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

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Abstract

Approaches toward engaging undergraduates in scientific research have included research experiences based in faculty laboratories (FLREs), course-based undergraduate research experiences (CUREs), and courses rooted in primary research literature that may be precursors to research experiences. We examined outcomes for undergraduate biology students enrolled in FLREs, CUREs, and a literature-based introduction to research seminar course. Students engaging with research that involved authentic, student-centered inquiry had significant increases in research skills, but little change in their self-efficacy. Students engaging with research in a more structured or guided experience did not exhibit the same gains in skills. Additionally, although they began with comparatively low self-efficacy scores, students enrolled in the seminar course increased in self-efficacy to levels equivalent to those of students engaging in FLREs. Across all types of engagement, students who reported a change in their future goals post-graduation tended to add pursuing a Ph.D. to their future plans - this was most evident in the seminar course. We therefore recommend an introduction to research seminar course for novice students toward building self-efficacy early in their careers as a way to prepare for - and potentially increase - engagement in CUREs and FLREs, and matching undergraduates with potential mentors for future research experiences.

Introduction

A growing number of faculty at many universities are incorporating 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 to 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 learners across demographic groups, it is especially beneficial for learners from underserved minoritized groups, and therefore may contribute to increased diversity and inclusion within science courses (Ballen et al., 2017; Bangera & Brownell, 2014; Espinosa et al., 2019; Haak et al., 2011; Lopatto, 2007; Sloane et al., 2021; Snyder et al., 2016). These observations 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 been shown to improve science self-efficacy (or one's confidence in their abilities regarding science), science identity, research skills, science communication skills, and alter 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 both 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, such as self-efficacy and research skills, and engage in scientific inquiry.

FLREs are considered to be the most "authentic" (Weaver et al., 2008, pg. 579), research-based type of research engagements, as students have the opportunity to directly engage in lab work and original research in a professional setting. In these experiences, students are engaging in authentic inquiry, defined as students collecting data and engaging in novel research, either independently or collaboratively with other lab members. FLREs have been shown to be beneficial to students in a variety of ways. Students who participate in these experiences have reported an increase in self-efficacy, science identity (Adedokun et al., 2013; Gardner et al., 2015; Marrero et al., 2017), 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). They also promote positive faculty mentor-mentee relationships (Frantz et al., 2017; Hippel et al., 1998; Kardash, 2000), and provide for near-peer mentorship from more senior undergraduate researchers, graduate students, and postdocs (K. M. Schmid & Wiles, 2022). Such beneficial changes and relationships can illicit positive outcomes for student success and persistence in science, as such, it has been shown that involvement in FLREs increase students' desire to pursue research in the future, either through a career or graduate studies (Hathaway et al., 2002; Hippel et al., 1998; Hunter et al., 2007; Kardash, 2000; Linn et al., 2015; Lopatto, 2007; Marrero et al., 2017). Ultimately, there are numerous benefits to engaging in novel research alongside scientists in faculty labs and can results in increases persistence in science for students.

While the benefits of FLREs are well known, the main limitation to these experiences is their availability. Within a university department, there are only so many faculty, so many labs, and so many spaces within each lab (Frantz et al., 2017). As such, since there is often an application/interview process, these experiences also are often biased towards to higher achieving students and those with greater science self-efficacy who may feel more comfortable approaching and speaking to faculty (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 enrollment capacity than FLREs. These are courses in which students are introduced to primary literature, independently formulate research questions, design experiments, collect and analyze data, and write using scientific conventions (Brownell et al., 2015; Brownell et 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 in which students are engaging (Brownell & Kloser, 2015) from authentic inquiry, where students are designing an independent research project, to structured or guided inquiry, where students are collecting and analyzing data for a preexisting project. These experiences have been 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 alter 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 undergraduate research experiences are relatively well understood, how we can make research experiences more accessible to students (through CUREs or seminar courses) and 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 (Committee on Strengthening Research Experiences for Undergraduate STEM Students et al., 2017). These are courses in which students are required to read the primary scientific literature, discuss it, and write scientifically (Brownell et al., 2013). Such courses have been 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 these 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 been 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). 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.

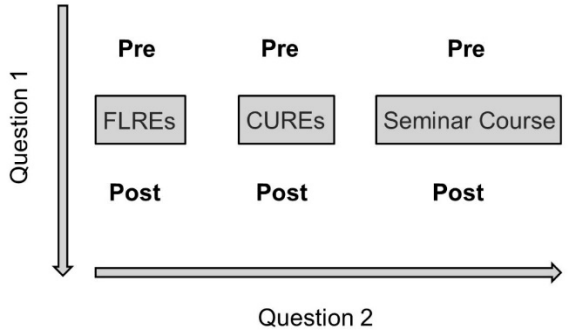
It is important to assess the effectiveness of various types of undergraduate research engagement on the improvement of students' self-efficacy and research skills in order to inform and support implementation and improvement of such experiences. Engaging in these experiences can help students in science fields to graduate with a clear understanding of what it means to engage in scientific inquiry 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 a greater number of undergraduates in the sciences with an opportunity to engage with research, potentially improving their personal and professional development as bourgeoning scientists.

Here, we investigate the effects of FLREs, CUREs, and a research seminar course offered at a large, private, research-intensive (Carnegie R-1 designation) university. This study aims to address the following questions (Figure 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 from one another in their effect on students' self-efficacy, research skills, and future goals?

Figure 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 from one another in their effect on students' self-efficacy, research skills, and future goals?



Methods

Participants and Instruments

All participation in this research by students was voluntary and uncompensated, and all data were collected under IRB-approved protocol (#17-249). We surveyed and assessed students enrolled in three different experiences at a large, private, research-intensive 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 al., 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 prior experience (Table 1)

Student responses to the 23 questions in the self-efficacy scale are measures 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.

Table 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

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 Qualtrics, while the skills assessment was administered in-person during class or outside of class by appointment. 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 (15 weeks). Students participating in a FLRE (n=12, Table 2) were able to participate regardless of the time they have been working in the lab.

To determine which courses in the biology 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 available to students. Four courses fell into a CURE category, three were offered at the time of the research, and 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 1.) students were involved in independent, student-driven research and were expected to complete a research project of their own design, which most closely aligned with the open or authentic inquiry lab type described by (Brownell & Kloser, 2015). In contrast, CURE 2 (n=20, Table 1) had students collect and analyze data for a research project that had been designed by the instructor, which 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 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 (Schmid & Wiles 2019).

Analyses

Self-efficacy was measured along three factors previously described by Baldwin et al. (1999). Students' 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-experience 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 that 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-experience responses in SPSS version 28 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.

Results

To test our hypothesis that engaging in a research experience will shift students' future goals towards some sort of Ph.D. program involving research, we first examined whether the different research experiences affected the future career goals of the participants. Previous research has shown that participation in research experiences increases students' interest in graduate programs. Therefore, we examined the effects of engaging in research experiences on students' future goals. 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 2). This category 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

Table 2. Student responses 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%

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..

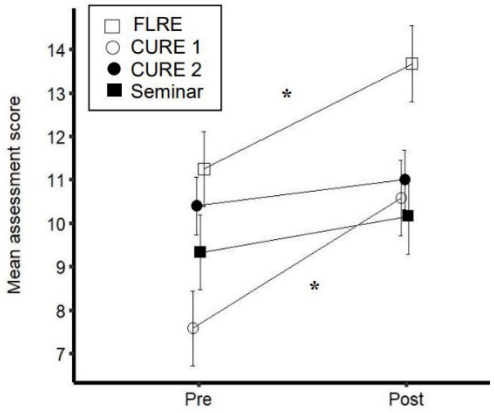
The remaining students indicated that their future goals included pursuing a career in the health professions, industry positions, or non-science positions.

Analysis of student responses to the pre-experience survey to the post-experience survey shows that within each type of engagement the percentage of students that indicate a shift in their future goals and where these shifts happens. Of the students in FLREs, 38% reported a shift in their future goals. These shifts happened from a desire to pursue a M.D. to either an M.D./Ph.D. or "other." Of the students enrolled in CURE 1, 33% reported a shift in their future goals. Students who experienced a shift went from the desire to pursue "other" pre-experience to a desire to pursue a graduate program in science post-experience. Of the students enrolled in CURE 2, 35% of the students reported a shift in their future goals. Students who experienced a shift went from the desire to pursue an M.D. pre-experience to an M.D./Ph.D. post-experience. The greatest shift happened within the research literature seminar course, with 50% of the students reporting a shift in their future goals. Of these students, the shift was from the desire to pursue an M.D. or "other" pre-experience to an M.D./Ph.D. post-experience.

To investigate the impact of the different research experiences on the students' research skills, we examined students' ability to come up with hypotheses and design an experiment based on a question using a skill assessment (Etkina et al., 2006). We found that the FLRE and CURE 1 experiences (or those that engage students in authentic inquiry) have the largest increase pre- to post- experience. Surprisingly, CURE 1 had the lowest score for pre- scores, despite all of these students being seniors (Figure 2). Additionally, the CURE 2 and seminar experiences did not have a significant effect on skills assessment (Figure 2). More specifically, students engaged in a FLRE had significantly higher assessment scores than CURE 2 ($p=0.002$), and the seminar ($p=0.01$)(Figure 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 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 2). A 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) indicating that all experiences resulted in an increase from pre- to post-, as well as a main effect of experience ($F_{1,52}$=4.22, p=0.01) indicating that experiences differed from one another in their mean student score.

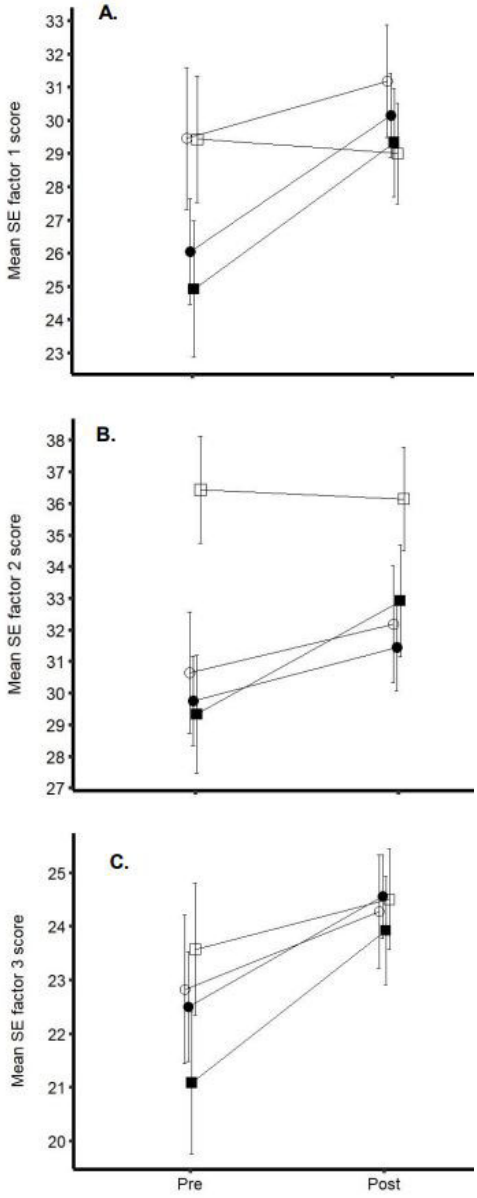
Figure 2. Estimated marginal mean skill assessment scores pre and post experience.



Open shapes correspond with experiences considered to engage students in authentic inquiry (FLRE and CURE 1), while closed shapes correspond with experiences not considered to engage students in authentic inquiry (CURE 2 and seminar). * indicates a significance value p=<0.05.

To investigate the effect of different research experiences on students' science self-efficacy, we next examined science self-efficacy using the science self-efficacy scale (Baldwin et al., 1999). For factor one questions (methods of biology), the FLRE and CURE 1 exhibit higher pre-experience scores compared to CURE 2 and the seminar. However, after the research experience, the CURE 2 and seminar scores (comprised of more novice students) increase so that they are statistically similar to the FLRE and CURE 1 post-experience scores. In addition, 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 3A). Thus, our results indicate that participation in experiences similar to CURE 2 and the seminar can increase factor one self-efficacy (Figure 3A).

Figure 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 (FLRE and CURE 1), while closed shapes correspond with experiences not considered to engage students in authentic inquiry (CURE 2 and seminar).

A.) Shows mean scores pre- and post-experience for the eight questions in factor one (methods of biology). B.) Shows mean scores pre- and post-experience for the nine questions in factor two (generalization to other biology/science courses and analyzing data). C.) Shows mean scores pre- and post-experience for the six questions in factor three (to application of biological concepts and skills).

In contrast, questions that measure factor two (generalization to other biology/science courses and analyzing data) for the biology self-efficacy indicate that students in a FLRE experience have significant higher pre-experience scores compared to the other courses, but do not result in measurable improvements in the post-experience analysis. CURE 1, CURE 2, and the seminar all show score improvements in the post-experience test but maintain score averages below the FLRE. 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 3B). Thus, students in each of the experiences tend to show an increase in factor two self-efficacy over a semester.

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, novice 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 3B).

Furthermore, when we examined factor three questions, we observed that all experiences resulted in an increase in average scores from pre- to post-experience. The seminar and CURE 2 courses showed significant improvements, such that the post-experience scores for each course were statistically similar. 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 3C). Thus, we find that student participation in FLRE, CUREs, or a seminar yield benefits for factor three self-efficacy. 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).

Discussion

Previous 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 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.

All experiences result in increased interest in engaging in future research

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). The population of students that participated in this study is largely comprised of individuals who express a desire to pursue a medical degree or other health profession post-graduation (Table 2). Our results indicate that there was a marked shift in students' future

goals from pre to post engagement. This shift was largely towards an increased interest in working towards a Ph.D., either as the primary goal or in addition to an M.D. (Table 2). Students in the seminar course experienced the greatest change, with 50% indicating a shift in their future goals pre to post course (Table 2). This suggests that engaging with the primary literature and learning more about biological research may play an important role in the decisions 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; therefore, an introductory course in scientific literature is particularly beneficial for shaping novice students' interest in pursuing research opportunities in graduate school.

Engaging in authentic inquiry increases student science process abilities

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 2). A significant increase in scores from pre to post experience was also shown for students in CURE 1 (Figure 2). This suggests that engaging in authentic inquiry, as is done in the FLRE or CURE 1, results in students that have greater skill in engaging with the process of science and participating in research work. While students in CURE 2 began with similar scores to those in a FLRE, there was less of a shift in these scores from pre to post. Similarly, students in the seminar course did not experience a significant shift. This is likely due to the course design not including a lab component. Students in CURE 2 and the seminar course are not engaging in authentic inquiry, which might be what is limiting their growth in this skillset. These results indicate that courses like CURE 1, in which an authentic question generated by the student is investigated, can be especially helpful in developing students' science process abilities, which can be beneficial in preparing them to engage in an FLRE.

Participating in a research seminar course increases novice students' self-efficacy

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 further highlight these benefits. We found that students in FLREs experienced exhibited a higher self-efficacy overall, but little change pre experience to post experience (Figure 3A, 3B). This result is an important indicator of who is ending up in FLREs. These experiences are often more selective in the students that are able to participate, often requiring an application process. Our results show that students with a high self-efficacy are those that are seeking out and participating in these more selective research experiences. On the other hand, students in the research seminar course exhibited a significant increase in science self-efficacy from pre to post experience (Figure 3A, 3B, 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. If students with an already high self-efficacy are the ones that are engaging in FLREs, and participating in a seminar course as a novice student increases student self-efficacy, then participation in such a seminar course might increase the likelihood that those students will apply for and engage in an FLRE. This is an important finding, as it suggests that a research seminar course can increase access, thus increasing equity and inclusion, into FLREs.

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, 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).

Limitations

Included in the limitations of this study is that students varied in academic year level. This variation existed between research experiences and, to a lesser extent, within research experiences. Academic year level may be correlated with students' levels of intellectual development, which may impact the student outcomes measured. However, these differences between experiences are especially difficult to control given prerequisites and availability. Another limitation is that the sample size of this study is both small and limited to a single institution. While this does not impact the validity of the results found among participants, it suggests that conducting similar studies across a broader student population would provide more insight across varied contexts.

Conclusions

The results from this research suggest that participating FLREs, CUREs, or a research seminar course all have important positive outcomes for students. Specifically, a research seminar course for novice students seems particularly beneficial for student self-efficacy, which may have important implications in their likelihood to seek out FLREs in the future, thus increasing access to these more selective experiences. Investigating 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 these experiences 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. This may help them to become more confident and better prepared to pursue research experiences in the future, thus improving access to more authentic research experiences.

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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. Jason Wiles contributed to the conceptual development of the study and oversaw its implementation. All authors contributed to the development of the final manuscript.

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