they changed over time based on their newfound scientific knowledge.

Data analysis

The classification system outlined by Lederman et al. (2002) divided student NOS understanding into two major categories: naïve and informed responses. For the purposes of this study, I adopted a similar rating system. For each domain, Lederman et al. (2002) reported target responses that were subsequently used to rate student understanding as either unclear, naïve, or informed. Informed responses are defined in the following terms, "If a respondent provides a response consistent across the entire questionnaire that is wholly congruent with the target response for a given aspect" (Lederman et. al, 2014, p. 80). Naïve responses were contradictory to the accepted response or offered no supporting evidence for the claims that they made.

Based on written survey results and structured interviews, I classified each participant's responses as either unclear, naïve, mixed, or informed. I compared student responses directly with the Lederman et al.'s (2002) target responses. I then calculated a percentage of informed responses both treatment and control groups. All interviews were transcribed verbatim and codes were then identified and applied across data sets. Major themes were then extracted form data as well as extended memos that were also produced during the process.

Student sampling

The pre-assessment was administered to all general chemistry students during the second week of the course. Students enrolled in the Synapse cohort for the academic school year of 2014-2015 were considered the treatment group while students concurrently enrolled in chemistry and biology but were not randomly selected to participate in the Synapse project were considered the control. Follow-up individual interviews were conducted throughout the month of September 2014 with a purposely-selected sample of students that reflected a diversity in levels of understanding. I coded each completed student response as either “naïve”, “mixed”, or “informed”. I then selected at random three students from each category to personally interview. These students also participated in the post-test assessment in the spring semester. Purposeful selection was conducted in order to get a range of beliefs associated with the NOS, from “naïve” to “informed”. The number of students selected as participants in the post assessment closely aligns with numbers reported in Lederman et al.’s (2002) original work.

Additional qualitative methods

In order to better understand how this integrated laboratory model functioned in real-time, I also gathered additional data sets in the form of participant observations, Synapse student focus groups, and instructor interviews. These findings provide a more holistic view of each participant in the Synapse class that serves to contextualize their responses from the VNOS survey. The additional data sets served to triangulate information retrieved from the VNOS survey and follow-up interviews. Synapse students also participated in an entrance and exit focus group that sought to explore their experiences with the integrated learning modules and the overall utility in the collaborative model.

Results

Pre-assessment analysis

As to be expected from first year undergraduate students with limited previous exposure to NOS principles, both groups had relatively low overall scores, ~29%, as compared to Lederman et al.’s (2002) survey results of both novices and experts who received 33% and 89% respectively (pg. 506). In the first NOS domain, empirical nature of scientific knowledge, many students conveyed the naïve conception that knowledge is absolute until proven otherwise. In domain 3, the indicator ‘theories change with new evidence’ reported a nearly 100% informed agreement by both groups. Dave was the only student whose beliefs did not align with this understanding. Highest scores were found in the NOS domain relating to the nature of scientific theories. Students in both groups agreed with the sentiment that theories change based on new evidence at a level 68% in the Synapse group and 85% in the control group. Student responses tended to center around the generation of new knowledge and not on the new ways of looking at existing evidence. Another area of general confusion between both groups was in the NOS aspect of theories versus laws. As a whole, students were unable to consistently provide examples of either a law or a theory and lacked operational definitions for each. Classic textbook examples, such as the theory of evolution and the law of conservation of energy were offered with only superficial explanations of their purpose. Students often referred to laws as absolutes while theories as more subject to change. Both groups scored the similarly in the NOS domain that featured creativity in science. There was a consensus of both groups that science does possess creative elements.

Since interviews were conducted during the month of September, there was some exposure to NOS principles. During general chemistry and biology lectures, students were provided with historical background of relevant scientific theories. As part of their communications course, Synapse students were also privy to NOS related readings and panel discussions that added to their understanding of the subjective nature in which scientific practices are conducted. A single student from the Synapse group gave mention to the peer review system. At the time of the interview, Synapse group engaged in a mock peer review process for their first formal integrated lab report. The Synapse group received a 67% versus 22% in the control in the area 'theories are well substantiated.' Overall, the pre-assessment found that the Synapse group scored seven percent higher than their non-Synapse counterparts (See Table 2).

Table 2. Pre-assessment results of student NOS knowledge

NOS domain	Number of informed views			
	Synapse group *n (N=9)	Synapse group %	Control group *n (N=9)	Control group %
Domain 1: Empirical nature of scientific knowledge				
-Observations used to make scientific claims	4	(67%)	2	(22%)
-Science does not rely solely on empirical evidence	0	(0%)	1	(11%)
-Supports rather than proves scientific claims	2	(22%)	0	(0%)
Domain 2: Inference and theoretical entities in science				
-Inferential nature of atomic models	1	(11%)	2	(22%)
Domain 3: Nature of scientific theories				
-Theories change due to new evidence	8	(89%)	9	(100%)
-Theories change due to new ways of looking at existing evidence	0	(0%)	0	(0%)
-Explanatory power of scientific theories	2	(22%)	2	(22%)
-Theories are well-substantiated	6	(67%)	2	(22%)
-Theories provide a framework for current knowledge and future investigations	2	(22%)	2	(22%)
Domain 4: Scientific theories vs. laws				
-Nonhierarchical relationship	1	(11%)	0	(0%)
-Laws may change	0	(0%)	0	(0%)
Domain 5: Creativity in science				
-Creativity permeates scientific processes	4	(44%)	4	(44%)
-No single scientific method	1	(11%)	0	(0%)

Domain 6: Subjectivity in science (theory-ladenness)				
-Differences in data interpretation	6	(67%)	6	(67%)
-Science is necessarily a mixture of objective and subjective components	3	(33%)	3	(33%)
Domain 7: Social and cultural influences				
-Science as a culture within itself	3	(33%)	1	(11%)
-Peer review limits subjectivity	1	(5%)	0	(0%)
-Society as an influence on science	3	(33%)	1	(11%)
Overall	46	(28%)	35	(21%)

Post-assessment analysis

Domain 1: Empirical nature of scientific knowledge

There were negative gains made involving the indicator 'observations are used to make scientific claims' indicator reported negative gains in understanding for the Synapse group. The Non-Synapse percentage for this indicator improved but the students responding as informed changed from the pre-assessment. Deb and Tim did not offer an informed response for this section, Jade, Sylvia, and Diane did. There were modest gains in the additional categories in both treatment and control groups. Billy and Sylvia were the only two participants to change from naïve to informed in categories that initially had zero ideal responses.

Domain 2: Inference and theoretical entities in science

This area was found to have drastic increases in student understanding as compared to the fall pre-assessment results. In the Synapse group only one participant, Erin, mentioned the 'inferential nature of atomic models' whereas in the post assessment only Kevin did not possess an informed belief in this domain. The Non-Synapse group also had substantial gains in this area, with a majority of students aligning their opinions with an ideal informed response. Sylvia had an initial informed response, but did not respond in the same manner during the post assessment.

Domain 3: Nature of scientific theories

For the indicator, 'theories change with new evidence', all respondents from both groups had an informed response. This was the highest reported percentage of any of the indicators investigated as part of this study. Understanding of the 'explanatory power of theories' increased slightly in both groups, but with different respondents comprising the informed views section. Only Billy from Synapse acknowledged the fact that 'theories can change due to new ways of looking at existing information'. There was a substantial discrepancy in the responses for 'theories provide a framework for current knowledge and future investigations' category among Synapse and Non-Synapse students. More than half of the respondents in the Synapse group possessed informed responses, while only a single student in the Non-Synapse expressed an informed response. This is a visible divergence from the pre-assessment survey data where each group had two informed responses.

Domain 4: Scientific theories versus laws

A majority of students from both the Synapse and Non-Synapse group gave naïve responses when asked to explain differences between theories and laws. The only growth reported was found in the indicator 'laws can change', where two students from the Non-Synapse group responded with an informed view on the subject.

Domain 5: Subjectivity in science (theory-ladenness)

For both categories, increases in understanding were documented for both Synapse and Non-Synapse students. A majority of Synapse students reported that data can be interpreted in multiple ways. Only two of the nine students in the Non-Synapse group disagreed with this view. While both groups increased their understanding of objective and subjective components of science, the Non-Synapse group had a greater percentage of informed responses for this indicator.

Domain 6: Social and cultural influences

In the post-assessment, the Non-Synapse group was able to raise its percentage of understanding to the initial level of the Synapse students from the fall. The Synapse students continued to develop their understanding of the social and cultural milieus that affect the construction of scientific knowledge. Three Synapse students and one Non-Synapse directly referenced peer review as a means to reduce subjectivity in science. Synapse students used the term 'scientific community' with much more frequency in the post assessment. Overall, each group showed a significant improvement in their overall NOS understanding. Representative responses are provided for each domain in Table 3. The Synapse group initially scored higher in the VNOS assessment and demonstrated consistent growth (see Table 4).

Table 3. Illustrative examples of responses from post-assessment

NOS Aspect	More Naïve Views	More Informed Views
Empirical nature of scientific knowledge	[Data] Um, it's something that happens in nature. It is something that happens in the environment and happens consistently. Not all data has to be consistent but good data generally is. (Alana, Synapse)	Science is made up of the observations and ideas of others, even if it isn't set in stone like some may want. By saying it's a theory, we can always come back and change if it we realize something isn't quite right as we teach it. (Sylvia, Non-Synapse)
Inference and theoretical entities in science	I think it looks just like a dot but I don't think the scientists actually know what it looks like because they can't actually see it. For them its like the smallest thing basically its just like a little dot but it really could be like, anything. No one actually knows. (Renee, Non-Synapse)	If it [atom] were to be shown in a textbook it would be a really bad graphic because the nucleus is so much smaller than it is actually shown. I read somewhere if the nucleus were the sun, comparable to our solar system, the electrons would have to be as far away as Venus maybe, so you couldn't really show that in a textbook. (Billy,

		Synapse)
Nature of scientific theories	Scientific theory is science that is still trying to be explained and reviewed and proven correct. (Rachel, Non-Synapse)	We tend to teach theories because they represent our understanding of what we know in that moment. While that knowledge can be changed and updated, to change it scientists must be aware of what is the current belief and how to build off of it. (Alison, Synapse)
Scientific theories versus laws	Scientific law is something that has been proven and it has reasoning behind it, where scientific theory is a guess or a thought that hasn't been proven yet. (Renee, Non-Synapse)	Nothing is really proven in science so someone could turn around and question a law. (Rick, Non-Synapse)
Creativity in science	Some creativity might be needed in setting up an experiment, a procedure that can give you the data you are looking for. However once you have that data, you have to take back your creativity and feeling about what should happen and report on what did. (Tim, Non-Synapse)	Scientists must be able to interpret and look at a trend seen in data and view it in a new light. Other scientists preforming a similar trial before may have seen the same trend but cannot truly see the information in the same application as others. It is about perspective and exploring ideas original to each individual. (Rick, Non-Synapse)
Subjectivity in science	Mainly, like on facts you read in a textbook so, I can't find much room for bias in something. That is the way it has been for so long. (Dave, Synapse)	Scientists have to be careful with the presentation of their data to ensure they are not biasing the audience (Alison, Synapse)
Social and culture influences	Scientific knowledge could have two sides but like there always is a right side (Renee, Non-Synapse)	I definitely think culture impacts how they think, just think about women in science, many women had ideas that would have progressed science, I can't even imagine what would have happened if you let the other half of the population into the science world that we are still excluding them from. (Sylvia, Non-Synapse)

Table 4. Comparison of post-assessment results across groups

NOS domain	**Percentage of informed views** Synapse group pre (%)	Synapse group post (%)	Control group pre (%)	Control group post (%)

Domain 1: Empirical nature of scientific knowledge				
-Observations used to make scientific claims	67	22	22	33
-Science does not rely solely on empirical evidence	0	11	11	33
-Supports rather than proves scientific claims	22	44	0	11
Domain 2: Inference and theoretical entities in science				
-Inferential nature of atomic models	11	89	22	56
Domain 3: Nature of scientific theories				
-Theories change due to new evidence	89	100	100	100
-Theories change due to new ways of looking at existing evidence	0	11	0	0
-Explanatory power of scientific theories	22	33	22	11
-Theories are well-substantiated	67	44	22	44
-Theories provide a framework for current knowledge and future investigations	22	56	22	11
Domain 4: Scientific theories vs. laws				
-Nonhierarchical relationship	11	11	0	0
-Laws may change	0	0	0	22
Domain 5: Creativity in science				
-Creativity permeates scientific processes	44	67	44	67
-No single scientific method	11	78	0	89
Domain 6: Subjectivity in science (theory-ladenness)				
-Differences in data interpretation	67	100	67	78
-Science is necessarily a mixture of objective and subjective components	33	44	33	67
Domain 7: Social and cultural influences				
-Science as a culture within itself	33	56	11	33
-Peer review limits subjectivity	5	33	0	11
-Society as an influence on science	33	22	11	33
Overall	28	46	21	38

The Synapse integrated model

Rich collaborations between instructors were captured during periods of participant observation. During all three observations both the biology and chemistry instructor were present and clearly identified areas of crossover between disciplines. During a lesson on microscopy headed by the chemistry instructor the following interaction occurred. This discussion centers on an encounter with a particular plant during a field exploration at a nearby forest.

> Nick: I don't remember the name but when you get it on your hands it becomes painful and scratchy?
>
> Jim: Jack in the Pulpit.
>
> Nick: The pain comes from Calcium Oxalate. The surface structure is the root cause, a physical interaction where the compounds almost get trapped.

Nick then launches into a explanation of asbestos and its how is fibrous physical structure is so damaging to your lungs when inhaled.

> Nick: You see it's all about the surface.

This last sentence reinforces the connection to scanning electron microscopy. (Classroom observation, 9-18-14).

During instructor interviews, both instructors spoke of the positive impact this integrated instructional model has had on their practice.

> Jim: …answers to all of my questions as an ecologist are usually found in chemistry when you boil it right down. You've always gotta visit with a chemist. So, I'm learning chemistry again, I really am. And, and sometimes the way I approach the class is 'what do I need to do to learn the chemistry myself in order to teach the chemistry to my biology students, in order to apply the chemistry to my biology students. (Interview, 10-20-14)
>
> Nick: …working together with peers, especially in different disciplines, not in a research sense I guess but in, an educational curriculum development has been very different to learn why we are teaching in different ways for different reasons, so that has been very interesting plus I have taken writing courses and biology courses in the past, so I am learning content myself as a faculty member I've, I put on my chemistry hat or Jim will put on his biology hat and chime in on something that I wouldn't have even known about, or he wouldn't have known about or we could link it together in parallel structure in a writing project. (Interview, 10-22-14)

NOS in the Synapse laboratory

NOS aspects were found to be explicitly addressed as part of the laboratory instruction. While introducing a lesson on fungi reproduction the following dialogue was recorded:

> Jim: Is it JUST a theory? My point is it JUST the theory of endosymbiosis? No, it's supported by a large amount of evidence. (Classroom observation, 9-30-14)

In the VNOS post interview with Alana, she specifically cites the endosymbiotic theory as example of the creativity within the design and development of scientific knowledge. Her response below provides evidence for the use and application of NOS principles explicitly taught as part of the course.

> Alana: I forget her name, Lynn Margulis? She was the one that came up with endosymbiosis. She had to use creativity when she came up with that. Nobody around her was, there was no, real like, there probably weren't any whispers around, 'this is how this happens.' She had to go a

> little bit in the opposite direction to figure it out. I think that is creative. (Interview, 4-15-15)

Writing, communication, and NOS connections

The following excerpts were collected during a focus group conducted on April 28th, 2015. Students reflected on their experiences in the writing and communication courses as part of their Synapse coursework.

> Katie: Peer reviews, we did that a lot.

> Researcher: I was going to ask you about that. What did you like about peer reviews?

> Katie: Um, there were like, I found it, like, super helpful to peer review someone else's lab report in your section to see what approach they took. And like, how could improve yours (Focus group, 4-28-15).

> Alison: I feel like it [writing course] was really helpful that we did, like, APA format and topics that we covered and what we were expected to understand and that we looked at rhetoric of lab reports instead of just rhetoric in sciences (Focus group, 4-28-15),

> Harry: I was gonna ask like, why not learn about the implications of how science is communicated on the public and how the public views science? I think more like a media studies route would be more interesting, I don't know. That's just me (Focus group, 4-28-15).

Discussion

The Synapse group increased their NOS understanding by a substantial margin, an 18% improvement from the fall pre-assessment. The overall NOS understanding of the Synapse group was determined to be slightly greater than the Non-Synapse students. These results suggest that the Synapse model was successful at deepening student NOS understanding through the integration of chemistry, biology, and science communication. Based on evidence gathered as part of this study, increasing relevance of introductory science concepts improves NOS student understanding. Since the focus of the learning model was on building connections between disciplines, there is little likelihood that students simply memorized and recalled NOS ideal responses from their coursework.

Student exposure to NOS principles as part of the model began very early in the semester and was cultivated over multiple investigations. It is possible that laboratory instructors infused NOS principles early on in the beginning of their course. During the field investigation of primary and secondary forests, the students were given an opportunity to formulate a unique experimental design and carryout appropriate analyses. As a result, Synapse students learned through first-hand experiences the subjective process of data collection as well as differences in data interpretation.

The lecture portions of the biology and chemistry courses also covered the historical development of atomic models as well as the history of evolutionary discovery. During the year of this study, Nick taught both the chemistry lab and lecture, and therefore may have reinforced the lecture content in the laboratory explaining the high initial Synapse scores in Domain 3: Nature of scientific theories.

There was a marked improvement in student NOS understanding in the Non-Synapse group as well. While student proficiency was lower at the onset, Non-Synapse students also increased NOS understanding over the course of the two semesters. Students at all levels, from both groups improved, even those with a more nuanced view of the NOS aspects at the start of the study. The most rapid areas of growth were identified in the following domains: 'inferential nature of atomic models', 'nature of scientific theories', 'creativity in science', and 'subjectivity in science'. There were far fewer gains reported in 'scientific theories versus laws'. I speculate that further increases in NOS understanding among Synapse students may occur if additional integrated laboratory experiences are included. In this model, students were engaged in three primary interdisciplinary labs, two in the fall and one in the spring semester. Through greater contact with integrated curriculum and instruction, students will be able to engage more intimately in authentic science practices. Further exposure to integrated learning experiences can lend itself more aptly to explicit NOS instruction.

One major limitation of the study was that the control students may have had different laboratory instructors than Nick and Jim. While the laboratory curriculum was standardized, this change in instructor could account for differences in the VNOS results.

Conclusion

Student understanding of NOS principles hinge largely on teacher knowledge and exposure to NOS teaching approaches. Three primary approaches to teaching NOS have emerged: implicit, historical, explicit-reflective. Implicit approaches assume that students will uptake NOS principles through direct exposure to scientific investigations. There is no overt attempt made by the teacher to explain the NOS connection with the learning activity under this mode of instruction. The historical approach highlights the progression of scientific discovery through specific examples in history such as the development of atomic theory. The explicit-reflective approach involves scientific experimentation as well as open NOS-related discussions. Explicit-reflective models can either feature content-generic activities that do not have direct connections to the current concepts taught in class or content-embedded components that juxtapose NOS and subject-specific content. Of the three approaches, explicit-reflective is the most robust in its ability to convey NOS aspects to students. Content-embedded activities demonstrate the greatest potential for student internalization of NOS principles (Sardag et al., 2014).

Often teachers have had inadequate preparations in explicit-reflective NOS instructional practices that are content-embedded in nature (Sardag, et al. & Perihanoglu, 2014). In this study, both science instructors interviewed welcomed professional development that would assist them in the integration of NOS practices into their laboratory instruction. "Teaching science as inquiry and explicitly teaching about NOS are complex and sophisticated instructional approaches that demand significant PD" (Capps & Crawford, 2013, pg. 524). NOS teaching can be considered "craft knowledge" that involves deep and on-going refinement through active practice and reflection of beliefs (Capps & Crawford, 2013).

While participant observation comprised only a modest amount of this particular study, its contribution is worthy of further in-depth exploration. Student survey and structured interview responses provided insights into student thinking while classroom observations yielded data on how students actively process NOS related information and apply it within the laboratory context. The degree of transfer of NOS knowledge may be gleaned from the type and frequency of questions posed by students. Robust student questions tended to spur further discussion of a concept that benefitted the entire community of learners. This study necessitates the need for further investigation on the impact of teacher-student questioning interactions on NOS understanding. Expansion of similar methodologies to new contexts and settings could glean multi-dimensional findings.

The students of this study can be viewed as products, not only of higher education, but also of their collective K-13 science education. In secondary science, their level of exposure to the practices of sciences varied greatly from individual to individual. Inquiry-based experiences ranged from lengthy independent research investigations to sanitized recipe lab 'experiments'. "Lack of a professional language that defines and communicates the categories of activity that students should experience-that is a workable classification of educational practice-undermines the professional practice of teaching science" (Osbourne, 2014, p. 178). With inquiry often perceived as 'hands-on' learning opportunities, science is portrayed in schools as purely experimentation based thus deemphasizing the role of theory in the construction of knowledge. "The outcome is that too many students fail to see that it is really theories that are the 'crowning glory of science'" (Harre, 1984, Osbourne, 2014, p. 182). Results from this study support this sentiment; many naïve NOS beliefs centered on theories, both their definition and function.

A science major's first-year coursework experience is influential as they begin to formulate an academic focus. By focusing on student NOS understanding at this formative period, students will be better prepared for more challenging future coursework. By creating a sound NOS foundation, students can forge long-lasting conceptual frameworks that can extend from schooling to career. This study found that a first-year integrated laboratory-based learning model improved student NOS understandings of science. Further investigation of this mode of instruction and its relation to NOS teaching warrants future exploration in order to fully ascertain its value. Multi-disciplinary models of instruction should be considered as a means to combat naïve NOS conceptions due to their authentic depiction of scientific processes.

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Notes on contributors

Margery A. Gardner, Director of Teacher Preparation, Colgate University, New-York, USA.

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