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Undergraduate research experiences in biology: Roles of mentors and impacts of early exposure and types of engagement on student outcomes

Kelly Marie Schmid
Syracuse University

Abstract

Within the sciences, it is important to provide all students access to undergraduate research experiences and mentoring relationships that are beneficial to their learning and success. As such, this research investigates the following aims: (1) Develop a seminar-style course for 1st and 2nd year biology undergraduate students that involves reading and discussion of primary scientific literature, writing about science, and engaging with researchers within the department. (2) Assess how an introduction to biological research course, that does not include explicit nature of science (NOS) instruction, affects students' nature of science understanding. (3) Assess how faculty lab-based research experiences (FLRE), course-based research experiences (CURE), and a research seminar course effect students' self-efficacy, research skills, and future goals, as well as how these experiences differ in their effect on students in these areas. (4) Assess the different mentor-mentee relationships that exist within an undergraduate students' FLRE and the roles of each of these mentors within the experience, as well as differences in science identity of the students engaged in this experience.

Results from this research suggest that engaging novice students in a research seminar course increases their NOS understanding, self-efficacy, and desire to pursue research post-graduation. We also found that FLREs and some CUREs increase students' skills formulating hypotheses and designing experiments. Results also suggest that students engaging in FLREs largely consider the lab member who spends the most amount of time directly supervising them to be their primary mentor, and these are most often non-faculty post-graduates. Finally, among students engaging in FLREs, men students were more likely to identify as scientists and women students were less likely to identify as such. Together, these results highlight the importance of undergraduate research experiences and mentoring for student success in the sciences.

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Kelly M. Schmid

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Introduction

Discipline-based education research (DBER) is a field of study that investigates teaching and learning of science content and is situated within the scholarly community of the content discipline. More specifically, biology education research (BER) is a field of study grounded in biological content knowledge that investigates the teaching and learning of biology using a variety of methods within the context of the professional biological community (National Research Council 2012, Chapter 3). According to National Research Council (2012, Chapter 3) BER is believed to have emerged at the beginning of the twentieth century, primarily aimed toward investigating the differences in student learning between types of course design (lecture + demonstration vs. labs) and how students learn (conceptualize vs. memorization, collaborative vs. individual). While such investigation has proven to be very important, there was initial resistance on the part of science faculty to recognize its value, and it took several years to develop an infrastructure for dissemination of this research (National Research Council 2012, Chapter 3). Over the past ten years in particular, the field of BER has experienced substantial growth. Areas of study within the field have grown to include learning surrounding specific areas of biology, such as climate change and evolution, as well as continued investigation into course design and outcomes, and students' learning.

BER is considered to be a subfield of biology, and, while some institutions have lagged behind their peers, many life-science departments recognize and value it as such (National Research Council 2012, Chapter 3). While earlier research in this field sometimes did not involve complex analyses or quantitative investigation, BER has more recently shifted towards a more rigorously quantitative field supplemented with systematic qualitative techniques and well-developed, complex analyses and approaches to investigating research questions. Like the science disciplines in which they are situated, DBER has grown to be an interdisciplinary field with researchers work in collaboration across institutions and publish results in a growing number of peer-reviewed journals including many of the same journals in which their colleagues in the sciences they support have traditionally published. Ultimately, continuing the growth of BER programs within existing biology departments will aid in the understanding of course outcomes and learning outcomes, provide results that may help to inform teaching, and help to provide information upon which advising and program progression may be scaffolded.

The biology education research presented in this dissertation was conducted within a biology department and utilized quantitative and qualitative approaches. With a broad interest in active learning and a specific goal to better understand the effects of different undergraduate research experiences and mentoring, this research highlights the beneficial outcomes of these experiences and relationships. As science departments continue to shift towards a more active classroom environment, and as they will benefit from informing their efforts in training apprentice scientists with systematically collected and rigorously analyzed data, this research will contribute to the evidence supporting this type of teaching and learning.

At colleges and universities nationwide, there has been a recent push from lecture based courses towards a more active classroom environment where students are engaging in course material, rather than passively listening (Deslauriers *et al*., 2019; Freeman *et al.*, 2014; Gormally *et al.*, 2009). This shift has been especially important within the sciences wherein such active learning techniques have shown to increase student learning, as well as increase equity and inclusion within the classroom (Ballen *et al.*, 2017; Cooper *et a*l., 2019; Deslauriers *et al*., 2019; Haak *et al.*, 2011a). While a wide range of active-learning techniques and tools exist, we are especially interested in undergraduate research experiences and mentoring, and ways to prepare students for engagement in these experiences.

Broadly, there are two types of undergraduate research experiences. The most common and “authentic” (i.e. students are engaging in novel, collaborative research) is one in which students are engaging in faculty lab-based research experiences (FLRE). The second is where students are engaging in a course-based undergraduate research experience (CURE). While such experiences have been shown to positively affect students’ self-efficacy, science communication skills, and future goals (Carpi *et al.*, 2017; Gardner *et al.*, 2015; Thiry *et al.*, 2012), we were interested to see how these outcomes differed between courses in a single biology department.

One important aspect to an undergraduate research experience, especially FLREs, is mentoring. Quality mentor-mentee relationships and having role models can have many beneficial effects on students, including increasing their feelings of inclusion into the scientific community and their desire to pursue research in the future (Carpi *et al*., 2017; Herrmann *et al.*, 2016; Morales *et al.*, 2018). While the literature has largely focused on the effects of quality mentorship as previously mentioned, we are interested in who students perceive to be their mentors in their FLRE and the role that those mentors play in their experience. Furthermore, previous research has suggested that increased science identity is one important outcome of an FLRE (Dolan & Johnson, 2010; Estrada *et al*., 2018). We are interested in whether this is the case in our population of students and, more specifically when they have or will perceive themselves to be scientists.

While engaging in an undergraduate research experience is beneficial for students in many ways, courses designed around engaging students in the primary literature have shown to be beneficial for students in developing key skills in reading the literature and communicating about science (Aoh, 2018; Brownell, *et al.*, 2013; Colabroy, 2011; Carter & Wiles, 2017; Gottesman & Hoskins, 2013; Halbisen & Ralston, 2017; Hoskins, *et al*., 2007; Sandefur & Gordy, 2016). Such courses vary in the ways in which they are implemented; however all have similar goals surrounding student engagement with the literature. We are interested in such courses as a way to engage first and second year students in developing key skills, such as reading the literature, and key outcomes, such as self-efficacy and nature of science (NOS) understanding, to better prepare them for research experiences that will be available to them as they progress through university.

This research addresses four aims toward investigating the effects of undergraduate research experiences and an introduction to research seminar course on students' self-efficacy, research skills, NOS understanding, and future goals, as well as the role that mentoring plays in certain undergraduate research experiences. Chapter one addresses the following aim: Develop a seminar-style course for first and second year biology undergraduate students that involves reading and discussion of primary scientific literature, writing about science, and engaging with researchers within the department. Here we provide a detailed description of the course that we designed, as well as provide all the necessary materials for implementing this course. Students in this course participated in surveys and assessments for subsequent aims, therefore this course played a significant role in this research. This chapter has been peer-reviewed and published in the *Journal of College Science Teaching* (Schmid & Wiles, 2019).

Chapter two addresses the following aim: Assess how an introduction to biological research course, that does not include explicit nature of science instruction, affects students' nature of science (NOS) understanding. Here we represent results from a qualitative study where students enrolled in the seminar course previously mentioned were asked to answer a series of four open-ended questions from the VNOS-C at the beginning and end of the course. Student responses to these questions were qualitatively analyzed and coded. We discuss the ways in which students' NOS understanding changed and in what areas they remained the same. This chapter has been accepted for publication in the *Journal of College Science Teaching*.

Chapter three addresses the following aim: Assess how faculty lab-based research experiences (FLRE), course-based research experiences (CURE), and a research seminar course effect students' self-efficacy, research skills, and future goals, as well as how these experiences differ in their effect on students in these areas. Here we present results surrounding changes in the aforementioned factors from pre to post experience using validated surveys and assessments that utilize quantitative and qualitative methods. This chapter has been accepted for presentation at the 2020 International Conference of the National Association for Research in Science Teaching (NARST). Papers proposed for presentation at NARST are submitted as full research reports (not mere abstracts) which are double-blind peer reviewed.

Chapter four addresses the following aim: Assess the different mentor-mentee relationships that exist within an undergraduate students' FLRE and the roles of each of these mentors within the experience, as well as differences in science identity of the students engaged in this experience. Using a qualitative approach, we present results surrounding who students engaging in FLREs consider to be their mentors and the roles that each mentor plays in the students' experience. We also present results concerning differences in science identity between women and men students engaged in an FLRE. This chapter has been proposed for presentation at the 2020 annual meeting of the Society for the Advancement of Biology Education Research (SABER).

Chapter 1. An Introduction to Biological Research course for undergraduate biology students

Kelly M. Schmid and Jason R. Wiles

1.1 Abstract

Undergraduate research experiences have been shown to be extremely beneficial for students, as have preparatory experiences that help students to develop scientific reading, writing, and communication skills prior to engaging in research. Here we describe an introduction to a biological research seminar course that we designed for first-year university students. Our aim was to give students a broad introduction to biological research and the nature of science through reading and discussion of primary scientific literature, writing about science, and engaging with the scientists who performed the research. An additional goal was to make students aware of the various research programs of faculty members in our department toward better matching of students with potential faculty research mentors. Student feedback indicated that this course helped them to feel more confident in reading and writing scientifically. By giving novice students experience and training in reading and communicating about science in this course, we are able to better prepare them for upper division seminar courses as well as course-based and laboratory or field-based undergraduate research experiences.

1.2 Introduction

A great deal of research-based evidence has led to a growing trend of transitioning from traditional lecture to active learning in university-level science, technology, engineering, and mathematics (STEM) courses (Freeman *et al*., 2014; Gormally *et al*., 2009). There are many active learning strategies that can be implemented in STEM classrooms, the most authentic being undergraduate research experiences (Lopatto, 2007). Such experiences have been shown to be extremely beneficial to undergraduates. While research experiences are the most authentic and beneficial, it has been suggested that participation in another type of course might be beneficial to undergraduates prior to participating in an undergraduate research experience. The National Academy of Sciences suggests an introductory course on reviewing scientific literature as a precursor to a research experience (National Academies of Sciences, 2017). These are courses in which students read the primary scientific literature, discuss it, and write scientifically (Brownell *et al*., 2013). Such courses are ways for students to develop key skills in reading scientific literature and communicating about science early in their career. Students are thereby better prepared to enter into an undergraduate research experience, understanding their participation in context. Courses of this nature have also been shown to help facilitate student transitions into a graduate program (Kozeracki *et al.,* 2006).

An introductory course on reviewing scientific literature can be designed in many ways. Such courses have been implemented at various universities with success (Brownell *et al*., 2013; Colabroy, 2011; Gottesman & Hoskins, 2013; Halbisen & Ralston, 2017; Hoskins et al., 2007; Sandefur & Gordy, 2016). While they all include practice in reading and writing scientifically, they differ in other ways. Brownell *et al.* (2013) designed such a course, but also included practice in different types of science writing (e.g. writing for the non-scientist public in *New York Times* style). Sandefur and Gordy (2016) designed their course as a journal club rather than a seminar style course. (Hsu *et al*., 2016) implemented a course that was led by graduate students and post-doctoral researchers. Each of these courses were intended to help improve students' science literacy and communication skills, but each successfully approached these goals in different ways.

Based on the experiences of other researchers and educators described in prior literature, we designed a seminar-style course for first-year biology students that engaged them in the reading of primary research articles. We incorporated writing assignments and class discussions to help improve students' abilities in writing about and otherwise communicating science to others – critical skills for scientists. Unlike most courses described in prior literature, we also incorporated student interaction with the scientists who performed the research to foster a better understanding of what biological research actually entails. This addition also serves to introduce students to active research programs at our university so that, should they become interested, they will be better informed about the breadth of opportunities available and better able to identify a faculty mentor for a research experience that closely matches their interests.

1.3 Our course and students

This course, titled "Introduction to Biological Research," was a seminar-style course designed for no more than 15 students per section, which mirrors the format of upper division seminar courses in our department. It was offered during the spring semester at a large, research intensive university in the northeastern United States. The first author of this article, a Ph.D. candidate in biology, was the instructor for the course under the supervision of the second author, a faculty member in the same department. Students were recruited for the course from a population of first and second year students with majors in biology or biology-related fields who had completed the general introductory course for life science majors during the previous semester. (Table 1.1; Table 1.2).

There were no prerequisites for the course. However, students had taken the general biology course required for biology majors in the immediately preceding semester, and most were simultaneously enrolled in the second semester of the general biology sequence. The 2-credit elective course met once per week for two hours for the entire 15 week semester. It was held in a small classroom with individual desks that we regularly arranged in a circle to promote discussion.

1.4 Course materials and assignments

The course activities were designed by the first author. The course began with general instruction for the first two weeks. This consisted of an overview of the course syllabus and course goals, which were as follows: (1) To give a broad introduction to biological research. (2) To learn what research is and what types of research are being done at the university. (3) To gain skills in reading, writing, and discussing science. (4) To learn more about topics in biology and the scientific process. Additionally, there was a discussion of the different types of science writing. The students were given examples of science writing for the general public as well as for other scientists, in the form of a *New York Times* article and the associated primary research article. The similarities and differences of these two types of writing were addressed in a small group and whole class discussions. Literature review articles were presented as another type of scholarly writing, but this was reserved for later in the course as students were preparing to write their own review papers. Students were coached in techniques for reading scientific articles. The suggested method centered on identifying important information in each section of a paper and interpreting figures to further understand the findings before summarizing the research and why it was important. Finally, the course assignment outlines, rubrics, and expectation were discussed. The relative weights of different course components toward students' grades are shown in Table 1.3. With active participation and contribution to discussion accounting for a substantial portion of the students' grades, students were expected to come to class prepared to engage in the small group and whole class discussion, ask relevant questions, and think critically about the topic with their peers.

After the first two weeks of class, the next nine weeks consisted of student presentations of assigned primary research articles, with the first week being an example presentation given by the instructor. To develop key scientific reading and writing skills, for each of these weeks, the students who were not presenting were charged with reading the assigned primary research article and coming to class prepared to discuss it. Employing the model of Brownell *et al.* (2013) in a similar course, students in our course wrote summaries of the assigned papers in the style of the *New York Times* (i.e. for a general, non-science audience) (Appendix 2). This included a title, brief background, overview of the problem, the research questions, brief description of how the research was performed, the main findings, and the bigger picture of the research and its importance in context. Summaries were not to exceed one single-spaced page, and students were to bring a paper copy of their work with them to use as a reference in class and to turn in for grading. Over the course of the semester, each student read nine primary research articles and wrote summaries for eight of them.

To give students a better understanding of what research entails and the types of biological research being done in the department, each student engaged with the members of faculty research labs and gave a presentation on their experiences (Appendix 3; Appendix 4). Students were allowed to work either independently or in pairs. At the beginning of the semester, students chose from a list of eight research labs in the biology department whose faculty leaders had agreed to participate in our course. These labs were equally representative of the Ecology and Evolution and Cell and Molecular divisions of our department. For the lab that they chose, students were assigned to meet with the faculty Principle Investigator (P.I.) of the lab, at least one graduate student, and one undergraduate student to ask them questions about the lab and their research. Students were given a list of example questions for each type of lab member (P.I., graduate student, and undergraduate student) (Appendix 5), and they were encouraged to ask additional questions of their own. The students also toured the labs to observe the facilities and typical research activities.

Our students each gave 10-15 minute PowerPoint presentations about the lab that they visited to their classmates, addressing the questions they asked during the researcher interviews and describing the lab environment they encountered during their tours. There were opportunities for their peers to ask follow-up questions at the end of each presentation. The class then discussed the assigned primary research article produced by the lab that had been presented. Students were asked to print out a copy of this paper to use during class, rather than use an electronic copy. To promote student involvement and discussion, students were first given the opportunity to discuss the paper in small groups before coming together for a whole-class discussion about the paper and its findings. Students who presented on a faculty member's lab took the lead in facilitating the class discussion of the paper from that lab, with some assistance from the instructor when needed. The students who were not presenting were assigned to write *New York Times* style summaries of the paper, to which they could refer during discussion of the paper. These were turned in to the instructor at the conclusion of that day's class.

Once the nine weeks of presentations concluded, students were instructed on the nature and importance of scientific literature reviews, who they are written for, and how to write one. They were given examples of literature reviews to read and discuss, and reviews were compared and contrasted with the different types of science writing they had learned about throughout the semester. Students were instructed on how to properly cite scientific literature and about the nature of plagiarism and how to avoid it. For their final assignment, each student chose a biological topic (either from among the topics discussed in prior class sessions, or not) about which to write a brief literature review (Appendix 6; Appendix 7). The brief literature review was to be two single-spaced pages in length and cite at least four primary research articles. Students engaged in a peer review session during one of the final course meetings to give them the opportunity to give and receive constructive feedback toward improvement of their papers. During this session, each student read their partner's paper and were asked to identify at least five things the author did well and five things the author could improve. At the completion of the review session, the students were given a week to edit their papers prior to turning them in at the final class meeting. The papers were submitted both as a paper copy and through Turnitin.com to check for plagiarism.

1.5 Conclusions

At the completion of this Introduction to Biological Research course, students were asked to anonymously take an online course evaluation reflecting on their experience. Students unanimously reported that they did not feel confident reading the primary literature or writing about science at the beginning of the course, however they reported an improvement in these skills by the end of the course. Many students also reported that they felt more confident discussion science after taking the course. Furthermore, students reported an increased interest in pursuing future undergraduate research opportunities after taking the class. Typical student comments on the course overall included:

“I really enjoyed this course because it allowed me to further learn about topics that I was interested in, but had little knowledge about. This course broadened my knowledge about different fields in biology and inspired me to pursue an alternate major in the field. I enjoyed being able to meet with people who work in the labs, because I could see the application of a biology degree in a job setting. I had never really thought about the process that goes behind writing a research article, so being able to go “behind the scene” in a sense and see and talk to the actual people writing these articles was really eye-opening.”

“My overall experience in this course was positive. Learning how to interpret more complex styles of scientific writing and managing to write my own personal summaries in a more widely understandable text is certainly very beneficial to me, especially for the type of research-based experiences I plan on pursuing in the future.”

“I really enjoyed taking this course; I've learned a lot - not only science related, but becoming better at reading comprehension and writing. This course will for sure help me in the future since I do plan on major in one of the many science fields, whether being reading/ understanding scientific research articles or writing summaries/ papers of what I've read in relation to science.”

These student reviews suggest that, for these students, this course successfully met the goals outlined and helped students to gain confidence in their ability to read the primary literature and communicate science to scientists and non-scientists alike, two key skills for scientists to develop. Additionally, we were able to provide students with insight into what it means to do scientific research and what types of research are being done at their university.

We are encouraged by the apparent success of this course, and would like to offer such an experience to a larger number of first year students. As is the case in many colleges and universities, our first-year introductory biology courses are very large indeed. While this type of intensive experience may not be easily applicable to large lecture-style sections, it would be feasible to implement as part of the smaller laboratory or recitation components of these courses. We envision that the activities described herein could be implemented as a team-based learning exercise wherein student groups of four (the usual number of students collaborating in our existing lab assignments) visited one of our faculty research laboratories and presented a representative research paper in their lab or recitation section. Other students in the section could read the articles ahead of class and write *New York Times* style summaries as part of their regular pre-lab or pre-recitation assignments. Developing students' confidence and abilities in these areas early in their academic career is especially important so that they may be better prepared to engage in future research experiences.

1.6 Tables and Figures

Table 1.1. Breakdown of the represented majors enrolled in the course

Student's declared major	Number of students
Biology	6
Unspecified major: Pre-med track	2
Undeclared	2
Forensic Science	1
Health and Exercise Science	1
Psychology	1
Earth Science	1
Communications Design (with the intent to switch to Biology)	1

Table 1.2. Break down of enrolled students year and gender (n=15)

First-year students	Second-year students	Female	Male
11	4	10	5

Table 1.3. Activity and assignments completed in the course and how each contributes to the overall course grade.

Activity or Assignment	Percentage of grade
Participation (small group and large group)	30%
Weekly paper summary	20%
Presentation and leading discussion	25%
Brief literature review	25%

Chapter 2. Early exposure to primary literature and interactions with scientists influences novice students' views on the nature of science

Kelly M. Schmid, Ryan D.P. Dunk, Jason R. Wiles

2.1 Abstract

Instructors in undergraduate science programs often hope to help students better understand the processes of science by exposing students to research reports in the scientific literature. Even without explicit Nature of Science (NOS) instruction, undergraduate students in seminar courses focused on reading and discussion of primary research literature will encounter some of the major elements of NOS. This study is a phenomenological, qualitative exploration the effects of an Introduction to Primary Literature course (see Chapter 1) on novice undergraduate students' (n=12) views on NOS. The course was rooted in the primary literature and interactions with scientists, and did not include explicit NOS instruction. Student responses to questions from the VNOS-C administered before and after the course suggest that that participation in this course shifted students' perceptions in three areas: from the idea that science is universal to the idea that science is influenced by society and culture; in their self-definition of science – from a linear process to a broader, more naturalistic field; and in what areas of science they indicated were creative – from experimental design only to also including interpretation and communication of results. Students, however, did not improve in their understandings of the nature of theories, a key NOS concept. Results from this suggest that participation in a course that engages students in reading the primary literature and interacting with scientists allow novice students to experience shifts in their NOS understandings of the tools and products of science and the human elements of science, but are not likely to develop their conceptions of other elements of NOS without more targeted instruction.

2.2 Introduction

Experiential science courses, such as Course-based Undergraduate Research Experiences (CUREs), are growing in popularity as evidence-based ways to enhance students' scientific engagement, mastery of science skills, and content knowledge. In contrast to traditional lecture courses, experiential courses provide students with opportunities to read and discuss the primary literature, engage with scientists, and gain socially-constructed insight into the processes of science (Brownell & Kloser, 2015; Brownell *et al.*, 2015; Bangera & Brownell, 2014; Colabroy, 2011; Gormally *et al.*, 2009). Exposure to such experiences early in students' academic careers has also been shown to increase the probability of students' subsequent interest and enrollment in doctoral and other graduate programs in science (Kozeracki *et al.*, 2006; Hathaway *et al*., 2002). Students who take experiential courses tend to show improvement in critical scientific skills including their ability to design experiments and interpret data (Kloser *et al.*, 2013; Brownell *et al.*, 2015).

Additionally, these experiences have been shown to help develop students' understanding of the nature of science. Nature of science (NOS) is a term used to broadly describe a rich description of what science is, how it works, how scientists operate as a social group, and how society itself both directs and reacts to scientific endeavors (McComas *et al*., 1998, p.4). Studies have shown that developing student NOS understanding is an important outcome for students in experiential science courses. For example, Linn *et al.* (2015) named NOS development as a key outcome/opportunity of undergraduate research experiences. They outlined the development of students NOS views, specifically the processes of science, when encountering failure in the lab. However, despite the clear importance of students' NOS understanding, how to best increase such understanding remains an open question.

Research has shown that developing NOS understanding can be accomplished in various ways across a variety of course types. Experiential courses that involved a research-based laboratory were shown specifically to improve students' ideas about the process of science (Russell & Weaver, 2011; Szteinberg & Weaver, 2013; Seymour *et al.*, 2004; Ryder *et al.,* 1999). Russell and Weaver (2011) also found that student engagement in laboratory research contributes to the development of students' conceptions of theories and their ideas surrounding creativity in science. While students engaged in these experiences exhibit development in some areas of NOS understanding, such as the definition/process of science and an explanation of theories, most areas, like the influence of society and culture on science, remain unchanged (Szteinberg & Weaver, 2013; Ryder *et al.*,1999).

In this study, we focus on an Introduction to Primary Literature (IPL) course and measure changes in students' NOS conceptions across the semester. Although we did not design the course as a specific intervention for teaching NOS, we realized that exposure to primary literature and formal engagement with research scientists might elicit changes in NOS understanding without explicit NOS instruction. Introduction to Primary Literature (IPL) courses have been suggested as a precursor to experiential courses (National Academy of Sciences, 2017) and are designed around reading published scientific research, often with writing assignments (Sandefur & Gordy, 2016; Brownell *et al.*, 2013). IPL courses are primarily intended to increase students' confidence in reading and communicating science, and have been shown to be effective in doing so (Sandefur & Gordy, 2016; Brownell *et al.*, 2013; Hoskins *et al.*, 2007; Carter & Wiles, 2017.; Sloane & Wiles, 2020). However, while students in IPL courses would be expected to show improvement in their understandings of the process of science directly related to the primary literature (such as experimental design, representation and interpretation of data, and other processes of science; DebBurman, 2002; Hoskins *et al*., 2011; Levine, 2001; Smith, 2001), misconceptions about the non-linear ways in which science sometimes progresses may remain due to the way that primary research presents scientific inquiry as linear, omitting any meanderings, dead-ends, and negative results along the way.

There has been extensive research surrounding the development of NOS understanding in pre-service teachers. This extensive body of knowledge might help to conceptualize changes in NOS understanding in undergraduate science student populations in which NOS understanding is understudied. Explicit NOS instruction in addition to experiential learning has been shown to elicit significant development in NOS understanding in these student populations (Schwartz *et al.*, 2004; Akerson *et al.*, 2000). Pre-service teachers indicate that the reflective part of these courses, involving journaling and discussing their experiences with their peers, was the most influential to their development of NOS understanding. They also indicated that their inquiry experiences provides important context for their reflective activities (Schwartz *et al.*, 2004). Similarly, Abd-El-Khalick and Lederman (2000) found that programs with explicit NOS instruction, in addition to inquiry-based activities were the most successful in developing pre-service teachers' NOS understanding. However, Akerson *et al.* (2000) warn that there is potential conflict between the pre-course NOS understanding and specific NOS instruction, making designing and delivering such instruction a challenge.

Comparatively, undergraduate students in the sciences are an understudied population with regard to NOS conceptions and changes therein. Furthermore, how to best increase undergraduate science students' NOS understanding remains an open question. Here, we investigate the effects of an introduction to biological literature course on specific aspects of novice students' NOS understanding. Considering the major elements of NOS as construed by

McComas (2008, 2015), we presented students with representations of the “tools and products of science” through reading and discussion of primary research literature. Students engaged with the “human elements of science” through personal interactions with the biology faculty and their lab members who performed the research reported in assigned articles. This also involved student visits to research laboratories and conversations with scientists at various points in their careers including undergraduate researchers, graduate students, post-doctoral fellows, technicians, and tenured and tenure-track faculty of all ranks.

2.3 Methods

Participants and the course

This research was approved by IRB protocol #17-249 (Appendix 1). All participation by students was voluntary and they were not given any compensation for their participation. Participants in this study were undergraduate students in either their first (n=11) or second (n=4) year, enrolled in a seminar-style introduction to biological literature course at a large, research-intensive university (Carnegie R1 designation) in the northeastern United States. Participants in this course were majoring either in biology or a field related to biology (exercise science, psychology/neuroscience, etc.). This course ran during the spring semester and met once a week for two hours. There were no formal prerequisites listed for the course, however all students had taken at least one semester of general biology for majors. Students read and discussed one primary research article per week, first in small groups and then as a class. Students also wrote a short summary of each primary research article using the *New York Times* science page as a guide toward style (as in Brownell *et al.*, 2013).

Each week, a different research lab in the biology department was featured for discussion. Each student chose a different lab to visit from among those who had volunteered to participate. During their lab visits, the students met with lab members across different experience levels (postdoctoral, graduate student, technicians, and undergraduate researchers). Students also interviewed the labs' principle investigators (PIs) to gain additional insight into the labs' long-term goals. After their visits, students consulted with the PIs to choose one paper for the class discussion. In class, the students gave a presentation detailing the lab of their choice before leading discussion on the paper. In addition, students wrote a brief literature review about a biological topic of their choice. Readers seeking additional course details considered outside the scope of this paper should be aware a more detailed description of this course has been recently published (Schmid & Wiles, 2019).

The stated goals for this course were: (i) to give students a broad introduction to biological research, (ii) to help them learn more about what types of research are being done at the university, (iii) to help students gain skills in reading, writing, and discussing science, and (iv) to learn more about particular topics in biology. It is important for the purpose of this study to note that this course included no specific instruction on nature of science, nor was it designed specifically to change students' NOS conceptions

Assessment and analysis

To assess potential changes in nature of science understanding, we used four questions (Table 2.1) from the View of Nature of Science Questionnaire–C (VNOS–C; Lederman *et al.*, 2002). Specifically, we chose questions that we expected might change based on the course experiences and matched aspects of the nature of science that we have previously measured in our student population (Dunk & Wiles, 2018). Students were asked to answer each of the four questions at the beginning of the course (during the first class meeting) and at the end of the course (during the second to last class meeting). Of the 15 enrolled students, three were either ineligible for participation in research or were missing post-course data, and thus all comparisons between the beginning and end of the course had a sample size of 12.

Following the completion of the course, all student responses were scanned into PDF documents and read by each of the first two authors of this manuscript. Responses were independently coded by each researcher using a constant comparative method (Glaser, 2008). Following this, the two coders met via teleconference and compared codes until consensus was reached. The authors then combined codes into themes. Themes were analyzed between the beginning and end of the semester to determine if the frequency and/or makeup of themes changed throughout the semester.

2.4 Results

Self-definition of science. At the beginning of the semester, when students were asked "what is science?" they responded uniformly in terms of science as being process oriented. Students described how science is "a constant process of theorizing, hypothesizing, and experimenting" and how it is done "by asking questions, conducting experiments, and theorizing different hypotheses." Students also discussed the idea of science being *testable* and *repeatable*, noting, for example, that science involves "a hypothesis that can be supported or refuted through repeated experiments" and that "science is testable and those tests are repeatable." At the end of the semester, when students were asked the same question, their responses included similar themes, but also noted that science is *naturalistic*. They wrote that science is the "study of things in real life" and involves "observing actual things." They also discussed how scientists work to "discover more about the natural world."

Science as a creative process. When students were asked about the role creativity plays in science at the beginning of the semester, they uniformly responded that creativity exists in experimental design. They stated that "without creativity, all experiments would be the same" and "questions are not straightforward to answer, so scientists must be creative when figuring out how to answer them." Another student summarized their thoughts saying thusly, "the experiments that they thought were going to work or give them good results might not. Therefore, they might have to create new experiments that they haven't done before." At the end of the semester, when asked the same question, students uniformly maintained that science is a creative process and that the creativity lies in the experimental design. However, some students added that there is creativity in the interpretation of results, stating that the "results of experiments are open to interpretation." They also discussed how conveying the findings of research require creativity: "it takes creativity to make results interesting and applicable to others" and "scientists DO use their imagination and creativity… for writing."

Science is universal or influenced by society and culture. At the beginning of the semester, when asked the third question (Table 1), "is science universal or social and cultural?" the majority of students indicated that science is universal and not influenced by society and culture (Table 2.2). These students defended their statements with assertions that scientific methods and results are universal. When discussing the idea of scientific methods being universal, students stated that "data will not change when tested under different cultural settings" and that ideas and questions "can be retested anywhere given consistent conditions." One student also discussed how science "deals with things that are the same over the entire world, like atoms and elements and mammals” and, therefore, is universal. When discussing the idea of scientific results being universal, students stated that “science and experiments can be repeated many times” and that “anywhere you are conducting an experiment, as long as the materials are kept constant, you will most likely gain the same result.”

Students also indicated that science is universal because of the multi- or cross-culturalism of science. When discussing this reason, students stated that “scientific theories go under many review processes including replication and peer review by people all over the world” and that “scientists from all different backgrounds collaborate together for research.” For the students that maintained that science is universal from pre- to post-course, there was little change in their responses.

In contrast, those students that indicated that science is influenced by society and culture stated that social and/or cultural context may influence science in two main areas: the research agenda, and the interpretation and reception of results. When explaining how society and culture influence research agendas, these students stated that “the way scientists come up with experiments, or why they test what they can do, can be a reflection of our society.” One student offered, “People study/test certain things because of personal desires and sometimes those desires can skew results.” Students also identified ways that society and culture influence the interpretation and reception of the results, noting that “different values in culture affect how we view the same issues” and “maybe science’s results are not themselves political, but the way results are used are.”

Finally, when discussing the influence of society and culture on science, students talked about the idea of social controversy. They explained how “some choose not to accept concepts due to their specific beliefs” and “people’s views tend to be more segregated, thus there is more controversy on scientific topics." One student offered evolution as an example, stating that some people "do not think evolution occurred due to their beliefs." The number of students that stated that science is influenced by society and culture increased from the beginning of the semester to the end of the semester, with the majority indicating that they now believe that science is influenced by society and culture (Table 2.2). The common themes remained the same from pre- to post-course; however, students increasingly talked about the idea of social controversy and mentioned scientific topics like evolution, vaccination, etc. as being influenced by culture.

Scientific theories. At the beginning of the semester, when asked whether or not theories change (Table 2.1), all but one student responded affirmatively (Table 2.3). This changed little by the end of the semester, and students' rational for why theories change also remained very similar pre- to post-course. Students' descriptions for theories changing included the introduction of new evidence/information, new technology, and the idea that theories are falsifiable.

When discussing the introduction of new evidence/information, students stated that theories change "when new evidence is presented through experiments that contradict or disprove the first theory" and that "there is a very high possibility of new information or corrections that could occur." Students also discussed how "it is possible when new technology is available that new research could disprove a theory" and that "as technology improves, new evidence is found to alter and improve these theories." When discussing the idea that theories are falsifiable, students stated that "as we discover more and learn more in science, maybe past theories do not link up or connect with our current knowledge" and that "new information could be discovered at any time and may change a theory in some way." In line with this, we noted that some students almost conceptualized theories as fragile (i.e adding to a theory is changing a theory). Students suggested that "scientific theories are always changing depending on new evidence that is being discovered with every new experiment" and that "it only takes one of those experiments to be contradicted and the theory now change(s) as well."

2.5 Discussion

Coding of students' responses indicated that students experienced the most changes from pre- to post-course on their perceptions of what science is and whether it is universal or influenced by society and culture (Table 2.2). There was no direct NOS instruction within the course; therefore, although we cannot eliminate experiences and lessons learned in other courses, we argue that these changes were, at least in part, a result of students' experiences within the course, including reading primary literature and interaction with research lab members in the department.

At the beginning of the semester, when asked to explain "what is science?" students talked about the specific processes of science. They discussed things such as hypotheses and conducting experiments. These are specific identifiable parts of science, often tied to ideas such as the "scientific method." At the end of the semester when asked the same question, however, students responded with much broader ideas, such as making observations about the natural world and then formulating questions. This suggested that their ideas of science shifted from a narrow, defined, process-driven idea to a much broader and encompassing field of study. These changes may have been influenced by various parts of the course, perhaps especially the students' reading of research across the breadth of biology and discussions with faculty and research lab members employing diverse methods. By interacting with faculty and lab members, students may have able to gain a better understanding of how projects are done and what research looks like on a day to day basis. This could help to deconstruct their ideas surrounding the linear process of science that they may have previously been taught and help to better facilitate a better understanding of scientific research within the context of a research team and science as a field. Developing an understanding of the process of science in novice students could eventually aid in the development of more mature epistemological beliefs, something that Hoskins *et al.* (2011) found to be an important outcome of a similar course for more senior students.

When comparing pre- and post-course responses to the question regarding science as a creative process, students uniformly indicated that coming up with questions and designing experiments requires creativity. While this remained the same from pre- to post-course, after the course students also included ideas about how analyzing and interpreting data requires creativity. This addition might be the result of reading primary literature and being exposed to a variety of ways of visually conveying data within the literature. The interpretation of figures and tables was a large portion of class discussion on a daily basis and might have been a contributing factor to this outcome. There was also significant discussion about the "what's next?" for each primary article read. This opportunity to think creatively to come up with new research questions and experiments may have also been a contributing factor to this outcome. Hoskins *et al.* (2011) has reported that such opportunities are important in shifting students' views on science as a creative process, and may develop students' interest in science careers.

At the beginning of the semester, when asked to explain whether science is universal or influenced by society and culture, the majority of students indicated that science is universal (Table 2.2). When asked the same question at the end of the semester, the majority of students wrote that science is influenced by society and culture. This shift in thinking could be due to the classroom discussions surrounding primary literature as well as interaction with faculty and their lab members. By interacting with faculty and lab members, students were able to see how the questions they were reading about in the primary literature are pursued. Additionally, by reading primary literature authored by researchers in the department, they were able to make the connection between the lab and the authors. Reading the literature and discussing it, coupled with interacting with researchers in the department, might have allowed students to see science as a human endeavor (Hoskins *et al.*, 2011), and these experiences combined might have contributed to this shift.

There was little change in student responses pre- to post-course regarding if theories change. At the beginning of the semester, all but one student responded that theories do change; only one student shifted their answer from yes to no post-course (Table 2.3). Theories were not discussed in this course and therefore, any misconceptions that students had upon entering the course were likely not remediated through the use of the primary literature and interactions with researchers. More direct instruction surrounding theories, however, may better facilitate student understanding.

Of particular note is that students initially held conceptions of theories as being “fragile”, and their understandings of the durability of science did not appear to change over the course of the semester. And this illustrates a key weakness of our instructional model. While we did not specifically intend the course to be oriented toward improving students’ NOS conceptions, it certainly was an opportunity to do so. Figure 2.1 (reproduced with permission from (McComas, 2015) illustrates the major elements of NOS for science instruction. Our approach indirectly emphasized the “Tools and Products of Science” (through the reading and discussion of the primary literature) and the “Human Elements of Science” (through interaction with scientists), but without any direct NOS instruction on the nature of theories and largely scanting the limits of science.

This qualitative study suggests that, even without explicit NOS instruction, participation in a course that includes reading the primary literature and inviting students to learn more about biology labs allows students to experience shifts in their NOS understanding. This suggests that any changes in students' NOS understanding come from the course experience, such as reading and discussing the primary literature or interacting with faculty and the members of their labs. But we have also learned that intentional, direct NOS instruction may be necessary for our students to develop a more complete understanding of science.

2.6 Acknowledgments

We express our gratitude to the undergraduate students at the participating institution for taking part in this research. We also thank the Biology Department at the participating institution. Kelly Schmid and Ryan Dunk were supported by a Howard Hughes Medical Institute (HHMI) Inclusive Excellence Grant and a Syracuse University Summer Dissertation Fellowship.

2.7 Author contributions

Kelly Schmid designed and taught the seminar course, administered the VNOS-C, and wrote the initial draft on the manuscript. Ryan Dunk chose the specific VNOS-C questions that were given to students and contributed significantly to the writing and editing of the manuscript. Kelly Schmid and Ryan Dunk contributed equally to data analysis.

2.8 Tables and Figures

Table 2.1. Four questions chosen from the VNOS–C (Lederman *et al*., 2002) that were administered to students at the beginning and end of the course.

1	What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
2	Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations? •If yes, then at which stages of the investigations do you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate. •If you believe scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.
3	Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced. •If you believe that science reflects social and cultural values, explain why. Defend your answer with examples. •If you believe that science is universal, explain why. Defend your answer with examples.
4	After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? •If you believe that scientific theories do not change, explain why. Defend your answer with examples. •If you believe that scientific theories do change: (a) explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

Table 2.2. Number of student responses to question three, indicating if science is influenced by society and culture or if it is universal.

	Society and Culture	**Universal**
Pre-course	4	7
Post-course	9	3

Table 2.3. Student responses to question four, indicating if scientific theories change.

	Yes	**No**
Pre-course	10	1
Post-course	9	2

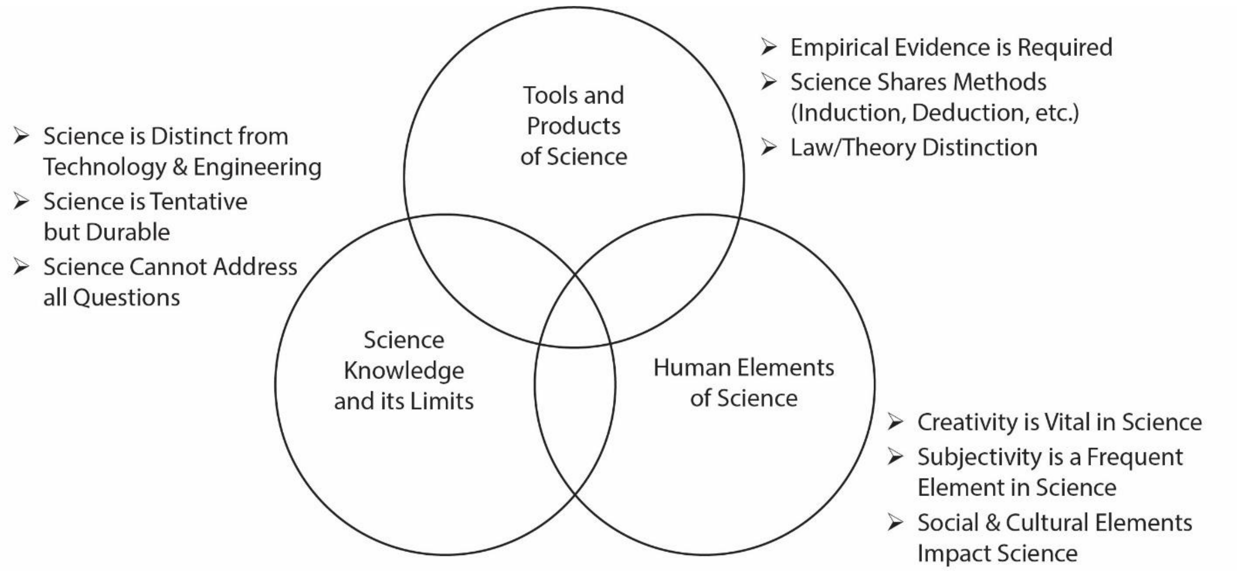

Figure 2.1. The major elements of NOS for science instruction. Redrawn with permission from McComas (2015).

Chapter 3. Different approaches for engaging undergraduates in research: Differential impacts on students' self-efficacy, science research skills, and future goals

Kelly M. Schmid, Sarah E. Hall, and Jason R. Wiles

3.1 Abstract

Several approaches toward engaging undergraduates in scientific research are common at colleges and universities, including undergraduate research experiences based in faculty laboratories, course-based undergraduate research experiences (CUREs) and types, and courses rooted in primary research literature that may be precursors to research experiences. We examined the outcomes for students enrolled in faculty laboratory research experiences (FLREs, n=12), CUREs (n=20), and a literature-based introduction to research seminar course (n=12) within an integrated biology program. Students engaging with research that involved authentic, student-centered inquiry had significant increases in research skills, but exhibited little change in their self-efficacy. Students engaging with research in a more structured or guided experience did not exhibit the same shift. Additionally, students enrolled in the research seminar course increased in their self-efficacy. Across all types of engagements, students who reported a change in their future goals post-graduation tended to add working toward a Ph.D. to their future plans. This was most evident in the seminar course, where the highest percentage of students experienced this shift. We therefore recommend an introduction to research seminar course for novice students toward building self-efficacy early in their undergraduate careers as a way to prepare for and potentially increase engagement in CUREs and FLREs, and possibly as a way to match undergraduates with potential mentors for future research experiences.

3.2 Introduction

There has been a growing movement to incorporate active learning into science courses in place of the traditional lecture format. Active learning has been shown to improve student performance in such courses (Deslauriers *et al*., 2019; Freeman *et al*., 2014; Gormally *et al.*, 2009), as well as increase recruitment and retention in the sciences (Cooper *et al*., 2019; Haak *et al*., 2011; Lopatto, 2007). While active learning has been shown to benefit all learners, it is especially beneficial to underrepresented minority learners, and therefore increase diversity and inclusion within science courses (Ballen *et al*., 2017; Bangera & Brownell, 2014; Espinosa *et al.*, 2019; Haak *et al.*, 2011; Lopatto, 2007). Such studies have helped to promote the initiative to implement active learning in undergraduate science courses (Olson & Riordan, 2012; Schneider *et al.*, 2015; Wyckoff, 2001) Undergraduate research experiences are among the most impactful active learning strategies (Lopatto, 2007). Participation in undergraduate research has shown to improve science self-efficacy (or one's confidence in their abilities regarding science), science identity, research skills, science communication skills, and future goals of undergraduates in science fields (Carpi *et al*., 2017; Gardner *et al*., 2015; Seymour *et al.*, 2004; Thiry *et al*., 2012). Such engagement includes students participating in faculty lab research experiences (FLRE) and course-based undergraduate research experiences (CURE). These experiences each provide students with the opportunity to improve professional and personal factors, like self-efficacy and research skills, and engage in science.

FLREs are considered to be the most authentic, research-based type of research engagement (Weaver *et al.*, 2008), as students have the opportunity to directly engaging in lab work and original research in a professional laboratory. In these experiences students are engaging in authentic inquiry, defined as students designing their own research project and collecting data for it. Students in FLREs may be working on their own research project or collaborating on other projects in the lab. With similar findings for both summer and regular-semester experiences (Gardner *et al.*, 2015; Marrero *et al.*, 2017), FLREs have been shown to increase self-efficacy and science identity (Adedokun *et al.*, 2013). Additionally, through working in the lab, students have reported an increase in their lab skills and inclusion into the science community (Gardner *et al.*, 2015; Hathaway *et al.*, 2002; Hunter *et al*., 2007; Linn *et al.*, 2015; Lopatto, 2004; Marrero *et al.*, 2017). Involvement in lab research has also resulted in student reposted increases in science communication skills and desire to pursue research in the future, either in their careers or graduate school (Hathaway *et al.*, 2002; Hippel *et al.*, 1998; Hunter *et al.*, 2007; Kardash, 2000; Linn *et al.*, 2015; Lopatto, 2007; Marrero *et al.*, 2017).They also promote positive faculty mentor-mentee relationships (Frantz *et al.*, 2017; Hippel *et al.*, 1998; Kardash, 2000). It has been shown that the longer a student remains in a lab, the higher their reported gains (Seymour *et al.*, 2004; Thiry & Laursen, 2011). These findings suggest that students benefit from multi-semester or multi-year lab research experiences. However, the main limitation to these experiences is their availability. There are only so many faculty mentors, so many labs, and so many spaces within each lab (Frantz *et al.*, 2017). These experiences also are often bias towards to higher achieving students and those that feel more comfortable approaching and speaking to faculty that are admitted into research labs (Cotten & Wilson, 2006; Gardner *et al.*, 2015). The broad goal to make science more inclusive cannot likely be entirely met at a university through these experiences given limitations to access.

An increasingly common way to provide research experience to a larger number and wider diversity of students is through CUREs, undergraduate courses that engage students in a research experience in the teaching laboratory or classroom at a higher capacity than FLREs.

These are courses that are open for student enrollment (and may even be required) in which students read the primary literature, independently formulate research questions, design experiments, collect and analyze data, and write scientifically (Brownell *et al*., 2015; Brownell *e*t *al.*, 2012; Brownell & Kloser, 2015; Corwin *et al*., 2015; Kloser *et al.*, 2013; McLaughlin *et al*., 2017). CUREs can vary in the type of inquiry that students are engaging in (Brownell & Kloser, 2015), from authentic inquiry where students are designing an independent research project to structured or guided inquiry where students are not necessarily coming up with an independent project but are still collecting and analyzing data and thinking critically about the overall project. These experiences have shown to elicit similar results to those of the FLRE, such that students report similar improvements in their self-efficacy, science identity, research skills, science communication skills, and future goals (Brownell *et al*., 2012; Brownell & Kloser, 2015; Colabroy, 2011; Harrison *et al.*, 2011; Kloser *et al*., 2013; Shortlidge *et al.*, 2016). Prior research suggests that CUREs may not only involve more students in a research experience, but also inspire more students to seek out future research experiences (Harrison *et al.*, 2011). However, as students generally spend less time engaged in research activities in CUREs, and often with less direct mentoring, such experiences can be limited in the research abilities that students may acquire (Frantz *et al.* 2017; Corwin *et al.*, 2015).

While the benefits of participating in an undergraduate research experience are well understood, how we can better channel students into these experiences remains an open question. The National Academies suggest an introductory course on reviewing scientific literature as a precursor to these experiences (National Academy of Sciences, 2017). These are courses where students are required to read the primary scientific literature, discuss it, and write scientifically (Brownell *et al.*, 2013). Such courses have shown to be beneficial precursors to FLREs and

CUREs; with students gaining a conceptual, if not practical, understanding of research through reading and discussing the primary scientific literature and learning to write scientifically (Brownell *et al.*, 2013). Developing such important scientific skills prior to entering a research experience has been shown to be particularly beneficial (Hoskins *et al.*, 2007; Hsu *et al.*, 2016). Participation in this type of course has shown to help students to learn how to effectively read the primary literature and discuss science not only with other scientists, but with the general public as well (Brownell *et al.*, 2013; Gormally *et al.*, 2009; Hoskins *et al.*, 2011; Sloane & Wiles, 2020). This type of course has also shown to improve students' ability to writing scientifically (Brownell *et al*., 2013; Colabroy, 2011; Gormally *et al*., 2009; Gottesman & Hoskins, 2013). While these courses do not provide students with the opportunity to directly engage in hands-on research, they provide students with an important foundation to build upon in future research experiences. Some educators have employed research literature selected from faculty in their local departments as a method for helping students identify potential mentors for FLREs (Schmid & Wiles, 2019). However, how such courses might impact novice students in particular is still not well understood.

It is important to assess the effectiveness of various types of undergraduate research engagement on the improvement of students' self-efficacy and research skills in order to inform and support implementation and improvement of such experiences. Engaging in these experiences can help students in science fields graduate with a clear understanding of what it means to do science and enter the next phase of their career or education as more confident and competent scientists. Multiple studies have shown the importance of these experiences at the undergraduate level (Ballen *et al*., 2018; Brownell & Kloser, 2015; Hoskins *et al*., 2007; Shortlidge *et al.*, 2016) however, few (Auchincloss *et al.*, 2014; Brownell *et al.*, 2012) have addressed how various types of experiences available to students in the same undergraduate program might impact students differently during their early career development. While not all students in a large program with comparatively few faculty members will be able to engage in a traditional FLRE a department that provides all three of these opportunities may be able to provide all undergraduates in the sciences with an opportunity to engage with research, potentially improving personal and professional development as bourgeoning scientists. Furthermore, providing novice students with the opportunity to engage in a research seminar course, prior to participating in research, may help to boost these student's self-efficacy and research skills so that they might feel confident enough to seek out a research experience and are better prepared when they begin.

Here, we investigate the effects of FLREs, CUREs, and a research seminar course offered at a large private R1 university. This study aims to address the following questions (Figure 3.1): (1) What effect might faculty lab –based research experiences, course-based research experiences, and a research seminar course have on students' self-efficacy, research skills, and future goals? (2) How may faculty lab-based research experiences, course-based research experiences, and a research seminar course differ in their effect on students' self-efficacy, research skills, and future goals?

3.3 Methods

Participants and Instruments. This research was conducted according to an IRB-approved protocol (#17-249)(Appendix 1). All participation by students was voluntary, and they were not compensated for their participation. We surveyed and assessed students enrolled in three different experiences at a large, private, research-intensive (Carnegie R-1 designation) University in the northeastern United States. The survey and assessments administered to students included the Survey of Undergraduate Research Experiences (SURE) (Lopatto, 2004), the Biology Self-Efficacy Scale (Baldwin *et al.*, 1999), and a science process abilities assessment (Etkina *et a*l., 2006). Student responses to survey questions (Lopatto, 2004) pertaining to demographic information indicated that the population of students was diverse with regard to gender, year in school, and whether or not they had prior experience (Table 3.1.).

Student responses to the 23 questions in the self-efficacy scale are given on a 1-5 Likert scale and are assessed according to the three factors previously described and analyzed by Baldwin *et al.*, (1999). Factor one includes eight questions related to biological research methods. Factor two includes nine questions related to generalization to other biology/science courses and analyzing data. Factor three includes six questions related to application of biological concepts and skills.

Using the protocol outlined for the science process abilities assessment (Etkina *et al*. 2006), we developed an assessment that asked students to "Design an experiment to test the following question: 'Can stress early in life (i.e. starvation/nutrient availability) affect the development of an organism?'" The assessment included a series of tasks for the students to complete pertaining to this question and these can be found in section 3B. in Etkina *et al.* (2006). The same question was asked of all student participants. Student responses were scored using a rubric consisting of six assessment areas.

These instruments were chosen because they were previously validated and were specific to the factor of interest. The SURE and Biology Self-Efficacy Scale were administered online via Qualtirics, while the skills assessment was administered in-person during class or outside of class at a time of the students' choosing. All three instruments were administered pre- and post-experience, coinciding with the beginning (within the first two weeks) and end (within the last two weeks) of the academic semester.

Students participating in a FLRE (n=12, Table 3.1) were working in a faculty member's lab on their own project or contributing to an existing project in the lab with other lab members (n=12). These students were able to participate regardless of the time they have been working in the lab. These data are presented in Table 1.

To determine which courses in the department qualified as CUREs, syllabi were collected and evaluated according to the criteria established by Brownell and Kloser (2015, see Table 1.) Courses designated as CUREs were further classified according to the type of inquiry students were engaging in. Four courses fell into a CURE category, three were offered at the time of the research, and, of these two were taught by professors who were willing to participate. The two CUREs included in this research differed in the type of engagement students had with research and the type of inquiry involved. In CURE 1 (n=12, Table 3.1.) students were involved in independent, student-driven research and were expected to design and run a final research project of their own. This is mostly closely aligned with the open or authentic inquiry lab type described by (Brownell & Kloser, 2015). CURE 2 (n=20, Table 1) did not involve independent, student-driven research, however students collected data that contributed to a broader research project to which the students had been introduced. This is most closely aligned with the structured or guided inquiry lab type described by (Brownell & Kloser, 2015).

The Introduction to Biological Research course (n=12, Table 3.1.) was a seminar style course designed for first- and second-year biology majors (or related majors) that focused on reading, discussing, and writing about primary literature and exploring the types of research done in the university's Biology department (a detailed description of this course can be found in chapter one and has been published by Schmid & Wiles (2019)).

Analyses. Self-efficacy was measured along three factors previously described by (Baldwin *et al.*, 1999). Factor 1 includes questions related to scientific methods for biological research. Factor 2 includes questions related to generalization to other biology/science courses and analyzing data. Factor 3 includes questions related to application of biological concepts and skills. Student's responses to each question within the three factors were added together to create a score for each factor. Repeated Measures ANOVAs were performed on students' pre and post responses in SPSS for each of the three factors across the experiences.

Student pre and post experience responses to the science process abilities assessment were scored using a rubric. This rubric was developed using the protocol outlined by Etkina *et al.* (2006). The rubric consisted of six assessment areas that were scored on a scale of 0-3, for a total possible score of 18. Repeated measures ANOVAs were performed on students' pre and post responses in SPSS across the experiences.

Student pre- and post-experience responses to the question asking about their plans post-graduation were analyzed by comparing pre- and post-experience responses per individual. The percentage of individuals that indicated a shift in goals was calculated for each experience.

3.4 Results

Analysis of student responses to the pre-experience survey question pertaining to their future goals post-graduation shows that the majority of the students in this population began with an interest in medical school or other health profession upon graduation (62%)(Table 3.2.). This includes students that indicated that their goal was to go to medical school for an M.D. degree, to go to school for an M.D./Ph.D., to enter post-graduate programs for other health professions, or to obtain a paying job for a time and then go to school for an M.D. or Ph.D.. Analysis of student responses to the pre-experience survey to the post-experience survey shows that 50% of the students that participated in the research literature seminar course reported a shift in their future goals, 38% of the students that participated in the FLRE reported a shift in their future goals, 33% of the students that participated in CURE 1 reported a shift in their future goals, and 35% of the students that participate in CURE 2 reported a shift in their future goals. Of the students that indicated a change in their future goals from pre to post experience, the most common change was a shift toward more interest/emphasis on pursuing Ph.D. degrees (Table 3.3). This includes changing their interest from an M.D. to an M.D./Ph.D., from an M.D./Ph.D. to Ph.D. in a biology-related field, or from an M.A. or other choice to a Ph.D. in a biology related field.

Repeated measures ANOVA of student scores on the science process skills assessment indicated a significant main effect of time ($F_{1,52}$=13.48, p=0.001) and experience ($F_{1,52}$=4.22, p=0.01). Students engaged in a FLRE differed significantly from CURE 2 (p=0.002), and the seminar (p=0.01)(Figure 3.2), whereas FLRE scores did not significantly differ from CURE 1 scores. This suggests that students participating in experiences that engage them in authentic inquiry (FLRE and CURE 1) exhibit the most significant increase in mean score from pre- to post-experience (Figure 3.2), despite the FLRE having the highest pre score (Estimated marginal mean=11.25, SE=0.861) and CURE 1 having the lowest (Estimated marginal mean=7.58, SE=0.861)(Figure 3.2).

Repeated measures ANOVA of student scores for questions that fall under factor one (methods of biology) for the biology self-efficacy scale indicated a significant main effect of time ($F_{1,53}$=11.21, p=0.002)(Figure 3.3A). Students participating in experiences that did not engage them with authentic inquiry (CURE 2 and the seminar) tended to have the greatest shift from pre- to post- (Figure 3.3A).

Repeated measures ANOVA of student scores for questions that fall under factor two (generalization to other biology/science courses and analyzing data) for the biology self-efficacy scale indicated a significant main effect of time ($F_{1,53}$=5.48, p=0.02) and experience ($F_{1,53}$=3.13, p=0.033)(Figure 3.3B). Students engaging in a FLRE had significantly higher pre (Mean=36.43, SE=1.701) and post (Estimated marginal mean==36.14, SE=1.641) mean scores then CURE 1 (p=0.038), CURE 2 (p=0.006), and the seminar (p=0.025), despite exhibiting a slight non-significant decrease from pre- to post-. However, students that participated in the seminar course tended to exhibit the greatest increase in scores from pre- (Estimated marginal mean=29.33, SE=1.873) to post- (Estimated marginal mean=32.92, SE=1.773) (Figure 3.3B).

Repeated measures ANOVA of student scores for questions that fall under factor three (to application of biological concepts and skills) for the biology self-efficacy scale indicated a significant main effect of time ($F_{1,53}$=13.48, p=0.001)(Figure 3.3C). Students that participated in the seminar course experienced the greatest increase from to pre- (Estimated marginal mean=21.08, SE=1.324) to post- (Estimated marginal mean=23.92, SE=1.014).

3.5 Discussion

Recent research suggests the benefits of active learning over traditional lecture courses (Deslauriers *et al.*, 2019; Espinosa *et al.*, 2019; Freeman *et al.*, 2014). Specifically, undergraduate research experiences, including FLREs and CUREs, are able to elicit benefits across a number of factors (Linn *et al.*, 2015; Lopatto, 2007; Marrero *et al.*, 2017); while seminar courses rooted in primary research literature may affect students writing and communication skills (Brownell *et al.*, 2013). This study illustrates the potential importance of FLREs for developing students' science process skills, as well as the benefits that engaging in a research seminar course has on novice students' science self-efficacy, a potential determining factor regarding whether they move forward in their training. This research is valuable, as few studies have investigated the effects of different experiences at an integrated program on students' science process abilities or how such experiences affect novice students in particular. Given the known benefits of participating in a research experience as an undergraduate, it is important that we explore the differences that might exist between types of experiences and how we might better prepare students for success in these experiences. This research adds to the growing body of literature on the impacts of undergraduate research experiences.

Faculty lab-based research experiences, course-based research experiences, and a research seminar course positively affect students' self-efficacy, research skills, and future goals. Prior research has shown that participation in an undergraduate research experience can influence students future goals post-graduation (Harrison *et al*., 2011; Linn *et al.*, 2015; Marrero *et al.*, 2017), however this can differ greatly based on the population of students. The population of participating students in the biology department at this institution is largely comprised of individuals who express a desire to pursue a medical degree or other health profession post-graduation (Table 3.2). When asked what their future goals were before and after engaging in one of the four experiences, there was a marked shift post engagement toward interest in working toward a Ph.D., either as the primary goal or in addition to an M.D. (Table 3.2, Table 3.3). The most change was exhibited by students in the seminar course, with 50% indicating a shift in their future goals pre to post course (Table 3.2, Table 3.3). This suggests that engaging with the primary literature and learning more about biological research may play an important role in the decision that students make post-graduation. Furthermore, the students in this course were first or second year students who may not have formed a clear picture of their future goals, compared to CURE and FLRE students who are in their third and fourth years and have had the time to make this decision. Therefore, an introductory course in scientific literature might be particularly beneficial for shaping novice students' interest in pursuing research opportunities in graduate school post-graduation.

The results of student scores on the science process abilities assessment indicate that FLREs significantly affect students' abilities to formulate hypotheses and design an experiment (Figure 3.2). A significant increase in scores from pre to post experience was also shown for students in CURE 1 (Figure 3.2). This suggests that students that engage in authentic inquiry, as in the FLRE or CURE 1, exhibit the greatest increase in their science process abilities assessment, whereas students who do not engage in authentic inquiry, as in CURE 2 or the seminar course, do experience similar gains (Figure 3.2).

When comparing novice students working in a faculty lab to experienced students working in a faculty lab, Thiry *et al.* (2012) found that these two groups differed in their perceived gains from the experience. Their qualitative results showed that novice students reported an increase in their self-confidence, while more experienced students reported an increase in their professional confidence. Results from this research contribute to this understanding. We found that students in FLREs experienced exhibited a higher self-efficacy overall, but little change pre experience to post experience (Figure 3.3A, 3.3B). On the other hand, students in the research seminar course exhibited a significant increase in science self-efficacy from pre to post experience (Figure 3.3A, 3.3B, 3.3C). It is important to note that the students in this course were all first and second year students with very few (n=3) having prior research experience. This increase in self-efficacy may be especially important for these students as they move forward in their undergraduate education and potentially seek out research opportunities like FLREs and CUREs.

Faculty lab-based research experiences, course-based research experiences, and a research seminar course do not differ in their effect on students' self-efficacy, research skills, and future goals. While there were significant changes in self-efficacy and research skills from pre- to post-experience within each of the four research engagements, our results did not show any significant interaction between time and experience, suggesting that experiences do not differ in their effect on students' self-efficacy or research skills and that all across all experiences there is an average increase in scores from pre- to post-experience. This result is not unexpected, as it has previously been shown that CUREs often elicit similar benefits for students when compared to FLREs (Brownell *et al*., 2012; Brownell & Kloser, 2015; Colabroy, 2011; Harrison *et al.*, 2011; Kloser *et al*., 2013; Shortlidge *et al*., 2016).

We were interested to find that there was no difference between CUREs and FLREs when compared to the seminar course is surprising. Given that CUREs and FLREs both have students directly engaging in research, we would expect that these students would significantly differ from those in the seminar course. Similarly, we would expect that students in the seminar course would significantly differ from those in FLREs and CUREs in their self-efficacy outcomes, since students in CUREs and FLREs commonly enter these experiences with a higher self-efficacy (Gardner *et al.,* 2015). Given the significant findings from pre- to post-experience within each experience, we suggest that this is likely that result of a low sample size and we would suspect that this might be mediated if more students were sampled across each experience.

Conclusion. The results from this research suggest that participating FLREs, CUREs, or a research seminar course all impact students' interest in pursuing research opportunities post-graduation. This is especially the case for novice students. Additionally engaging in authentic inquiry, like that in a FLRE or certain CUREs is particularly beneficial for improving students' science process abilities; however no such increase was found for science self-efficacy. Students who are not engaging in authentic inquiry, like that in CURE 2 or the seminar course, experience a significant increase in their science self-efficacy. Assessing the FLREs and CUREs offered is important for understanding how, and whether, we are contributing to the success of students. Working to implement opportunities, such as additional, early-career CUREs and research literature seminar courses, may help us to prepare students for authentic research experiences, and it is an important part of providing access to more students. We suggest using the criteria established by Brownell and Kloser (2015, see Table 1.) to evaluate current CUREs offered within an institution and scaffold advising and program progression such that more students have the opportunity to engage in research. We recommend that more courses like the research seminar course for first-year students, or that they be exposed to research literature as part of general introductory courses, to provide them with earlier insight into the nature of research so that they may be more confident and better prepared to pursue research experiences in the future.

3.6 Acknowledgments

We express our gratitude to the undergraduate students at the participating institution for taking part in this research. We also thank the course professors of the CUREs for allocating class time for students to participate in this study, as well as Dr. Jason Fridley for his help with statistical analyses. Kelly Schmid was supported by a Howard Hughes Medical Institute (HHMI) Inclusive Excellence Grant and a Syracuse University Summer Dissertation Fellowship.

3.7 Author contributions

Kelly Schmid was responsible for experimental design, data collection and analysis, as well as writing the initial draft of the manuscript. Sarah Hall designed the specific questions and rubric for the science process skill assessment to be administered to participants. Additionally, she contributed significantly to the editing of the manuscript.

3.8 Tables and Figures

Table 3.1. Demographic information of students participating in each of the experiences.

Experience	Students that identify as women	Students that identify as men	1st year students	2nd year students	3rd year students	4th year students	Students with prior experience
FLRE (n=12)	9	3	2	2	2	6	10
CURE 1 (n=12)	8	4	0	0	0	12	8
CURE 2 (n=20)	14	6	0	0	3	17	8
Seminar (n=12)	8	4	11	1	0	0	3

Table 3.2. Student responses pre experience to the SURE (Lopatto, 2004) question about student goals post-graduation.

Percent of students who responded that their goal is to…								
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Experience	medical school for an M.D. degree	medical school for an M.D. degree	school for a M.D./Ph.D.	school for a M.D./Ph.D.	graduate school for a degree in science	graduate school for a degree in science	Other	Other
FLRE (n=13)	46.1%	30.7%	15.3%	23%	15.3%	15.3%	23%	30.7%
CURE 1 (n=12)	16.6%	16.6%	8.3%	8.3%	41.6%	58.3%	33.3%	16.6%
CURE 2 (n=19)	26.3%	15.7%	5.2%	15.7%	31.5%	31.5%	36.8%	36.8%
Seminar (n=12)	33.3%	16.6%	8.3%	16.6%	50%	66.6%	8.3%	0%

Table 3.3. Student responses that changed from pre to post experience when asked what their goals were post-graduation.

Experience	Pre	Post
FLRE	My goal is to work, then go to school for my M.D., Ph.D., or other professional degree	My goal is to go to medical school for an M.D. degree
	My goal is to go to school for an M.D./Ph.D.	I plan to work in a science related career without going to school after college
	My goal is to go to medical school for an M.D. degree	My goal is to go to school for an M.D./Ph.D.
	My goal is to go to medical school for an M.D. degree	My goal is to go to graduate school for a Ph.D. degree in a biology-related field
	My goal is to go to medical school for an M.D. degree	My goal is to go to school for an M.D./Ph.D.
CURE 1	My goal is to go to graduate school for an MA or Ph.D. degree in a field other than science	My goal is to work, then go to school for my M.D., Ph.D., or other professional degree
	My goal is to go to school for other health professions	My goal is to go to graduate school for a Ph.D. degree in a biology-related field
	My goal is to go to graduate school for an MA in the life sciences	My goal is to go to graduate school for a Ph.D. degree in a biology-related field
	My goal is to go to graduate school for a Ph.D. degree in a biology-related field	My goal is to work, then go to school for my M.D., Ph.D., or other professional degree
CURE 2	My goal is to go to medical school for an M.D. degree	My goal is to go to school for an M.D./Ph.D.
	My goal is to go to medical school for an M.D. degree	My goal is to go to school for an M.D./Ph.D.
	My goal is to go to graduate school for a Ph.D. degree in a biology-related field	My goal is to go to graduate school for an MA in the life sciences
	My goal is to go to graduate school for an MA or Ph.D. degree in a field other than science	I plan to work in a non-science career without going to school after college
	My goal is to go to graduate school for an MA in the physical sciences (including math, engineering, computer science, etc.)	My goal is to go to graduate school for an MA in the life sciences
	My goal is to go to graduate school for an MA in the life sciences	My goal is to go to graduate school for a Ph.D. degree in a biology-related field
Seminar	My goal is to go to medical school for an M.D. degree	My goal is to go to school for an M.D./Ph.D.
	My goal is to work, then go to school for my M.D., Ph.D., or other professional degree	My goal is to go to graduate school for a Ph.D. degree in a biology-related field
	My goal is to go to medical school for an M.D. degree	My goal is to work, then go to school for my M.D., Ph.D., or other professional degree
	My goal is to go to school for a professional degree such as law or business	My goal is to go to school for an M.D./Ph.D.
	My goal is to go to graduate school for a Ph.D. degree in a biology-related field	My goal is to go to graduate school for an MA in the physical sciences (including math, engineering, computer sciences, etc.)
	My goal is to go to school for an M.D./Ph.D.	My goal is to go to graduate school for a Ph.D. degree in a biology-related field

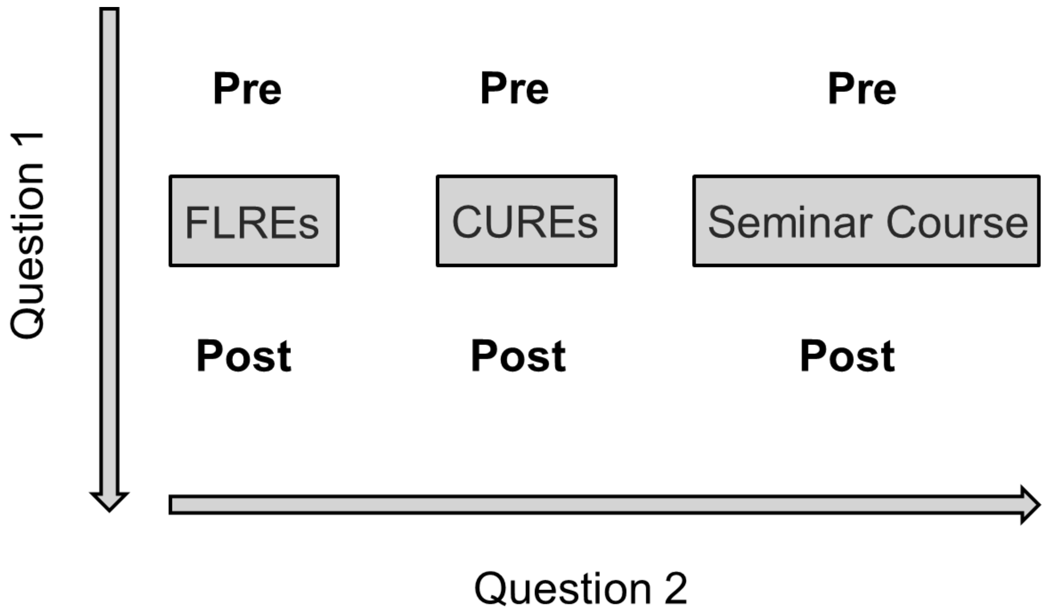

Figure 3.1. Visual representation of research questions:
(1) What effect might faculty lab-based research experiences, course-based research experiences, and a research seminar course have on students' self-efficacy, research skills, and future goals?
(2) How may faculty lab-based research experiences, course-based research experiences, and a research seminar course differ in their effect on students' self-efficacy, research skills, and future goals?

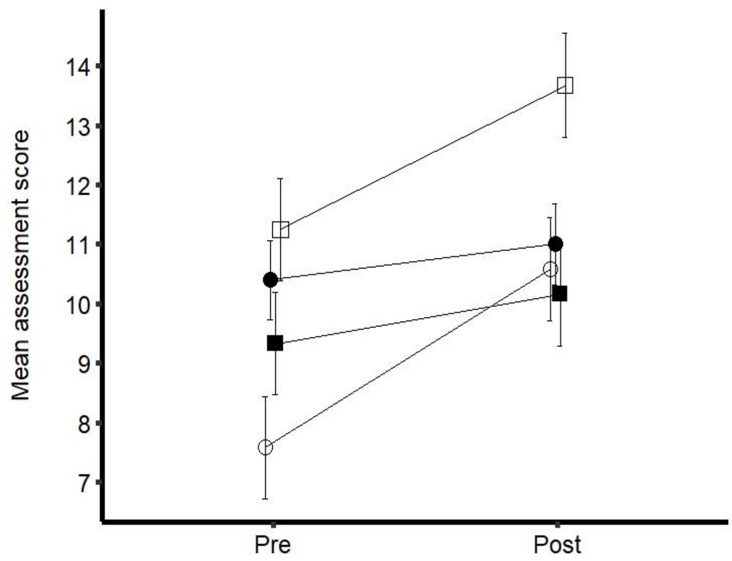

Figure 3.2. Estimated marginal mean skill assessment scores pre and post experience. Open shapes correspond with experiences considered to engage students in authentic inquiry, while closed shapes correspond with experiences not considered to engage students in authentic inquiry. Open squares correspond with the FLRE experience. Open circles correspond with CURE 1. Closed circles correspond with CURE 2. Closed squares correspond with the seminar.

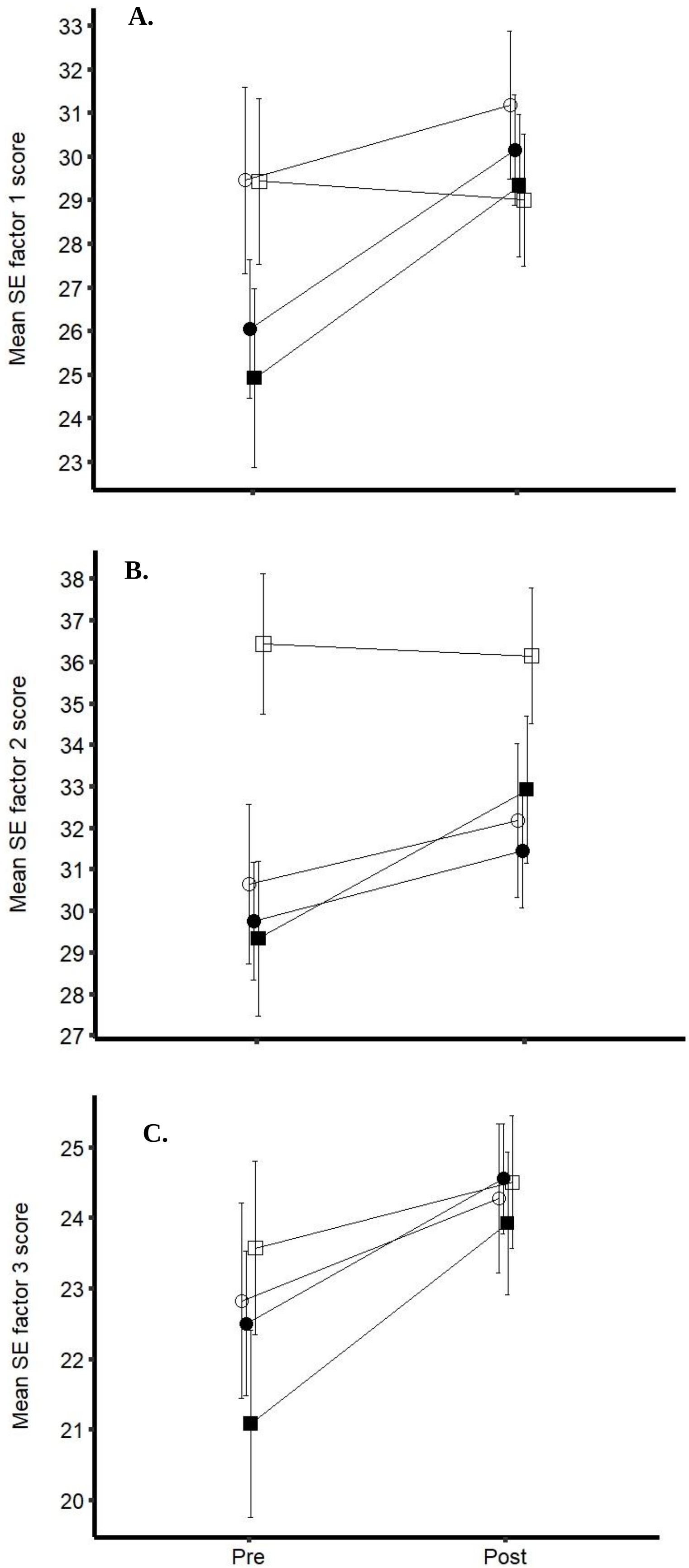

Figure 3.3. Estimated marginal mean biology self-efficacy scale scores pre and post experience. Open shapes correspond with experiences considered to engage students in authentic inquiry, while closed shapes correspond with experiences not considered to engage students in authentic inquiry. Open squares correspond with the FLRE experience. Open circles correspond with CURE 1. Closed circles correspond with CURE 2. Closed squares correspond with the seminar.
A.) Shows mean scores pre- and post-experience for the eight questions in factor one. B.) Shows mean scores pre- and post-experience for the nine questions in factor two. C.) Shows mean scores pre- and post-experience for the six questions in factor three.

Chapter 4. The role of mentors in faculty lab-based undergraduate biology research experiences and outcomes for student science identity

Kelly M. Schmid and Jason R. Wiles

4.1 Abstract

Mentorship plays an important role in undergraduate research experiences where students are working in a faculty lab. Within a lab environment, students may interact with a variety of mentors that are at different career stages. Using qualitative interviews of undergraduate students (n=19) engaging in research in faculty labs and their faculty mentors (n=14), this study aims to investigate the roles of mentors in the context of faculty laboratory-based research experiences. The science identity of these undergraduates was also explored. Results suggest that students considered their primary mentor to be whomever they spent the most time with or worked most closely with. In most cases, this individual was a non-faculty post-graduate. They indicated that this person is who they would go to learn a new technique, had a question, or encountered a problem. Students and faculty mentors both indicated that the role of the faculty was aimed more towards framing the research in "big picture" context, executive oversight, and occasional career advising. We found a large (70%) disparity between women and men students' science identity, while nearly all faculty members considered the undergraduates in their labs to be scientists. Explanations of criteria for identifying as scientists also varied. Results from this study suggest that all mentors, including faculty and post-graduates, play important, but different roles in the research experiences of their undergraduate mentees. Furthermore, more targeted mentorship towards developing the science identity of women undergraduates may help to decrease the disparity between genders.

4.2 Introduction

Faculty-student relationships play a critical role in many aspects of undergraduate science students' experiences. Faculty members often have multiple roles in the development of undergraduate science students, including being course instructors, serving as academic advisors, and mentoring their undergraduate students in research experiences. Effectively carrying out such roles can positively affect student outcomes, with students consistently ranking mentorship as having the largest impact on academic success (Kendricks *et al.*, 2013). Within challenging science courses, such as Organic Chemistry, students who have a better connection with their course professor perform better in the course (Micari & Pazos, 2012), highlighting the importance of these relationships within the classroom. While faculty-student relationships play an important role in the classroom, these relationships are particularly important part of any undergraduate research experience where students are engaging in research in faculty labs (Thiry et al., 2011). Such relationships have been shown to play an important role in significantly improving students' science self-efficacy and future goals (Campbell & Skoog, 2004; Carpi *et al.*, 2017; Frantz *et al*., 2017; Hammick & Acker, 1998; Kardash, 2000; Robnett *et al*., 2018). However, these relationships play an especially important role in increasing student's science identity, which can lead to an increase in students' desire to pursue future research in graduate school (Dolan & Johnson, 2010; Estrada *et al*., 2018).

Effective mentor-mentee relationships are important and beneficial for all undergraduate students in the sciences. However, it has been shown that these relationships are especially important for women and underrepresented minorities (URM), as they provide the students with a positive and relatable role model (Campbell & Skoog, 2004; Carpi *et al.*, 2017; Herrmann *et al*., 2016) and help students to feel included in the scientific community and increase self-efficacy, thus improving retention in the sciences (Robnett *et al*., 2019; Wilson *et al*., 2012). In addition to providing women and URM students with role models, faculty mentors may also provide these students with important networks within the scientific community that they would not have access to otherwise (Towns, 2010). Within a mentor-mentee relationship, communication is a key component. Studies have shown that the gender of the mentor and mentee often shapes how they communicate, particularly with women (Carlone & Johnson, 2007; Hammick & Acker, 1998). Providing these groups of students with a positive and productive mentorship experience has been shown to increase feelings of inclusion for these students, thus increasing retention in the sciences (Carpi *et al*., 2017a; Estrada *et al*., 2018; Griffin *et al.*, 2010; Hippel *et al.*, 1998; Wilson *et al*., 2012).

While faculty mentor-mentee relationships are an important and beneficial part of a student's experience working in a faculty lab, these relationships can be complex as they involve different people with potentially different personalities. An effective mentor-mentee relationship is driven by a variety of factors that are determined by the nature of the relationships and the role that the mentors play in an undergraduate's research experience (Byars-Winston *et al.*, 2015; Daniels *et al.*, 2019; Hammick & Acker, 1998). The mentor's ability to give constructive feedback, help the mentee to understand the project's context and broader impact, and help the mentee feel included in the lab are key components of a successful mentoring relationship (Byars-Winston *et al*., 2015).

The traditional "apprenticeship" model, consisting of a faculty mentor and student mentee, has long been the most common formal mentorship model. While faculty mentors play an important role in undergraduate students' experiences within their labs, a network of mentor-mentee relationships can actually exist between various people at different career stages in lab groups. This includes faculty and student, postdoctoral researcher and student, graduate student and student, and peer to peer. The idea that there can be multiple mentors that an undergraduate encounters while working in a lab has resulted in the advent of multiple different mentoring models. There has been evidence to suggest having multiple mentors is beneficial to the student.

One type of mentoring model that has been shown to be beneficial is the faculty, post-graduate (postdoctoral researcher or graduate student), undergraduate triad. Undergraduates who are interacting with both the faculty member and post-graduate report higher gains in thinking like a scientist (Aikens *et al*., 2016, 2017). Another model that has recently shown to be beneficial to students is the community mentoring model (Kobulnicky & Dale, 2016). Under this model, students interact with multiple faculty, postdoctoral researchers, graduate students, and peers on a large collaborative project. This type of mentoring provides students access to multiple mentors, limiting the possible negative effects of personality clashes. It also reinforces the idea that science is collaborative (Kobulnicky & Dale, 2016). This model is likely not as common as a result of its reliance on a large collaborative project across multiple labs, however a version of this model can easily be implemented within a single lab or close-working lab groups. Mentoring models like these or some version of these, where undergraduate students are mentored by multiple people at various career stages, including peers, can be implemented within a single lab or across labs to provide students access to multiple mentors and collaborative opportunities(Aikens *et al*., 2016, 2017; Kobulnicky & Dale, 2016).

If undergraduate students are interacting with multiple mentors, such as faculty and post-graduates, during their research experience in a faculty lab, and knowing that effective mentoring plays such a critical role in science students' undergraduate experience, we are interested in investigating the roles that different mentors play in an undergraduate research experiences.

Additionally, since we know that participating in these experiences is associated with an increase in science identity, we are interested in determining at what point in their training that students and their faculty mentors perceive students to *be* scientists. This study aims to qualitatively explore the following questions from both the students' and the faculty mentors' perspectives: (1) What is the nature of mentor-mentee relationships that undergraduates and faculty mentors perceive to exist within research labs, and how might these perceptions differ? (2) What roles do different mentors play in the mentee's undergraduate research experience? (3) How do undergraduate researchers and their mentors articulate the undergraduates' identities as scientists? Ultimately, we hope to help better understand the complicated network of mentor-mentee relationships that emerge from undergraduate research experiences and their relative impacts.

4.3 Methods

Participants. This research was conducted under an approved IRB protocol (#17-249)(Appendix 1). Participants in this study included undergraduate students (n=18) engaged in research in faculty labs in a biology department, and faculty members (n=14) in the same department at a large, research-intensive university (Carnegie R1 designation) in the northeastern United States. All participation by students and faculty was voluntary, and they were not given any compensation for their participation. The criteria for student participation in this study were that participants were working on their own project or contributing to a larger project within a faculty member's lab. Student participants ranged from first year students to fourth year students, and all but one were majoring in biology or a field related to biology (biotechnology, public health, etc.). Students also varied in the time that they had been conducting research in a faculty lab

(Table 4.1). Faculty member participants were research advisors of the student participants. They varied in the total time that they have been a faculty member (Table 4.2). They were asked to participate in this study to capture a more complete picture of mentoring roles and expectations within the labs, however to maintain confidentiality, neither students nor faculty knew that the other was being asked to participate.

Interviews and analysis. Semi-structured interviews were conducted with student participants during a time that was mutually agreed upon. Interviews took approximately thirty minutes and were conducted in a private office at a table where the interviewer and interviewee sat across from one another. All interviews were recorded on a laptop using standard voice recording software and a microphone. Following the completion of all interviews, the audio recordings were uploaded and transcribed via Trint, an online transcription software tool.

Faculty participants were asked to complete a series of open-ended questions online via Qualtrics. These questions coincided with the questions asked of the student participants to allow comparisons to be drawn between student mentee and faculty research advisor responses and perceptions of mentoring in the labs. Faculty participants received the link to the questions via e-mail and were able to complete it at their convenience.

Following the completion of the interview transcriptions, the transcripts were read through completely and compared to the audio to check for any errors. Once all the transcripts were cleaned up, they were re-read and coded. The codes were then combined into themes and analyzed to see if there were common themes across all student participants or distinct differences of note. Similarly, once all of the faculty participants had completed the open-ended questions their responses were downloaded from Qualtrics and compiled into an Excel file. Faculty responses were read through completely and coded. The codes were then combined into themes and analyzed to see if there were similarities across all faculty participants. Themes between student participants and faculty participants were also analyzed for similarities or differences in make-up between the two groups (Miles & Huberman, 1994).

4.4 Results

The nature of mentor-mentee relationships and the roles of mentors. When undergraduate students who were participating in research in a faculty lab were asked who they considered to be their primary mentor, 11 of the 18 interviewed students (61%) indicated that a post-graduate (graduate student, postdoctoral researcher, or lab technician) was their primary mentor, while three stated that their primary mentor was the primary investigator (P.I., faculty member)(17%), and three stated that they were equally mentored by the P.I. and post-grad (17%)(Table 4.1). Students unanimously indicated that the person that they spent the most time with was who they considered to be their primary mentor. Typical student explanations for this designation included that "she is always in the lab every day. So I kind of tended to go towards more of her if I have a problem or a question because she's either in the lab with me or she's a lot more familiar with my project." Another student stated "He's the one that I see every day… I've worked more closely with him. He's helped me and, like, we've worked on things together."

In addition to their primary mentors, students also indicated other lab members that they consider to be mentors, including other post-grads and the P.I. in the lab. This aligned with who the faculty members indicated to be mentors in the lab. When asked who in the lab do undergraduate students spend the most time with, 10 of the 14 faculty mentors indicated that students spend the most time with post-graduates (Table 4.2). When asked from whom do undergraduates feel the most comfortable learning techniques from, asking a question of, or going to with a problem they encounter, they indicated that, if a post-graduate works in their lab, that they would look to the post-graduate for this because they are closer in age (Vygotsky, 1978). Representative explanations for this pattern included that this was "because I know they used to be undergrads. So they understand. And like I told them like I have a different way of learning. I'm like a slow learner. So they understood that." Other students indicated that it was because they were more accessible, using explanations such as, "she is always there." Students indicated that they would not ask the faculty P.I. because they are not perceived to be as accessible. Typical articulations included, "He has classes that he teaches and has other things that he's working on." Students unanimously indicated that the P.I. is whom they would ask to write them a letter of recommendation, and who provides them with information regarding the broad context of the research they are working on. One student stated that "[Her role] tends to be more like funding and [who] you go to for grants and she's teaching as well." Another described this as "the principle investigators [are] more like a boss than anything else."

When asked what their role was in an undergraduate student's research experience, faculty mentors tended to express that it is to help them understand the "big picture" of their research project and advising on future goals. Representative explanations included, "I tend to restrict my role to discussion the bigger picture rationale of our research and assisting with data analysis and interpretation." and "I give practical advice about how their research experience can prepare them for the next steps in their career."

Undergraduate students' science identity. When asked whether they consider themselves to be scientists three of the 10 women students (30%) responded that they considered themselves to be scientists and all eight of the men students (100%) indicated that they considered themselves to be scientists (Table 4.1). Among students, all three of the women that considered themselves to be scientists had been working in the lab for more than one year, while the men varied in the length of time they've been in the lab, from one semester to two years (Table 4.1). There was also no clear correlation between student science identities and the gender of whom they considered to be their primary mentor. When the students who considered themselves to be scientists were asked when they perceived themselves to have become scientists, they tended to indicate that they became a scientist before entering their undergraduate programs, with typical responses including "I think I considered myself a scientist even [during] high school.", and

> "I definitely think it started probably back when I was in first grade. Just being exposed to it and just like wanting to get more and more involved and get more advanced and stuff like that."

However, other students indicated that they became a scientist once they achieved autonomy in their project with representative explanations including, "I think just once I kind of found some autonomy in my project, and realized I'm able to interpret these papers and apply it to my project, and kind of figure out what I'm going to do by myself." or that they became a scientist when they started "experiments by myself, and I started collecting data by myself…" Similarly, when the students that do not consider themselves to be scientists were asked under what conditions they might consider themselves to be scientists, they indicated that this would be when they experience autonomy in the project in the lab, with typical articulations including, "Probably once I start doing my own research and thinking about stuff critically instead of just doing other people's [projects]." and, "I guess to just have more of a sense and being able to have my own experiment. Knowing, like, what data I should be collecting and what I should be analyzing." Others stated that they would not consider themselves to be scientists until they earn a higher degree or certification, often explaining that one needs "a certain certification." There were also some students who were unsure of whether or not they considered themselves to be scientists. When asked whether or not they considered themselves to be a scientist one stated, “Yeah to a certain degree. I guess I've always thought of scientists as someone who had a Ph.D.”

All but one faculty mentor reported that they consider the undergraduate students working in their lab to be scientists or at least scientists-in-training (Table 4.2). When asked when these students became scientists, they indicated that this happened upon entering the lab and deciding to participate in a research experience. One mentor stated that this happens “when they walk in my lab.” Another stated that “anyone can be a scientist. They became scientists when they made the decision to engage in research.” Many went on to explain that students become a scientist once they engage in research, stating that they become scientists “when they start doing experiments in the lab” or “usually during the first or second semester of active research.”

4.5 Discussion

The nature of mentor-mentee relationships and the roles of mentors. Undergraduate students engaging in research in faculty labs interact with a variety of lab members at different stages in their careers. While the P.I. of the lab plays an important role as a mentor in these experiences, we found that the majority of the time undergraduate students do not consider them to be their primary mentor (Table 4.1). Rather, students consider the person that they work most closely with or spend the most time with in the lab to be their primary mentor. This person is usually a post-graduate. Students reported that this person is the person who they go to when they need to learn a technique, ask a question, or encounter a problem. Their reasoning for this is that they feel that these individuals are closer in age and experience, and they are more accessible.

However, students did indicate that they do rely on their P.I. for letters of recommendation and helping to better understand the big picture of their research. Student responses corresponded with those of the faculty, with faculty stating that undergraduate students spent the most time with post-grads and that their role was reserved for “big picture” context and advising on future goals and career plans. This suggests that there are multiple people within a lab group that the undergraduates consider to be mentors and that each of these mentors play an important role in their research experience. While the role of the faculty mentor in an undergraduate research experience is important and has been well studied, students have reported that it is the post-graduate that they are interacting with the most, and therefore these individuals also play a potentially equally important role. Similar to our findings, Dolan & Johnson (2010) have found that post-graduates are an important part of undergraduate research experiences and are often considered to be more approachable than faculty. These results suggest that an undergraduate research experience that incorporates multiple mentors at varies career stages, like a faculty-post-graduate-undergraduate triad, may provide undergraduate students with a more complete mentorship experience (Aikens *et al.*, 2016, 2017), and may lead to beneficial outcomes such as increased science identity and self-efficacy, as well as plans to pursue research in post-graduation.

Undergraduate students’ science identity. Science identity is one important outcome of an effective mentor-mentee relationship when students are engaging in research in a faculty lab (Dolan & Johnson, 2010; Estrada *et al.*, 2018). We found that while all but one faculty member indicated that they consider the undergraduates working in their labs to be scientists, there was a disparity between women and men students on whether or not they consider themselves to be scientists, regardless of the time that they have been in that lab (Table 4.1, Table 4.2). When exploring this further, undergraduate students fell into three categories regarding criteria for identifying as a scientist. One group considered themselves to be scientists before entering matriculating to their undergraduate programs – from an early as first grade to high school. Other students perceived status as a scientist was achieved when they experienced autonomy in their research or when they received a certain certification or degree. The faculty mentors fell into two categories when asked this question about the students. Some stated that students became scientists as soon as they entered the lab, while others said it was once they began doing research.

Conclusion. We are able to acquire a more in-depth understanding of the various mentor-mentee relationships that exist within an undergraduate research experience in a faculty lab. We have shown that each mentoring relationship within a lab plays a different role within the research experience for undergraduate students. Furthermore, we have shown that ideas surrounding what makes someone a scientist vary amongst faculty, but have an even greater disparity among women and men students. The disparity between genders in the sciences has been well documented with women students reporting feelings of inclusion and comfort when they have a mentor of their same gender to act as a role model (Daniels *et al.*, 2019; Herrmann *et al*., 2016). While the idea of what makes someone a scientist is certainly subjective, this may be an indicator for other important factors, such as imposter syndrome and inclusion into the scientific community. Given the disparity between women and men students and whether or not they consider themselves to be scientist, working to provide women with more opportunities to interact early-on with other women in science may help to improve this. Additionally, providing mentors , particularly post-graduates, with targeted professional development opportunities to develop their skills towards the mentorship of women and underrepresented minority groups, may help to mediate the differences in outcomes between genders (Prunuske *et al.*, 2013). Understanding the roles, impacts, and outcomes of mentor-mentee relationships within undergraduate research experiences in a faculty lab can help to improve these experiences, increase desired outcomes, and create a more inclusive field of study (Prunuske *et al.*, 2013).

4.6 Acknowledgments

We express our gratitude to the undergraduate students and faculty at the participating institution for taking part in this research. We also thank the Biology Department at the participating institution. Kelly Schmid was supported by a Howard Hughes Medical Institute (HHMI) Inclusive Excellence Grant and a Syracuse University Summer Dissertation Fellowship.

4.7 Tables and Figures

Table 4.1. Undergraduate student responses to interview questions regarding mentoring and science identity.

	≤ 1 semester in faculty lab	1 year in faculty lab	> 1 year in faculty lab	Primary mentor is PI	Primary mentor is PG	50/50 mentorship between PI & PG	Considers themselves to be scientists
Women undergraduate mentee (n=10)	10%	40%	50%	10%	80%	10%	30%
Men undergraduate mentee (n=8)	50%	12%	37%	25%	50%	25%	100%

Table 4.2. Faculty mentor responses to open-ended questions regarding mentorship within their lab, as well as the science identity of their undergraduate students.

	1-5 total years as faculty	5-10 total years as faculty	10+ total years as faculty	Meets with UG mentees ≤ 3 hours per week	Meets with UG mentees ≥ 4 hours per week	Seeks out opportunities to develop mentoring skills	Considers UG in lab to be scientists
Women faculty mentor (n=5)	20%	40%	40%	40%	60%	100%	100%
Men faculty mentor (n=9)	0%	0%	100%	55%	44%	44%	88%

Conclusion

With a broad interest in active learning and a goal to better understand the effects of different undergraduate research experiences and the role of mentoring, we aimed to design a seminar course for novice students and investigate the following: the effect that the seminar course had on students nature of science (NOS) understanding; the effects that different undergraduate research experiences (FLREs and CUREs), as well at the seminar course had on students self-efficacy, research skills, and future goals; the role of mentors in FLREs; and students' science identity. Throughout the four chapters, results presented have been able to address each of the original four aims.

In chapter one, we presented a detailed description, which has been peer-reviewed and published in a well-established journal, of the seminar-style course that we designed for first and second year biology undergraduate students. The course involved reading and discussion of primary scientific literature, writing about science, and engaging with researchers within the department. Through this course and analyses of data collected in the context of the course, we have been able contribute to the understanding of how we can better prepare first and second year undergraduate students for future research experiences, specifically through engaging them in a seminar course designed to give them experience engaging with primary literature, learning about research within the department through meeting with researchers, and discussing science with one another. The design and implementation of this course was important for filling a niche within the department and to begin to engage novice students with the aforementioned topics early in their undergraduate career.

In chapter two, we addressed our second aim to assess how an introduction to biological research seminar course, that does not include direct nature of science (NOS) instruction, affects students' nature of science understanding. We found that this course significantly increases students' NOS understanding in important areas – like whether science is universal or influenced by society and culture. However, without explicit NOS instruction, students' conceptions of aspects of NOS, like whether or not and how theories may change, did not significantly improve. In chapter three, we also found that students in the introduction to research literature course had a significant increase in their self-efficacy, which is a potentially important factor in their decision to pursue research in the future. Furthermore, we found a marked shift in these students' plans post-graduation – towards incorporating research into their future goals.

Combined, these results suggests that engaging in an introduction to research literature course such as this can have important outcomes for students, specifically when it comes to preparing them for future research experiences. While this course was successful in meeting the course goals and having beneficial outcomes for students, we understand the limitations due to its design and implementation for only a small portion of the large number of first and second year students within the institution in which the research was situated. Therefore, we suggest that important aspects of this course might be embedded into the large Introductory Biology sequence, thus giving more students the opportunity to engage with primary research literature.

In chapter three, we were able to successfully address aim three regarding how faculty lab-based research experiences (FLRE), course-based research experiences (CURE), and a research seminar course effect students' self-efficacy, research skills, and future goals. We further assessed how these experiences differ in their effect on students' self-efficacy, research skills, and future goals. Our results suggest that students engaging in research in faculty labs experience a significant increase in their ability to formulate hypotheses and design an experiment, as evidenced through their skill assessment scores. Students engaged in CUREs that involved authentic inquiry also exhibited this increase. However, while these students experienced a significant increase in their research skills, they did not experience a significant shift in their self-efficacy. This might be, in part, a result of their already high initial self-efficacy. Furthermore, these students were less likely to report changes in their future goals, however those that did shift their post-graduation plans tended to shift towards incorporating research into their reported goals. Combined these results suggests that FLREs and CUREs that involve open-ended, student-driven inquiry are important in developing students' research skills, which are crucial for scientists.

Given the beneficial outcomes of engaging in FLREs and CUREs, we can use these results to inform our practices. CUREs are accessible to a larger number of students, therefore we first suggest identifying courses within the department that are considered CUREs and using the criteria established by Brownell and Kloser (2015a, see Table 1.) to identify what type of CURE they are considered. We then suggest scaffolding advising and program progression accordingly so that more students may take the opportunity to engage in a research experience during their undergraduate careers.

We found evidence of the capacity of FLREs to help students develop key skills, however we were also interested in the roles the students' mentors had in their experiences. In chapter four, we addressed aim four, which was to assess the different mentor-mentee relationships that exist within an undergraduate student's faculty lab-based research experience and the roles of each of these mentors within the experience. We also assessed the science identity of students engaged in FLREs. While it is well understood that mentors are important in an undergraduate students' academic experience, and particularly within a research experience (Campbell & Skoog, 2004; Carpi *et al*., 2017; Frantz *et al*., 2017; Hammick & Acker, 1998;

Kardash, 2000; Robnett *et al*., 2018), we were able to qualitatively show the importance of different mentors within a lab and the roles that each play. We found that non-faculty post-graduates played the largest role in the day to day experiences of our undergraduate student participants, and that undergraduates considered these non-faculty post-graduates to be their primary mentors to whom they would go to for questions, concerns, or to learn new techniques. Student responses indicated that they considered the principal investigator of the lab to play a less personal, more "big picture" role.

While the literature has largely focused on the role of faculty mentors and the importance of faculty development in undergraduate research mentoring (Kendricks *et al*., 2013), our results suggest that post-graduates play a more day-to-day mentoring role, one that is different from faculty but equally important. Professional development opportunities for post-graduates to improve upon their mentoring skills are not often offered or required, however given the important role that these individuals play in undergraduates' FLREs we suggest that such opportunities should be offered and encouraged. In doing so, post-graduates will be more prepared to act as the primary mentors that they are considered to be by their students and better able to provide continued quality mentorship.

In addition to the role of mentors within their FLRE, we were also interested in qualitatively investigating whether or not students engaged in this research experience considered themselves to be scientists and if yes – at what point in their training did they identify as scientists, or if no – at what point or under what criteria would they consider themselves to be scientists. Our results indicated that all the men students interviewed considered themselves to be scientists, while the majority of women students did not consider themselves to be scientists, despite the majority of P.I.s indicating that they considered their students to be scientists. It was especially interesting that there was no clear correlation between science identity and time spent in the lab doing research, meaning that students who had been working in faculty labs for a year or more were not more likely to identify as a scientist, rather this seems to be driven largely by gender.

As previously mentioned, quality mentorship has an important role in an FLRE. Additionally, it has been shown that having a role model in the sciences is important, especially for women and underrepresented minority (URM) students (Campbell & Skoog, 2004; Carpi *et al*., 2017; Herrmann *et al*., 2016; Morales *et al*., 2018). We found no clear correlation between student science identities and the gender of whom they considered to be their primary mentor, therefore, one way to lessen the disparity in science identity between genders may be through more targeted professional development opportunities available to post-graduates, particularly development of skills towards the mentorship of women and underrepresented minority groups (Prunuske *et al.*, 2013).

Moving forward, the surveys and assessments used in this research may be used to continually assess the outcomes for students engaged in research experiences. In doing so, a larger sample size may be collected to highlight any further differences or similarities between experiences, or potentially between year in college. Increasing the number of students sampled in each experience may also allow for the analysis of differences between genders and URM groups, which could further highlight the importance of such experiences. Additionally, continuing to offer the research seminar course for first and second year students will give more students the opportunity to gain valuable skills and engage with researchers within the department. These students may be interviewed as third or fourth year students to gather data about whether or not they sought out research opportunities (through FLREs or CUREs) post-course. Finally, aspects of the research seminar course can begin to be incorporated into the Introductory Biology sequence so that all incoming first year biology students have the opportunity to improve their skills in important areas like reading the literature and potentially increase their self-efficacy.

Ultimately, this research plays an important part in developing an understanding of the benefits of undergraduate research experiences, how experiences differ, the roles of mentors within faculty labs, and how we can better engage and prepare novice students for future research experiences. The results from this research are especially important for highlighting the need for continued assessment of offered experiences and coursework to better inform our practice of teaching and mentoring undergraduate students. As such, the results from this biology education research contribute significantly to the BER field as well as the department in which it was conducted.

Appendices

Appendix 1. Syracuse University IRB protocol #17-249

SYRACUSE UNIVERSITY

INSTITUTIONAL REVIEW BOARD
MEMORANDUM

TO:	Jason Wiles
DATE:	July 31, 2017
SUBJECT:	**Determination of Exemption from Regulations**
IRB #:	17-249
TITLE:	*The Effects of Undergraduate Research Experiences and Mentoring on SU Biology Students Self-Efficacy, Science Identity, Research Skills, Science Communication Skills, and Future Goals*

The above referenced application, submitted for consideration as exempt from federal regulations as defined in 45 C.F.R. 46, has been evaluated by the Institutional Review Board (IRB) for the following:

1. determination that it falls within the one or more of the five exempt categories allowed by the organization;
2. determination that the research meets the organization's ethical standards.

It has been determined by the IRB this protocol qualifies for exemption and has been assigned to categories **1** & 2. This authorization will remain active for a period of five years from **July 28, 2017** until **July 27, 2022**.

CHANGES TO PROTOCOL: Proposed changes to this protocol during the period for which IRB authorization has already been given, cannot be initiated without additional IRB review. If there is a change in your research, you should notify the IRB immediately to determine whether your research protocol continues to qualify for exemption or if submission of an expedited or full board IRB protocol is required. Information about the University's human participants protection program can be found at: http://orip.syr.edu/human-research/human-research-irb.html Protocol changes are requested on an amendment application available on the IRB web site; please reference your IRB number and attach any documents that are being amended.

STUDY COMPLETION: Study completion is when all research activities are complete or when a study is closed to enrollment and only data analysis remains on data that have been de-identified. A Study Closure Form should be completed and submitted to the IRB for review (Study Closure Form).

Thank you for your cooperation in our shared efforts to assure that the rights and welfare of people participating in research are protected.

Tracy Cromp, M.S.W.
Director

DEPT: Biology, 450 Life Sciences Complex **STUDENT:** Kelly Schmid

Research Integrity & Protections | 214 Lyman Hall | Syracuse, NY 13244-1200 | 315.443.3013 | **orip.syr.edu**

Appendix 2. Description of *New York Times* style article summary given to students.

<u>*New York Times* Style Article Summary</u>
8 summaries total, worth 25 points each

Write a summary of the primary research article for a general, non-science audience. This should include a brief background (2 pts.), overview of the problem (5 pts.), the research questions (5 pts.), brief description of how the research was done (5 pts.), the main finding (5 pts.), and the bigger picture of why this research is important (3 pts.). You should also include a title for your summary. The summary should not exceed one page single spaced, but may be as short as 2 full paragraphs.

Appendix 3. Description of the presentation and discussion assignment given to students.

<u>Presentation and Discussion Assignment</u>

For this assignment you will chose a biology lab from the list of approved labs and further investigate the details of the lab. This will include e-mailing the PI and other lab members (at least one post-doc, one graduate student, and one undergraduate student, if possible) to set up a time to briefly meet with them to learn about the inner workings of the lab. I have provided a set of interview questions which you should ask, in addition to any other questions that you might have. In addition to the interviews you should ask for a quick tour of the lab. **Scheduling times that work for everyone is difficult so be sure to do this as far in advance as possible.**

Once you have interviewed lab members and toured the lab, you will put together a 15-20 minute PowerPoint presentation about what you learned from your interviews and tour. This will be presented to the class on your assigned day. The presentation should include enough information about the lab that your classmates are able to have just as clear of an understanding about the lab as you now have. There will be approximately 5-10 minutes for questions at the end of your presentation.

In addition to your presentation, you will have to choose a publication from the lab for the class to read and discuss. You can ask the PI of the lab for any paper recommendations when you are interviewing them**. To ensure that the paper is appropriate for class, you must submit it to me one week before your assigned date.** You will then be in charge of leading the whole class discussion about the paper.

Of course, I understand that much of this is very new for many of you and am happy to help with any questions or concerns you might have.

Appendix 4. Rubric for the presentation and discussion assignment.

Score	50	45	40	35	30
Slide Design	Each info slide outlines or supplements a major point or details previous point. Doesn't visually overload or contain small font – all text clearly visible. 10-30 words per slide. Completely logical sequence of ideas.	Most info slides outline or supplement a major point. Most don't visually overload or contain small font. 8-40 words on a few slides. Sequence of ideas mostly logical.	Some slides outline or supplement a major point. Most don't visually overload or contain small font – all words clearly visible. 645 words on a few slides. Hard to tell where talk was heading sometimes.	Few slides outline or supplement a major point. They often visually overload or contain small font – all words clearly visible. Too many or too few words. Direction of talk hard to follow.	Talk quite difficult to follow, slides typically confusing or presented in illogical order.
Organization & Content	Presentation includes clear descriptions and answers to the interview questions, as well as additional questions and comments.	One component not clear and organized.	Multiple components not clear and organized	One component missing, not clear and organized.	Multiple components missing, not clear and organized.
Presentation Style	Looks at audience while talking, doesn't read from slides. Speaks loudly and clearly. Presentation reflects lots of practice, and segues from one slide to the next	Occasionally talks to slide rather than audience, rarely read from slides. Speaks loudly and clearly. Presentation reflects some practice, and segues from one slide to the next.	Occasionally talks to slide rather than audience, rarely read from slides. Most speech loud and clear. Presentation reflects some practice, and segues from one slide to the next.	Talks to slide almost as much as to audience; reads from slides. Speech hard to hear at back of room; pace too slow or too fast. Presentation reflects need for more practice.	Presenter demonstrates clear lack of practice or preparation.
Paper Choice	Paper is appropriate length and level for the class. The paper is relevant to the topic and written by assigned lab.	Paper is slightly above or below length and level for the class. The paper is relevant to the topic and written by assigned lab.	Paper is Paper is significantly above or below length and level for the class. The paper is relevant to the topic, and written by assigned lab.	Paper is significantly above or below length and level for the class. The paper is relevant to the topic, but not written by assigned lab.	Paper is significantly above or below length and level for the class. The paper is not relevant to the topic and not written by assigned lab.
Discussion	The paper has clearly been read and the student has a general understanding of the material. Comes with questions and prompts to promote discussion.	The paper has clearly been read and the student has a general understanding of the material. Does not come with questions and prompts to promote discussion.	The paper has been read, but not as thoroughly as necessary and the student has some understanding of the material. Does not come with questions and prompts to promote discussion.	The paper has been skimmed at the most and the student has little to no understanding of the material. Does not come with questions and prompts to promote discussion	The paper has clearly not been read and the student has no understanding of the material. Does not come with questions and prompts to promote discussion

Appendix 5. Example interview questions for students to use during their interviews when the visit the lab of their choice.

Example questions

Faculty member:

- What are the broad questions that the lab aims to address?
- What organism(s) does the lab use to address these questions?
- What makes those organisms the best ones for this research?
- How does this lab's research contribute to a broader knowledge base?
- How are the projects in the lab funded?
- How many people typically work on one project?
- Do you collaborate with other labs either in the department or outside of the department?
- What are the general steps that members of you lab take when designing and running experiments?
- What is the most challenging part of the type of research that you do?
- Do most projects in your lab result in a publication?
- What journals do your manuscripts typically get published in?
- What papers that your lab has published would you recommend a first or second year undergraduate read?

Post-Docs, Grads, Undergrads (make sure to ask someone for a quick tour of the lab)

- What is your role in the lab?
- What project(s) are you currently working on?
- What will this research contribute to the field?
- How many people are working on this project with you?
- How did you come up with the idea for this project and/or why are you interested in this project?
- What are some techniques or methods that you are using?
- Do you plan to publish a paper(s) on this research?
- What has been the most challenging part of this research?

Appendix 6. Description of the brief literature review assignment given to students

Brief literature review (250 points)

For this assignment you will write a brief literature review on a topic of your choice.
The topic must be in the field of biology and must be approved by Kelly. The topic may be one that we discussed over the past 9 weeks of class, or another that you find interesting. You should e-mail your topic choice to instructor by April 16th.

Your review should describe the topic in detail, outline what is known about the topic (using the primary literature), and identify what still needs to be done or questions regarding the topic that still need to be answered.

-You are required to cite at least 4 primary research articles. They should be cited in the text and in a reference section at the end of the paper. Please also attach the abstracts from each of the articles to your paper copy only.
-The literature review should be approximately 2 pages single spaced, or 4 pages double spaced (the reference section does not count towards this page count).
-The font should be 12 point and the margins normal.
-At the top of the first page please put the title of your review and you name.

Appendix 7. Rubric for the brief literature review assignment.

Score	50	45	40	35	30
Overall writing style, grammar, and ability to follow directions regarding the paper (laid out in the description)	Student's writing style is clear and understandable. Proper grammar and punctuation has been used. All directions laid out in the assignment description have been followed.	Student's writing style is slightly unclear. A few grammatical errors and punctuation errors. All directions laid out in the assignment description have been followed.	Student's writing style is slightly unclear. Many grammar and punctuation errors. All directions laid out in the assignment description have been followed.	Student's writing style is very unclear. Many grammar and punctuation errors. Some directions laid out in the assignment description have not been followed.	Student's writing style is unclear and difficult to understand. Many grammar and punctuation errors. Most of the directions laid out in the assignment description have not been followed.
Topic Description	The topic is described completely and uses the literature to back up claims.	The topic is described but could be more complete. The literature is used to back up claims.	The topic is described but needs much more detail. The literature is used to back up claims.	The topic is described but needs much more detail. The literature is not used to back up claims.	The topic description is significantly lacking detail. The literature is not used to back up claims.
Outline of what is known about the topic	What is known about the topic is described completely and uses the literature to back up claims. The student does not simply summarize each paper.	What is known about the topic is described but could be more complete. The literature is used to back up claims.	What is known about the topic is described but needs much more detail. The literature is used to back up claims.	What is known about the topic is described but needs much more detail. The literature is not used to back up claims.	What is known about the topic is significantly lacking detail. The literature is not used to back up claims.
Identify what still needs to be done or questions regarding the topic that are still unanswered	What still needs to be done is identified and is described completely, using the literature to back up claims.	What still needs to be done is identified but could be described more completely. The literature is used to back up claims.	What still needs to be done is identified but needs much more detail. The literature is used to back up claims.	What still needs to be done is identified but needs much more detail. The literature is not used to back up claims.	What still needs to be done is significantly lacking detail. The literature is not used to back up claims.
References	There are 4 references properly cited in the text and in the reference section at the end of the document. The paper has not been plagiarized.	There are 4 references cited in the text and in the reference section at the end of the document. There are a few errors in the citation style and a few direct quotes. The paper has not been plagiarized.	There are 4 references cited in the text and in the reference section at the end of the document. There are many errors in the citation style and many direct quotes. The paper has not been plagiarized.	There are less than 4 references cited in the text and in the reference section at the end of the document. The paper has not been plagiarized.	There are less than 2 references cited in the text and in the reference section at the end of the document. The paper has not been plagiarized.

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Kelly M. Schmid
Syracuse University Department of Biology
107 College Place Syracuse, NY 13244
856.332.7374
kschmid@syr.edu
Portfolio: https://kschmid59.wixsite.com/portfolio

EDUCATION

Doctor of Philosophy-Biology, January 2017- May 2020 (Advisor: J.R. Wiles)
Certificate in University Teaching, granted by the SU Graduate School through the WiSE program
Syracuse University, College of Arts and Sciences, Syracuse, NY
Master of Science – Biology, August 2014-August 2016 (Advisor: J. Friedman)
Syracuse University, College of Arts and Sciences, Syracuse, NY
Bachelor of Science – Biological Science, Cum Laude, September 2009-May 2013
Rowan University, College of Science and Mathematics, Glassboro, NJ

RESEARCH EXPERIENCE

Ph.D. Research (Syracuse University), January 2017-present
Undergraduate research experiences in biology: Roles of mentors and impacts of early exposure and types of engagement on student outcomes
Advisor: J.R. Wiles
Investigating the effects of different types of undergraduate biology research experiences on students' science identities, self-efficacy, goals, achievement, and other outcomes, as well as the role of mentors within the lab.

Master's Research (Syracuse University), August 2014-August 2016
The effects of genetic and environmental variation on growth and flowering
Advisor: J. Friedman
Investigating the effect of photoperiod on flowering time and growth in a single population of *M. guttatus* that exhibits phenotypic variability.

Independent Undergraduate Lab/Field Research (Rowan University), January-May 2013
Herbivory and plant defense mechanisms: Glucosinolate production response in two *Brassica* species
Advisor: T. Scott
Studied the relationships between herbivory, phytochemical production, and resource allocation.

TEACHING EXPERIENCE

HHMI Active Learning Fellow
September 2018-present
This research and faculty development fellowship is funded by an Inclusive Excellence grant from the Howard Hughes Medical Institute.
General Biology Sequence, BIO121 & BIO123
Designed active learning modules and independently implemented them on a weekly basis in the fall and spring semesters of the large-enrollment (300-600 students) general biology course sequence. These

modules have been adopted into the curriculum for the introductory sequence ensuring an inclusive environment of active learning on an on-going basis.

Genetics, BIO326

Worked with professors during an HHMI-funded course redesign to familiarize them with current active learning techniques and helped them to design and implement active learning modules into their course.

Instructor

January 2018-May 2018

Introduction to Biological Research, BIO200

Designed and implemented a seminar-style, writing-intensive course for first or second year biology or biology-related, majors; with the goal of improving science communication skills, ability to read primary literature, familiarity with biological research concepts, better understanding of the processes of science. Taught 2 sections (15 students total).

Teaching Assistant

August 2014-May 2016, January 2017-May 2018

General Biology, BIO121 & BIO124

Taught two lab sections (48 students) per semester (11 sections total); requiring small class instruction, grading course materials, developing new quizzes, held regular office hours, mentor students as necessary.

Ecology and Evolution, BIO345

Conducted in-class review sessions before each of the 4 exams, held regular office hours, mentored students as necessary, graded course materials.

Genetics, BIO326

Assisted with administration of exams for 200 students.

MENTORING

Summer Undergraduate Research Forum, June 2017-August 2017, June 2018-August 2018, June 2019-August 2019

Mentored undergraduates (Jeff Darkwa and Anna Bjarvin) who assisted in my research, January 2015-August 2015

PROFESSIONAL DEVELOPMENT

HHMI Inclusive Excellence CHANcE workshop: A Guide to Inclusive Practices, October 2019
HHMI Inclusive Excellence CHANcE Hands-on workshop for Course Transformation, June 2019
Evo-Day Evolutionary Biology of Interacting Organisms Symposium at Cornell University, May 2019
WiSE Future Professoriate Program, November 2017-May 2019
HHMI Inclusive Excellence CHANcE Project Kickoff Workshop, January 2019
Plant Ecology and Evolution reading/journal group, August 2014-May 2018
Evo-Day Phylogenomics Symposium at Cornell University, May 2017
Evo-Day Evolution and Conservation Symposium at Cornell University, May 2016
WiSE Scientific Writing Workshop, January 2016
Center for Reproductive Evolution meeting, August 2014-May 2016

SERVICE

Biology Graduate Student Organization Curriculum Committee representative, May 2017-May 2018
Served on Curriculum Committee of the Syracuse University Department of Biology as the Biology Graduate Student Organization's appointed graduate student representative.

SUPA meeting talks (2), October 2016
Provided two professional development seminars for 35 high school teachers in the Syracuse University Project Advance (SUPA) program.

AWARDS

Carlock Award for Excellence in Graduate Research in Biology Education, Fall 2019
Syracuse University 2019 Summer Fellowship
Outstanding Teaching Assistant Award, Spring 2018
GSO Travel Award, May 2016, July 2018
Biology Travel Award, May 2016, July 2018, June 2019
Graduate Student Symposium Best Poster Award, March 2015

SOCIETY MEMBERSHIP

National Association for Research in Science Teaching (NARST)
Society for the Advancement of Biology Education Research (SABER)
Association of College and Biology Educators (ACUBE)

CONFERENCES & POSTERS/PRESENTATIONS

K.M. Schmid & J.R. Wiles. Exploring Approaches to Engaging Undergraduates in Research: Differential Impacts on Students' Self-efficacy and Science Skills. Talk at the National Association for Research in Science Teaching Annual Conference. Portland, OR. March 2020.

K.M. Schmid & J.R. Wiles. Exploring approaches to engaging undergraduates in research: Differential impacts on students' self-efficacy and science skills. Talk at the Association of College and Biology Educators
Annual Conference. Syracuse, NY. October, 2019.

K.M. Schmid & J.R. Wiles. Creating inclusive classroom environments through institutional change towards adopting active learning practices. Poster at the Society for the Advancement of Biology Education Research Conference. Minneapolis, MN. July, 2019.

K.M. Schmid, R.D.P. Dunk, & J.R. Wiles. The effects of an introduction to biological research course on novice students' views on the nature of science. Talk at the Society for the Advancement of Biology Education Research Conference. Minneapolis, MN. July, 2018

K.M. Schmid & J.R. Wiles. Potential effects of course-based undergraduate research experiences on students' self-efficacy, research skills, and future goals. Poster at the Society for the Advancement of Biology Education Research Conference. Minneapolis, MN. July, 2018.

K.M. Schmid & J. Friedman. Intra-population genetic variation for flowering and growth in response to photoperiod. Talk at the Evolution Conference. Austin, TX. June, 2016.

K.M. Schmid & J. Friedman. Effects of different environments on allocation strategies in plants. Talk at Biology Graduate Student Seminar Series. Syracuse, NY. April, 2015.

K.M. Schmid & J. Friedman. Effects of different environments on allocation strategies in plants. Poster at GSO Graduate Student Research Symposium. Syracuse, NY. March, 2015. (Best poster award)

K.M. Schmid, W. Hurley-Rioux, & T. Scott. Herbivory and plant defense mechanisms: Glucosinolate production response in two *Brassica* species. Poster at Ecological Society of America Mid-Atlantic Chapter Meeting. Dover, DE. April, 2013.

K.M. Schmid, W. Hurley-Rioux, & T. Scott. Herbivory and plant defense mechanisms: Glucosinolate production response in two *Brassica* species. Poster at Saint Joseph's Sigma Xi Research Symposium. Philadelphia, PA. April, 2013.

K.M. Schmid, W. Hurley-Rioux, & T. Scott. Herbivory and plant defense mechanisms: Glucosinolate production response in two *Brassica* species. Poster at Rowan University STEM Symposium, Glassboro, NJ. April, 2013.

PUBLICATIONS

Schmid, K. M., & Wiles, J. R. 2019. An introduction to biological research course for undergraduate biology students. *Journal of College Science Teaching*, 49(1), 48–52.

Rubin* M.J., **Schmid, K. M. *** & Friedman, J. 2018. Assortative mating by flowering time and its effect on correlated traits in variable environments. *Ecology and Evolution* 00: 1–11. Article DOI: 10.1002/ece3.4765. *equal contribution.

2020 **Schmid, K.M.**, Dunk, R.D.P., & Wiles, J.R. Early exposure to primary literature and interactions with scientists influences novice students' views on the nature of science. *Journal of College Science Teaching* (in press)

2020 Sloane, J.D., Dunk R.D.P, Snyder J.J., Winterton C.I., **Schmid K.M.**, & Wiles J.R. Peer-Led Team Learning improves minority student retention in STEM majors. *PLoS One* (in review).