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Articles

Building Confidence in Scientific Competence: Impacts of an Introduction to Primary Literature Course on Undergraduate Students' Science Identity and Interest in Research

Mariah C. Maxwell, Takunda Maisva, Jason R. Wiles

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Abstract

Introduction to Primary Literature (IPL) courses can be early-career precursors to undergraduate research experiences, whereby students can become familiar with potential mentors and their research toward better alignment with student/faculty interests and goals. IPL courses have been shown to increase student science self-efficacy and understanding of the nature of science to levels congruent with students entering Course-based Undergraduate Experiences (CUREs) and Faculty-Led Research Experiences (FLREs), which may increase the number and diversity of students engaging in these high-impact activities. Further research is needed to understand how an IPL course can impact students' science identity, defined as the extent to which one relates to science, which has been associated with student success and persistence in STEM degree programs. This study employed a quasi-experimental, mixed methods approach to explore the impacts of engaging with the products of research through reading primary research articles, communicating scientifically, and interacting with scientists of various levels on the science identities of undergraduate students enrolled in a seminar-style biology IPL course at a large, private, research-intensive institution in the Northeastern United States. Pre- and post-course surveys, as well as a focus group interview, were used to collect student information and measure the science identity of participants. Interpretation of the quantitative data and themes drawn from the qualitative responses are presented herein, notably that students became more confident in their abilities to understand science and scientific literature and in their competence as scientists in training.

Keywords: Introduction to Primary Literature (IPL) course, science identity, interest in research

Undergraduate Research Experiences (UREs), such as Faculty-Led Research Experiences (FLREs) and Course-based Undergraduate Research Experiences (CUREs) are often a student's first introduction to the true nature of science. Participation in UREs has been associated with increases in science self-efficacy and a strengthening of science identity which can help orient students towards graduate and professional programs in STEM (Chemers et al., 2011; Egan et al., 2013). URE participation has also been associated with increased student persistence and interest in pursuing research opportunities amongst students from underserved populations (Reig et al., 2018).

Despite their many benefits, UREs are often limited due to a lack of funding, staffing, or physical space (Frantz et al., 2017). To compound this issue, students from underrepresented groups and low-income households are often tasked with navigating existing barriers to research experiences, such as a lack of representation in the field, insufficient academic preparation, and historical barriers (Pierszalowski et al., 2021). STEM enrichment programs have been designed and implemented to introduce students to the research environment and provide opportunities for faculty mentoring (Merolla & Serpe, 2013).

Introduction to Primary Literature (IPL) courses have been recommended by the National Academy of Sciences (2017) as a steppingstone to help students access UREs by familiarizing students with potential mentors and their research, allowing for better alignment with student/faculty interests and goals, and the efficacy of this practice has subsequently been shown by Schmid, Hall & Wiles (2023). IPL courses often follow a seminar-style format in which students read, discuss, and write about primary literature in order to familiarize themselves with the products of science and scientific methods of communication (Brownell et al., 2013; Sandefur et al., 2016; Schmid & Wiles, 2019). IPL courses have been shown to increase student science self-efficacy and understanding of the nature of science to levels congruent with students entering UREs (Carter et al., 2017; Schmid, Dunk, & Wiles, 2021; Schmid, Hall, & Wiles, 2023). However, further research is needed to understand how an IPL course can impact students' science identity.

Science identity can be described as the extent to which one relates to science (Carlone & Johnson, 2007). Having a strong science identity is important for undergraduate STEM students because it has been associated with student persistence in STEM degree programs and interest in scientific careers (Chang et al., 2011; Perez et al., 2014). Participation in IPL courses could strengthen undergraduate students' science identities in several ways. Practice with reading, writing, and discussing scientific research could improve students competence and performance, which are key components of science identity. Being exposed to the products of science and exploring current hot topics in science could also pique students' interest in science and students' interest in pursuing graduate programs in science (Kozeracki et al., 2006; Hathaway et al., 2002). Additionally, being exposed to diverse scientists could also help students find relatable scientific role models (Fairlie & Robert, 2014).

Understanding how early exposure to research affects students' science identity will support the development and implementation of IPL courses, which may increase the number and diversity of students engaging in high-impact activities like UREs. For this study, we used a quasi-experimental, mixed-methods approach to explore the impact of participating in an IPL course on undergraduate students' science identities, at a large, private, research-intensive (Carnegie R1 designation) university in the Northeastern United States. We aim to address the following research questions:

1. Does participating in an IPL course impact undergraduate students' science identity? If so, how?
2. Does participating in an IPL course impact undergraduate students' interest in conducting biological research? If so, how?

Carlone and Johnson (2007) described three main ways to strengthen a science identity: (1) by fostering knowledge growth, (2) by providing opportunities to display scientific knowledge and practices in the presence of others, and (3) by being acknowledged as a science person by oneself and meaningful others. Therefore, we expected that participating in an IPL course would strengthen our students' science identities by helping them to gain knowledge about scientific practices and by giving them the opportunity to practice communicating about science with their peers. We also expected that interacting with diverse members of the scientific community would combat harmful stereotypes our students may have encountered about who is and is not a scientist, providing them a space to begin envisioning themselves as scientists. We also expected that exploring the breadth of research being conducted in the biology department would increase the likelihood of connecting with an area of research of specific personal interest.

Methods

Setting and Recruitment

The seminar-style biology IPL course was similar to other iterations of an IPL course designed to introduce students to research in our institution's biology department (Carter & Wiles, 2017; Humphrey & Wiles, 2021; Schmid and Wiles, 2019; Sloane & Wiles, 2020). A novel addition to our iteration of the IPL course was that students had opportunities to engage with potential faculty research mentors through an interview assignment and to engage with near-peer graduate researchers by attending their departmental research talks.

Students were recruited for the IPL course from among those who had taken the university's Introductory Biology course during the previous semester. The Introductory Biology course is primarily populated by first-year students, and it is required for Biology majors while also serving students from many other related and non-related majors. Ahead of the registration period for the following semester, the introductory course instructor presented the IPL course as an elective offering that could help prepare students for joining a faculty lab as an undergraduate researcher.

Data Collection

Students in the IPL course were given class time during the beginning and end of the semester to complete online surveys comprising Chemers and colleagues' (2011) science identity instrument, demographic questions, and open ended questions about students' career goals, interest in research, and reasons for taking the course. Chemers and colleagues' (2011) instrument contains seven items to which students respond using a five-point Likert scale (1 being strongly disagree, 5 being strongly agree). Pre- and post-course responses to the science identity scales were converted to percentages for graphical representation. Chronbach's alpha was .975 for the science identity scale, which indicates very good internal consistency of the instrument.

On the last day of class, students participated in a discussion led by the course instructor (Author 2). The instructor presented the discussion as a metacognition activity and the purpose and benefits of metacognition were explained. All students completed an informed consent form to be recorded and to have their contributions used for research purposes. During the class discussion, students were asked to write down their responses to a series of discussion questions which were projected on the classroom screen during the session. After a few minutes of quiet reflection, students were invited to join a discussion sharing their thoughts and feelings regarding the discussion prompts. The discussion questions were open-ended and intended to elicit students' thoughts about how the course may or may not have influenced their interest in conducting biological research and their science identity. For research purposes, this discussion group was treated like a focus group interview. This method was selected in lieu of individual interviews in order to maximize the number of students participating.

The group discussion was recorded via Zoom and transcribed using an online transcription service. The software NVivo was used to analyze qualitative data. Author 1 and Author 2 coded the data using a mix of predetermined codes and codes that arose based on the data, then compared codes until they reached 95% agreement. The responses of individual students of interest were then examined to find common themes regarding the change in science identity.

This research was conducted following a protocol approved by the Institutional Review Board of the study institution's Office of Research and Integrity and Protections (IRB#: 20-353).

Participants

Fourteen students initially enrolled in the course. One student (S12) dropped the course before the end of the add/drop period because of a change in schedule. Eleven of the students completed both surveys and agreed to have their information used for research purposes. One student (S13) only completed the post-course survey, and another student (S14) did not complete either survey. All remaining students participated in the focus group discussion. Of the 12 students whose demographic information were collected, nine identified as women, two (S5 and S13) identified as men, and one (S4) preferred not to disclose their gender identity (Table 1). Three students (S1, S3, and S13) were considered underserved marginalized (URM) students based on their self-reported race and ethnicity. All students were majoring in biology

Table 1. Demographics and majors of students enrolled in the IPL course.

Student ID	Category			
	Gender	**Hispanic, Latin*, or Spanish Origin?**	**Ethnicity**	**Major**
S1	Woman	No	Black or African American	Biology
S2	Woman	No	White	Biology and Entrepreneurship
S3	Woman	Yes	I prefer not to say.	Biology
S4	Prefer not to disclose	No	White	Biology
S5	Man	No	Korean	Biology
S6	Woman	No	Korean	Biology
S7	Woman	No	White, Chinese	Biology
S8	Woman	No	White	Biotechnology and Health Humanities
S9	Woman	No	White	Biology and Neuroscience
S10	Woman	No	White	Biology
S11	Woman	No	White	Neuroscience and Biotechnology
S13	Man	Yes	Black or African American	Biotechnology
S14	Undisclosed	Undisclosed	Undisclosed	Undisclosed

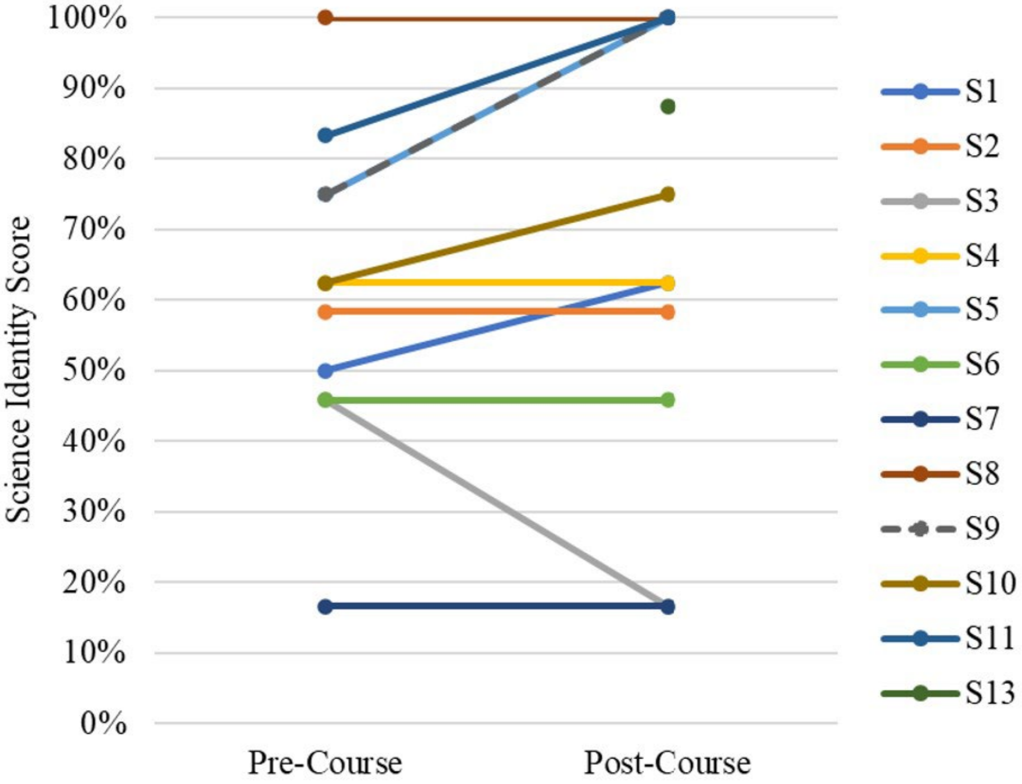
and/or a biology-related major like neuroscience or biotechnology.

Results and Discussion

Pre- to post-course, five students saw increases in their science identity score, five remained the same, and one saw a decrease (Figure 1). Inferential statistics were not performed because of the small sample size, although there was a small upward trend in science identity changes pre- to post-course for students who started with a science identity score of about 50% or higher. The median science identity score started at 63% (SD = 22%) and increased slightly to 69% (SD = 31%) by the end of the course. Three of the five students who saw increases in their science identity scored 100% on the post-course survey (S5, S9, and S11), and one student (S8) scored 100% on both the pre- and post-course surveys.

Recordings of student responses to questions asked during the metacognitive discussion were used to produce a codebook. Codes frequencies were based on the transcript. The code frequencies are meant to highlight the most relevant aspects of the discussion. It is

Figure 1. Change in science identity score pre- to post-course for each student (n=12). S5 and S9 had the same pre- and post-course scores, so their lines overlap.



important to note that though some codes like "science identity" have relatively low frequencies, some of these codes represent complex constructs that the students may not have been metacognitively aware of. Definitions of the codes and exemplar quotes have been provided for clarity and potential replication purposes (Table 2). The codebook consists of 16 codes designed to assist the researchers in organizing the experiences and responses of the participants of the course during the metacognitive discussion.

Exposure to "real science" increases competence and interest in conducting research

Student views of what a scientist looks like can influence the extent to which they see themselves in the field and whether they choose to continue pursuing STEM degrees (Cheryan et al. 2015). Though not directly engaged in the research themselves, students in our course were exposed to aspects of "real science" through discussions of primary literature and interacting with a diverse array of scientists. Examining primary literature has been associated with increases in undergraduate understanding of the nature of science particularly, the iterative nature of scientific research (Schmid et al, 2021). Our course aimed to provide students with an opportunity to engage with scientists and the products of science in a more accessible manner when compared to more traditional research experiences. Students shared that before participating in the IPL course science seemed intimidating, to the point where some students questioned their ability to succeed in their

Table 2. Group interview codebook for qualitative analysis.

Code	Frequency	Definition	Example
Interest in Research	26	Student mention of an interest in conducting research or learning more about research	"Yeah, mine was very similar. I was interested in research but like this kind of solidified it."
Research as an Undergraduate	7	Student mention of an interest in conducting research in an undergraduate program	"It made me feel better about science then if I was just not taking the course."
Research as a Graduate	2	Student mention of an interest in conducting research in a graduate program	"I was thinking about going into medicine. Maybe grad school before medical school, but I'm not sure yet."
Career Goals	9	Student mention of their career aspirations upon finishing their academic journey	"I also want to go into medicine. So it didn't really change anything, but if I didn't know what I wanted to do, it probably would have made me look into biological research more seriously."
Research Career	8	Student mention of enjoyment or fulfillment in terms of a research	"I think this course, if I go to grad school, made me want to do research in grad school, but I don't think I'd want to do research as a career."
Learned from the Course	17	Student mention of knowledge gained from participation in the course intervention	"The first couple times you read a paper it's totally hard because I thought "I don't know what you're doing," but after a while, once you know what to look for, I guess, it got a lot easier"
Aspect of the Course	5	Student mention of particular aspects of the course impacting them	"Thinking about the stuff that we talked about during the discussions when I was reading the articles on my own helped me understand them."
Writing the Literature Review	8	Student mention of completing the literature review assignment	"I think that doing [a literature review] made me realize that you can start anywhere, and it's just about actually doing the research."
Reading Literature	13	Student mention of completing the reading assignments	"When we had to read through and then pick through all the details and stuff, it really paid off because I'm much more confident in my ability to read and understand primary literature."
Guest Presenters	6	Student mention of impacts of guest presenters discussion of their research	"When you see another person, like the students who present their stuff, you see how competent they are, and it makes you think that you can do the same thing."
Presenting	1	Student mention of the impact of presenting on the information they received during lab interviews/tours	"My group's presentation was about proteins and that's a difficult topic. Having to lead the discussion and answer questions about it made me feel better about science."
Article Discussions	5	Student mention of the impact of class discussions of research articles	"Communicating with each other in the discussions and talking about science helped my confidence."
Lab Tour	7	Student mention of the impact of visiting the laboratory space during their lab tour	"Getting into a research lab and seeing the setup and how things are done really solidified in my head the process and how it would go if I were to join research."
Science Identity	2	Student mention of their perception of their science identity as well as any noticeable changes	"It's strengthened my science identity because I have a clear path of where I want to go if I do research."
Competence	11	Student mention of their perceived capability to complete scientific tasks	"It made me believe that I can actually learn the material, even though it's tricky and it may not come easy at first."
Performance	4	Student mention of how well they can display their scientific knowledge or skills to others	"Bio 200 has allowed me to become more confident incommunicating with other people, especially in science, given the questions that we were asking the presenters from the lab."

pursuing of STEM. S10 explained, "[Science] was really daunting at first because I didn't think that I was good enough to be able to get into it." S9 said, "Science can be really intimidating, especially when you're just getting into it." S14 said this course "made [science] seem less daunting. There's not as much of a learning curve as I thought there would've been to get into research." Some students even described specific science assignments as being scary, like S4 when they said,

> When I first found out about the literature review assignment, I was really scared. I was dreading it. But then I found a topic that I really liked, and I thought, *okay, I know I can actually do this*.

The fear students felt surrounding science could be in part due to having a novice understanding of the nature of science. Students mentioned that this course provided exposure to the nature of science ("real science"), something that doesn't happen in more traditional types of courses like lectures or laboratories. S9 said, "This course has provided a lot of exposure to real science. I don't get the same sort of experience in lectures or labs." S11 shared, "Before this class, I didn't really understand what happened with research." S14 stated, "Most of our experience in science so far has been as a student in the classroom. Reading the literature felt like something an actual scientist would do."

Learning about the nature of science by engaging with the products of science, conversing with research teams, and touring the spaces in which science is conducted helped students understand what it is like to conduct biological research and improved students' confidence in their ability to understand and communicate about science. S11 shared, "After reading the literature and touring the lab I understand research a lot more." S10 shared a similar sentiment when they shared that reading the articles, "made me believe that I can actually learn the material, even though it's tricky and it may not come easy at first." S10 also shared that they had a change in perspective about getting into science, stating, "I realized it just takes time and understanding. Everyone starts from somewhere." Although they did not directly use the word competence, S14 described an increase in their competence with regards to reading and understanding literature when they said, "Thinking about the stuff that we talked about during the discussions when I was reading the article on my own helped me understand them." In addition to having a better understanding of "real science", students may have a better idea of how to pursue FLREs as a result of this course. S8 shared, "I knew I was interested in doing research before this class, but I didn't know where to start. This class did a really good job of explaining how you would try to be in a research lab."

Overcoming the intimidation around science and feeling greater competence made students more interested in joining a research group. S11 shared, "I definitely want to join a research lab now." S9 summed up this theme well when she shared:

> Reading the primary literature articles … really paid off because I'm much more confident in my ability to read and understand primary literature. And that understanding has allowed me to overcome the intimidation that I have around science. And therefore, it has made me much more interested in pursuing research.

The students who experienced increases (and even some who stayed neutral) in their science identities clearly had overcome their intimidation around science, felt more competent in their ability to understand and communicate about science, and as a result, felt more inclined to pursue research opportunities.

Science identity versus other professional identities

Professional identity refers to the ways in which a student views themself as a professional member of a career pathway (Wilson et al., 2013). Professional identities, such as a science identity, or medical identity, or law identity, represent a students' beliefs about what it means to be a good professional in a specific career as well as the manner in which the student believes they should behave as a professional in a specific career (Coulehan, 2005). So, for the purpose of this article, science identity, medical identity, and law identity represent a students' thoughts about themself being and behaving as a good scientist, medical professional, and legal professional, respectively.

Of the twelve students in the course, nine (75%) were interested in a medical profession, five (50%) were interested in a research career, and three (25%) were interested in a law career (students could report being interested in multiple professions; Table 3). The large

Table 3. Career aspirations of students enrolled in the course. Letters in parentheses next to student IDs represent increases (I), no change (N), or decreases (D) in science identity scores pre- to post-course. Students are organized by magnitude of change with largest increases on the top, and largest decreases on the bottom. S13 and S14 did not complete both surveys.

Student	**Career Aspiration**
S5 (I)	Medical and Research
S9 (I)	Medical and Research
S11 (I)	Medical and Research
S1 (I)	Medical Only
S10 (I)	Medical Only
S2 (N)	Medical Only
S4 (N)	Law Only
S6 (N)	Research Only
S7 (N)	Law Only
S8 (N)	Medical Only
S3 (D)	Medical and Research
S13	Law and Research
S14	Medical Only

proportion of medically oriented students is not surprising, considering many of the students in the introductory biology course from which our IPL students were recruited are medically oriented, especially those from underserved backgrounds. Additionally, professional identity formation often begins before career-specific education, especially for medically oriented students (Wilson et al., 2013). Factors that influence medical identity before career specific education include having a family member who is a medical professional; the backgrounds, experiences, and values that students held when starting their medical education; or even learning about medical professions by watching medical television dramas (Baernstein et al., 2009; Cavenagh et al., 2000; Weaver & Wilson, 2011).

Science identity has not been well studied among populations of students who are interested in becoming a medical professional (Dou et al., 2021). Understanding the extent to which medically oriented students identify with science is important considering most of them start their undergraduate degree as a STEM major but fewer than half (41%) are accepted into medical school (Dou et al., 2021). One study, conducted by Dou and colleagues (2021), found that STEM majors on a pre-med/health track were more likely to have a stronger science identity than STEM majors who were not on a pre-med/health track.

The results of the current study supplement Dou and colleagues' (2012) findings, in that all of our students who saw increases in science identity were medically oriented. Additionally, one of two medically oriented students who did not see a change in science identity (S8) pre- to post-course started and ended with a score of 100%. However, we also found that medically oriented and research oriented students saw changes in their science identities in similar proportions. For students who reported interest in a medical profession, 63% (5/8) saw increases in their science identities, 25% (2/8) stayed the same pre- to post-course, and 13% (1/8) saw decreases. Similarly, for students who reported an interest in a research career, 60% (3/5) saw increases in their science identities, 20% (1/5) stayed the same, and 20% (1/5) saw decreases. For students who were interested in both medical and research careers, 75% (3/4) saw increases in their science identities and 25% (1/4) saw a decrease. In fact, the three students who saw the largest increases in their science identities were all interested in both a medical career and a research career.

Although our students' career aspirations did not change pre- to post- course, those who were interested in medicine or law showed more interest in conducting biological research as an undergraduate student as a result of our IPL course. S4 shared that as a result of this course, "I'm definitely more interested in doing research and I do want to volunteer in a research laboratory as an undergraduate student." Additionally, some of our medically oriented students may move towards incorporating research as a part of their career goals and identities. S9 shared:

> I want to be a physician. This course hasn't changed that, but rather added to what I want to do. I was not really aware about the research sides of medicine. I'm very interested in going into surgery. And I think just attending this course, let alone the effort that I put into this course, has allowed me to realize the diversity of topics I could pursue within research, or in the surgery-side. And my mind's just sort of going in all of these places, like what kind of clinical trials I could explore one day, what kind of drugs I could research with. So, this course has led into this enormous amount of exposure [to real science], and I'm really excited to keep going.

This increased interest in research could be because students believed that research would prepare them for their future profession. S1 who wants to be an anesthesiologist wrote, "Scientific research will help prepare me for the medical field by expanding my knowledge and helping me get experience." S10 who wants to be a physician shared, "[Scientific research] could help me get into medical school and also help me grow my interest for science." The students who aspired for a law career also believed that understanding biological research would help them in their careers. S4, who is interested in patent law, shared "I want to learn how to interact with researchers, how research labs work, and how to read research papers so that I can get a better understanding of the people I will most likely be working with."

Gender differences in criteria for being a scientist

One study that explored gender differences among undergraduate students who were participating in FLREs found that while 100% of male participants identified as scientists, only 30% of women did (Schmid & Wiles, 2022). This disparity was, in part, attributed to women having different self-imposed criteria for calling themselves scientists than did men. We found similar results in the current study. Many of our women students reported an increase in their competence, or that they saw themselves as more of a "science person" as a result of participating in this course, but that they did not yet consider themself a "scientist". For example, S1, a woman URM student, felt like the IPL course improved her ability to read and write scientifically but that her improvement in those areas wasn't enough for her to qualify as a scientist. She shared "I wouldn't say I feel like a scientist, but I definitely feel more knowledgeable in certain research topics, how to write a literature review, and how to read papers."

S9, who is also a woman, felt like this course strengthened her science identity because she had a better understanding of what type of research she would like to do. She said, "I think that it's easier to consider myself more of a science person when I understand what I want to do once I'm in the field." Despite feeling like her science identity was strengthened, she would not consider herself a scientist yet. She shared, "Taking this course has reassured me that I'm not a scientist yet, and that's okay. I'm going through this journey to get there. So, while I'm confident that [my science identity] increased, I still would call it neutral." These findings are interesting considering S9 scored 100% on the science identity scale on her post-course survey.

One of the male students, S5 held a differing opinion: one can be a "science person" simply by learning about science. He shared "Not knowing stuff doesn't stop me from identifying as a science person." However, S13 a man URM student, felt more similar to the women students, sharing “I feel like conceptually, I'd have to learn more [to identify as a scientist].” This finding was particularly interesting considering this student also shared that they were currently participating in a FLRE.

S14, whose gender identity was not disclosed, shared “I don't really feel like a scientist until I publish a paper or something like that.” However, they also shared that they “feel a little closer” to being a scientist after reading biological literature.

Limitations

Limitations of this study include that the group discussion was led by the course instructor. This may have made students less likely to volunteer negative experiences with the course, feelings of having a weak science identity, or opinions having to do with a lack of interest in biological research or scientific careers. The instructor made an attempt to minimize this potential bias and encourage all students to share their thoughts before the discussion by reminding students of the experimental nature of the course. More specifically, the instructor explained that while it is important to hear positive feedback about the course, it is equally if not more important to hear negative feedback in order to make effective changes to future iterations of the course.

Another limitation of this study is that we were not able to control for factors that were external to the course that may have influenced students’ science identity. Our students were likely participating in other STEM courses which may have influenced their identification with science.

Conclusions

Our findings support the implementation of IPL courses as a steppingstone to UREs. The experimental course includes interactions with scientists of all levels ranging from undergraduate researchers to principal investigators, and our data indicate that these interactions were beneficial to undergraduates. Notably, students articulated that participating in the IPL course increased their science identities in by increasing their interest in pursuing FLREs, their self-recognition as a scientist, and their competence in reading and understanding scientific content. Scaling up the methods used in this IPL course to the context of a larger enrollment introductory biology course could increase the number of students benefiting from early exposure to biological research, generating a larger impact. Underrepresented students and students from low-income communities have historically not been afforded access to early undergraduate research experiences and may experience greater benefits. We hope to use these results to inform scaling-up efforts as well as other UREs to increase the population of undergraduate students who might benefit from these interventions.

Acknowledgements

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References

Baernstein, A., Oelschlager, A. M., Amies, E., Chang, T. A., and Wenrich, M. (2009). Learning Professionalism: Perspectives of Preclinical Medical Students. Academy of Medicine. 84(5), 574-581.

Brownell, S. E., Price, J. v., & Steinman, L. (2013). A writing-intensive course improves biology undergraduates’ perception and confidence of their abilities to read scientific literature and communicate science. American Journal of Physiology - Advances in Physiology Education, 37(1), 70–79. https://doi.org/10.1152/advan.00138.2012

Carter, B. E., Wiles, J. R. (2017). A qualitative study examining the exclusive use of primary literature in a special topics biology course: Improving conceptions about the nature of science and boosting confidence in approaching original scientific research. International Journal of Environmental and Science Education, 12(3), 523–538.

https://doi.org/10.12973/ijese.2017.1245p

Cavenagh, P., Dewberry, C., Jones, P. (2000). Becoming professional: When and how does it start? A comparative study of first-year medical and law students in the UK. Medical Education. 34(11), 897-902.

Chang, M. J., Eagan, M. K., Lynn, M. H., & Hurlado, S. (2011). Considering the impact of racial stigmas and science identity: Persistence among biomedical and behavioral science aspirants. Journal of Higher Education, 82(5), 564–596.

https://doi.org/10.1353/jhe.2011.0030

Chemers, M. M., Zurbriggen, E. L., Syed, M., Goza, B. K., & Bearman, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. Journal of Social Issues, 67(3), 469–491. https://doi.org/10.1111/J.1540-4560.2011.01710.X

Cheryan, S., Master, A., & Meltzoff, A. N. (2015). Cultural stereotypes as gatekeepers: Increasing girls' interest in computer science and engineering by diversifying stereotypes. Frontiers in Psychology. https://doi.org/10.3389/FPSYG.2015.00049/BIBTEX

Coulehan, J. (2005). Today's professionalism: Engaging the mind but not the heart. Academy of Medicine. 80, 892-898.

Eagan, M. K., Hurtado, S., Chang, M. J., Garcia, G. A., Herrera, F. A., & Garibay, J. C. (2013). Making a Difference in Science Education: The Impact of Undergraduate Research Programs. American Educational Research Journal, 50(4), 683–713. https://doi.org/10.3102/0002831213482038

Fairlie, R., Hoffmann, F., & Oreopoulos, P. (2014). A community college instructor like me: Race and ethnicity interactions in the classroom. American Economic Review. 104(8)

http://dx.doi.org/10.1257/aer.104.8.2567

Frantz, K. J., Demetrikopoulos, M. K., Britner, S. L., Carruth, L. L., Williams, B. A., Pecore, J. L., Dehaan, R. L., & Goode, C. T. (2017). A comparison of internal dispositions and career trajectories after collaborative versus apprenticed research experiences for undergraduates. CBE Life Sciences Education, 16(1). https://doi.org/10.1187/CBE.16-06-0206/ASSET/IMAGES/LARGE/AR1FIG6.JPEG

Humphrey, E. A., & Wiles, J. R. (2021). Lessons learned through listening to biology students during a transition to online learning in the wake of the COVID-19 pandemic. Ecology & Evolution 11(8), 3450-3458. https://doi.org/10.1002/ece3.7303

Marx, J. D., & Cummings, K. (2007). Normalized change. American Journal of Physics, 75(1), 87–91. https://doi.org/10.1119/1.2372468

Merolla, D. M., & Serpe, R. T. (2013). STEM enrichment programs and graduate school matriculation: The role of science identity salience. Social Psychology of Education, 16(4), 575–597. https://doi.org/10.1007/S11218-013-9233-7/FIGURES/1

National Academies of Sciences, Engineering, and Medicine (NASEM). 2017. Undergraduate research experiences for STEM students: Successes, challenges, and opportunities. The National Academies Press. https://doi.org/10.17226/24622.

Perez, T., Cromley, J. G., & Kaplan, A. (2014). The role of identity development, values, and costs in college STEM retention. Journal of Educational Psychology. https://doi.org/10.1037/a0034027.supp

Pierszalowski, S., Bouwma-Gearhart, J., & Marlow, L. (2021). A systematic review of barriers to accessing undergraduate research for STEM students: Problematizing under-researched factors for students of color. Social Sciences, 10(9), 328. https://doi.org/10.3390/SOCSCI10090328

Reig, A. J., Goddard, K. A., Kohn, R. E., Jaworski, L., & Lopatto, D. (2018). The FUTURE program: Engaging underserved populations through early research experiences. ACS Symposium Series, 3–21. https://doi.org/10.1021/BK-2018-1275.CH001

Sandefur, C. I., Gordy, C., & Farm Road, M. (2016). Undergraduate journal club as an intervention to improve student development in applying the scientific process. Journal of College Science Teaching, 45(4), 52–58.

Schmid, K. M., Dunk, R. D. P., & Wiles, J. R. (2021). Early exposure to primary literature and interactions with scientists influences novice students' views on the nature of science. Journal of College Science Teaching, 50(6).

Schmid, K., Hall, S. E., & Wiles, J. R. (2023). Different approaches for engaging undergraduates in research: Variable impacts on students' self-efficacy, science research skills, and future goals. Bioscene: Journal of College Biology Teaching.

Schmid, K. M., & Wiles, J. R. (2019). Case study: An introduction to biological research course for undergraduate biology students. Journal of College Science Teaching, 49(01).

https://doi.org/10.2505/4/JCST19_049_01_48

Schmid, K. M. & Wiles, J. R. (2022). Call her a scientist: The role of mentors in faculty lab-based undergraduate biology research experiences & outcomes for student science identity. The American Biology Teacher 84(5), 273-278.

https://doi.org/10.1525/abt.2022.84.5.273

Sloane, J. D., & Wiles, J. R. (2020). Communicating the consensus on climate change to college biology majors: The importance of preaching to the choir. Ecology and Evolution, 10(2), 594–601. https://doi.org/10.1002/ece3.5960

Weaver, R., Wilson, I. (2011). Australian medical students, perceptions of professionalism and ethics in medical television programs. BMC Medical Education. 11(50).

Wilson, I., Cowin, L. S., Johnson, M. & Young, H. (2013). Professional identity in medical students: pedagogical challenges to medical education. Teaching and Learning in Medicine: An International Journal, 25(4), 369-373.

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.

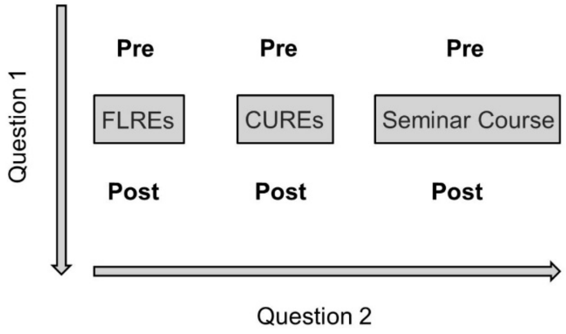
It is important to assess the effectiveness of various types of undergraduate research engagement on the improvement of students' self-efficacy and research skills in order to inform and support implementation and improvement of such experiences. Engaging in these experiences can help students in science 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%

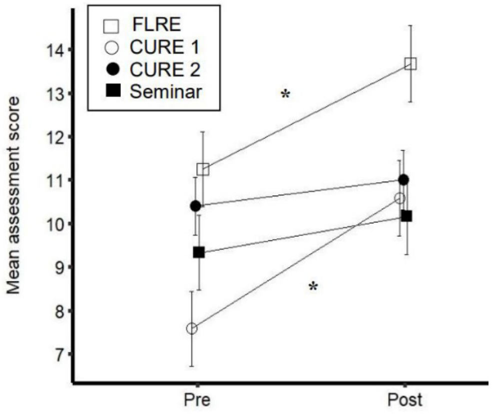
enter post-graduate programs for other health professions, or to obtain a paying job for a time and then go to school for an M.D. or Ph.D..

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.

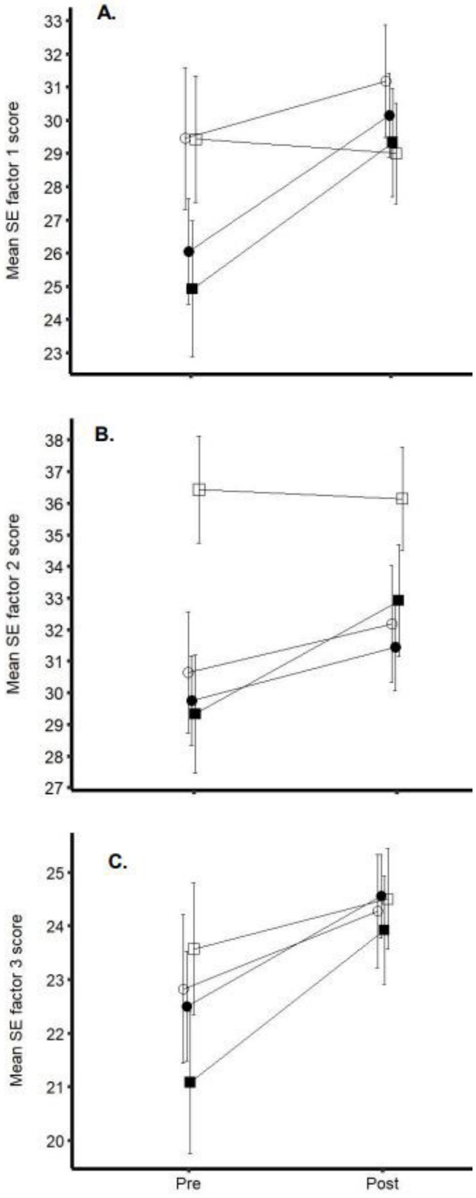
Figure 2. Estimated marginal mean skill assessment scores pre and post experience.



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.

References

Adedokun, O. A., Bessenbacher, A. B., Parker, L. C., Kirkham, L. L., & Burgess, W. D. (2013). Research skills and STEM undergraduate research students' aspirations for research careers: Mediating effects of research self-efficacy: Journal of Research in Science Teaching, 50(8), 940–951.
https://doi.org/10.1002/tea.21102

Auchincloss, L. C., Laursen, S. L., Branchaw, J. L., Eagan, K., Graham, M., Hanauer, D. I., Lawrie, G., McLinn, C. M., Pelaez, N., Rowland, S., Towns, M., Trautmann, N. M., Varma-Nelson, P., Weston, T. J., & Dolan, E. L. (2014). Assessment of course-based undergraduate research experiences: A Meeting Report. CBE—Life Sciences Education, 13(1), 29–40. https://doi.org/10.1187/cbe.14-01-0004

Baldwin, J. A., Ebert-May, D., & Burns, D. J. (1999). The development of a college biology self-efficacy instrument for nonmajors. Science Education, 83(4), 397–408.

Ballen, C. J., Thompson, S. K., Blum, J. E., Newstrom, N. P., & Cotner, S. (2018). Discovery and broad relevance may be insignificant components of course-based undergraduate research experiences (CUREs) for non-biology Majors. Journal of Microbiology & Biology Education, 19(2).
https://doi.org/10.1128/jmbe.v19i2.1515

Ballen, C. J., Wieman, C., Salehi, S., Searle, J. B., & Zamudio, K. R. (2017). Enhancing Diversity in undergraduate science: Self-efficacy drives performance gains with active learning. CBE—Life Sciences Education, 16(4), ar56
https://doi.org/10.1187/cbe.16-12-0344

Bangera, G., & Brownell, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. CBE—Life Sciences Education, 13(4), 602–606.
https://doi.org/10.1187/cbe.14-06-0099

Brownell, S. E., Hekmat-Scafe, D. S., Singla, V., Chandler Seawell, P., Conklin Imam, J. F., Eddy, S. L., Stearns, T., & Cyert, M. S. (2015). A high-enrollment course-based undergraduate research experience improves student conceptions of scientific thinking and ability to interpret data. Cell Biology Education, 14(2), ar21–ar21. https://doi.org/10.1187/cbe.14-05-0092

Brownell, S. E., & Kloser, M. J. (2015). Toward a conceptual framework for measuring the effectiveness of course-based undergraduate research experiences in undergraduate biology. Studies in Higher Education, 40(3), 525–544.
https://doi.org/10.1080/03075079.2015.1004234

Brownell, S. E., Kloser, M. J., Fukami, T., & Shavelson, R. (2012). Undergraduate biology lab courses: Comparing the impact of traditionally based "cookbook" and authentic research-based courses on Ssudent lab experiences. Journal of College Science Teaching, 41(4), 36–45.

Brownell, S. E., Price, J. V., & Steinman, L. (2013). A writing-intensive course improves biology undergraduates' perception and confidence of their abilities to read scientific literature and communicate science. Advances in Physiology Education, 37(1), 70–79. https://doi.org/10.1152/advan.00138.2012

Carpi, A., Ronan, D. M., Falconer, H. M., & Lents, N. H. (2017). Cultivating minority scientists: Undergraduate research increases self-efficacy and career ambitions for underrepresented students in STEM: Mentored undergraduate research at MSI. Journal of Research in Science Teaching, 54(2), 169–194.
https://doi.org/10.1002/tea.21341

Colabroy, K. L. (2011). A writing-intensive, methods-based laboratory course for undergraduates. Biochemistry and Molecular Biology Education, 39(3), 196–203. https://doi.org/10.1002/bmb.20496

Committee on Strengthening Research Experiences for Undergraduate STEM Students, Board on Science Education, Division of Behavioral and Social Sciences and Education, Board on Life Sciences, Division on Earth and Life Studies, & National Academies of Sciences, Engineering, and Medicine. (2017). Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities (J. Gentile, K. Brenner, & A. Stephens, Eds.). National Academies Press. https://doi.org/10.17226/24622

Cooper, K. M., Gin, L. E., Akeeh, B., Clark, C. E., Hunter, J. S., Roderick, T. B., Elliott, D. B., Gutierrez, L. A., Mello, R. M., Pfeiffer, L. D., Scott, R. A., Arellano, D., Ramirez, D., Valdez, E. M., Vargas, C., Velarde, K., Zheng, Y., & Brownell, S. E. (2019). Factors that predict life sciences student persistence in undergraduate research experiences. PLOS ONE, 14(8), e0220186.
https://doi.org/10.1371/journal.pone.0220186

Corwin, L. A., Graham, M. J., & Dolan, E. L. (2015). Modeling Course-Based Undergraduate Research Experiences: An Agenda for Future Research and Evaluation. Cell Biology Education, 14(1), es1–es1. https://doi.org/10.1187/cbe.14-10-0167

Cotten, S. R., & Wilson, B. (2006). Student–faculty Interactions: Dynamics and Determinants. Higher Education, 51(4), 487–519 https://doi.org/10.1007/s10734-004-1705-4

Deslauriers, L., McCarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. Proceedings of the National Academy of Sciences, 116(39), 19251–19257. https://doi.org/10.1073/pnas.1821936116

Espinosa, T., Miller, K., Araujo, I., & Mazur, E. (2019). Reducing the gender gap in students'

500 physics self-efficacy in a team- and project-based introductory physics class. Physical Review Physics Education Research, 15(1), 010132. https://doi.org/10.1103/PhysRevPhysEducRes.15.01 0132

Etkina, E., Van Heuvelen, A., White-Brahmia, S., Brookes, D. T., Gentile, M., Murthy, S., Rosengrant, D., & Warren, A. (2006). Scientific abilities and their assessment. Physical Review Special Topics - Physics Education Research, 2(2). https://doi.org/10.1103/PhysRevSTPER.2.020103

Frantz, K. J., Demetrikopoulos, M. K., Britner, S. L., Carruth, L. L., Williams, B. A., Pecore, J. L., DeHaan, R. L., & Goode, C. T. (2017). A Comparison of Internal Dispositions and Career Trajectories after Collaborative versus Apprenticed Research Experiences for Undergraduates. Cell Biology Education, 16(1), ar1. https://doi.org/10.1187/cbe.16-06-511 0206

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 515 111(23), 8410–8415.

Gardner, G. E., Forrester, J. H., Jeffrey, P. S., Ferzli, M., & Shea, D. (2015). Authentic Science Research Opportunities: How Do Undergraduate Students Begin Integration Into a Science Community of Practice? Journal of College Science Teaching, 44(4), 61–65.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2009). Effects of Inquiry-Based Learning on Students' Science Literacy Skills and Confidence. International Journal for the Scholarship of Teaching and Learning, 3(2).

Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased Structure and Active Learning Reduce the Achievement Gap in Introductory Biology. Science, 332(6034), 1213–1216 https://doi.org/10.1126/science.1204820

Harrison, M., Dunbar, D., Ratmansky, L., Boyd, K., & Lopatto, D. (2011). Classroom-Based Science Research at the Introductory Level: Changes in Career Choices and Attitude. CBE—Life Sciences Education, 10(3), 279–286. https://doi.org/10.1187/cbe.10-12-0151

Hathaway, R. S., Nagda, B. A., & Gregerman, S. R. (2002). The relationship of undergraduate research participation to graduate and professional education pursuit: An empirical study. Journal of College Student Development, 43(5), 614–631.

Hippel, W. von, Lerner, J. S., Gregerman, S. R., Nagda, B. A., & Jonides, J. (1998). Undergraduate Student-Faculty Research Partnerships Affect Student Retention. The Review of Higher Education, 22(1), 55–72.

Hoskins, S. G., Lopatto, D., & Stevens, L. M. (2011). The C.R.E.A.T.E. Approach to Primary Literature Shifts Undergraduates' Self-Assessed Ability to Read and Analyze Journal Articles, Attitudes about Science, and Epistemological Beliefs. Cell Biology Education, 10(4), 368–378. https://doi.org/10.1187/cbe.11-03-0027

Hoskins, S. G., Stevens, L. M., & Nehm, R. H. (2007). Selective Use of the Primary Literature Transforms the Classroom Into a Virtual Laboratory. Genetics, 176(3), 1381–1389. https://doi.org/10.1534/genetics.107.071183

Hsu, J. L., Wrona, A. M., Brownell, S. E., & Khalfan, W. (2016). The Explorations Program: Benefits of Single-Session, Research-Focused Classes for Students and Postdoctoral

Instructors. Journal of College Science Teaching 45(6): 78-86.

Hunter, A., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. Science Education, 91(1), 36–74. https://doi.org/10.1002/sce.20173

Kardash, C. (2000). Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors. Journal of Educational Psychology, 92(1), 191–201. https://doi.org/10.1037//0022-0663.92.1.191

Kloser, M. J., Brownell, S. E., Shavelson, R. J., & Fukami, T. (2013). Effects of a Research-Based Ecology Lab Course: A Study of Nonvolunteer Achievement, Self-Confidence, and Perception of Lab Course Purpose. Journal of College Science Teaching, 42(3), 90-99.

Linn, M. C., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Undergraduate research experiences: Impacts and opportunities. Science. https://doi.org/10.1126/science.1261757

Lopatto, D. (2004). Survey of Undergraduate Research Experiences (SURE): First Findings. Cell Biology Education, 3(4), 270–277. https://doi.org/10.1187/cbe.04-07-0045

Lopatto, D. (2007a). Undergraduate research experiences support science career decisions and active learning. CBE-Life Sciences Education, 6(4), 297–306.

Lopatto, D. (2007b). Undergraduate Research Experiences Support Science Career Decisions and Active Learning. CBE—Life Sciences Education, 6(4), 297–306. https://doi.org/10.1187/cbe.07-06-0039

Marrero, M. E., Riccio, J. F., Ben-Jacob, M., Canger, A., & Maliti, C. (2017). A Crash Course in Undergraduate Research. Journal of College Science Teaching, 46(5), 26.

Marrero, M., Riccio, J., Ben-Jacob, M., Canger, A., & Maliti, C. (2017). A Crash Course in Undergraduate Research. Journal of College Science Teaching, 046(5). https://doi.org/10.2505/4/jcst17_046_05_26

McLaughlin, J. S., Favre, D. E., Weinstein, S. E., & Goedhart, C. M. (2017). The Impact of a Four-Step Laboratory Pedagogical Framework on Biology Students' Perceptions of Laboratory Skills, Knowledge, and Interest in Research. Journal of College Science Teaching, 47(1), 83-91.

Olson, S., & Riordan, D. G. (2012). Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President. Executive Office of the President.

Schmid, K. M., & Wiles, J. R. (2022). Call Her a Scientist. The American Biology Teacher, 84(5), 273–278. https://doi.org/10.1525/abt.2022.84.5.273

Schmid, K., & Wiles, J. (2019). Case Study: An Introduction to Biological Research Course for Undergraduate Biology Students. Journal of College Science Teaching, 049(01). https://doi.org/10.2505/4/jcst19_049_01_48

Schneider, K. R., Bickel, A., & Morrison-Shetlar, A. (2015). Planning and Implementing a Comprehensive Student-Centered Research Program for First-Year STEM Undergraduates. Journal of College Science Teaching, 44(3), 37–43.

Seymour, E., Hunter, A.-B., Laursen, S. L., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. Science Education, 88(4), 493–534. https://doi.org/10.1002/sce.10131

Shortlidge, E. E., Bangera, G., & Brownell, S. E. (2016). Faculty Perspectives on Developing and Teaching Course-Based Undergraduate Research Experiences. BIOSCIENCE, 66(1), 54–62. https://doi.org/10.1093/biosci/biv167

Sloane, J. D., Dunk, R. D. P., Snyder, J. J., Winterton, C. I., & Wiles, J. R. (2021). Peer-Led Team Learning is Associated with an Increased Retention Rate for STEM Majors from Marginalized Groups. Proceedings of the 13th Annual National Association of Biology Teachers Research Symposium . https://files.eric.ed.gov/fulltext/ED630836.pdf

Sloane, J. D., & Wiles, J. R. (2020). Communicating the consensus on climate change to college biology majors: The importance of preaching to the choir. Ecology and Evolution, 2020(10), 594-601. https://doi.org/10.1002/ece3.5960

Snyder, J. J., Sloane, J. D., Dunk, R. D. P., & Wiles, J. R. (2016). Peer-Led Team Learning Helps Minority Students Succeed. PLOS Biology, 14(3), e1002398. https://doi.org/10.1371/journal.pbio.1002398

Thiry, H., Weston, T. J., Laursen, S. L., & Hunter, A.-B. (2012). The Benefits of Multi-Year Research Experiences: Differences in Novice and Experienced Students' Reported Gains from Undergraduate Research. CBE—Life Sciences Education, 11(3), 260–272. https://doi.org/10.1187/cbe.11-11-0098

Weaver, G. C., Russell, C. B., & Wink, D. J. (2008). Inquiry-based and research-based laboratory pedagogies in undergraduate science. Nature Chemical Biology, 4(10), 577–580. https://doi.org/10.1038/nchembio1008-577

Wyckoff, S. (2001). Changing the culture of undergraduate science teaching. Journal of College Science Teaching, 30(5), 306.

Innovations

Using 3MT Storytelling Approaches to Improve Science Communication

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Abstract

Traditional academic communication practices tend to be jargon-heavy jargon and lack public relatability. Thus, it is paramount that scientists learn to develop effective communication skills. The Three Minute Thesis (3MT) competition is one avenue to refine and build science communications skills. Using one static slide as a visual supplement, competitors have three minutes to explain their research goals and relevance through easily comprehended vernacular. Using an observation protocol including three criteria: presentation framing, verbal, and non-verbal communication, we identified characteristics of prior successful 3MT presentations. We also tested the identified characteristics by observing 15 local 3MT presentations and found that all successful presentations contained similar communication patterns. For example, we found that using storytelling frames resulted in the most compelling and successful presentations. Our study offers implications on how these identified characteristics can be used to help budding scientists build critical communication skills for sharing their research with non-scientists. Scientists can apply our outcomes to build effective presentations and successfully deliver science messages helping create a more informed public.

Key Words: Science Communication, Storytelling, Generalist Audience, Three-Minute Thesis

Introduction

With the influx of anti-science rhetoric, now more than ever, scientists need to develop their communication skills to provide the public with information in a comprehensive form they can understand and use (Jucan & Jucan, 2014). Unfortunately, traditional academic practices and the inherent complexity of academic disciplines have painted a picture of science that is isolated from everyday experiences, and the jargon-heavy language typical of academics has enforced the need for 'translators' to act as an intermediary between science and society (Avraamidou & Osborne, 2009). By borrowing skills from interpretive practices, scientists can be effective science communicators, even through messages as short as three minutes.

It is paramount for junior researchers to be able to develop effective communication skills throughout higher education as we fight to improve scientific literacy (Baram-Tsabari & Osborne, 2015). The Three Minute Thesis (3MT) competition serves as a platform for graduate students to refine their presentation and research communication skills while practicing explaining their research goals and relevance in a vernacular that caters to a broad but intelligent audience. During the 3MT, graduate students explain their thesis research within three minutes using only one static PowerPoint slide as a visual aid (University of Queensland, n.d.). Although graduate students deliver these presentations across all academic disciplines, and some presentations may lack professional

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polish, the 3MT has important educational value for how to approach communicating advanced research with non-specialist audiences (Hu & Liu, 2018). The 3MT allows for the cultivation of research-based technical skills that will supplement future endeavors in both academia and industrial projects. This is also a step in learning how to interpret a researcher's work for non-scientific persons.

While the 3MT began in 2008 at the University of Queensland with 160 postgraduate research students competing (University of Queensland, n.d.), today, the competition has been adopted in 85 countries outside of Australia, with over 900 competitions hosted annually. The 3MT competition provides an exciting competitive environment for students to practice and develop verbal science communication skills used in academia, popular media, community presentations, healthcare consumer, and funding bodies (Davidson & Ferguson, 2014). This academic genre allows graduate students to hone their interpretive communication skills with non-experts, foster presentational competence, and prepare to defend their research (Mezek & Swales, 2016). But like any skill set, understanding key elements and maintaining continued practice is essential for mastery.

The 3MT format may serve as a tool for those not only wishing to further their career but also their science communication skills. Still, amongst the litany of research articles on scientific communication and its place in academia, few have investigated the role of the 3MT (e.g., Carter-Thomas & Rowley-Jolivet, 2020; Hu & Liu, 2018; Hyland & Zou, 2021; Yang, 2020). In an effort to aid researchers across all science disciplines in increasing their communication efficacy, our study 1) examined what has made prior 3MT presentations successful, 2) created a set of critical communication characteristics based on successful 3MT presentations, and 3) tested identified parameters for communication effectiveness.

Literature Review

Unlike other interpretive communication outlets, the 3MT imposes a strict time restriction of three minutes and requires appropriate messaging for a non-specialized audience (Hu & Liu, 2018). A prior inquiry into 3MT presentations showed that successful presenters tended to use similar stable approaches across the board, regardless of discipline (Carter-Thomas & Rowley-Jolivet, 2020). In contrast, Hyland and Zou (2021) found that while the overall presentation structure may look similar due to the limited time structure and the anticipated audience, presenters used different approach stances depending on if they were communicating hard or soft science. They found that successful presenters of hard sciences tended to use hedges (acknowledgment of variability in the observation of results) and boosters (confidence and commitment) whereas successful presenters of soft sciences tended to focus more on self-assertion (Hyland & Zou, 2021). Further research has indicated that successful 3MT presenters communicate their research using a first-person, present tense, authoritative voice when engaging with their audience (Hu & Liu, 2018; Yang, 2020). These prior investigations did not consider the impact of nonverbal communication such as presenter blocking, eye contact, posture, facial expression, hand placement, types of visuals used, or size of visual content in their analysis of successful 3MT presentations. Additionally, these prior investigations did not review the role of the visual support provided by the single slide that presenters are allowed to use during the 3MT. Visual communication can help convey complex scientific ideas when represented in an accessible format (Daniel, 2018). However, scientists are not typically trained in visual communication. Thus, experts and novice scientists may both struggle to produce appropriate representations of their scientific data (Daniel, 2018; Hullman & Bach, 2018; O'Donovan et al., 2015).

Science Communication and Academia

A scientist's reputation and the impact of their research rely heavily on their ability to effectively communicate their findings (Becher & Trowler, 2001). Thus, there is a growing consensus that strong verbal communication skills are a vital asset for both early-career and established scholars (Shaikh-Lesko, 2014). While much scientific research is communicated via written manuscripts, oral presentations and interpretive messaging are becoming increasingly popular (Hyland, 2006; Lee, 2016). Still, traditional academic training in higher education does not typically prepare student scientists as effective science communicators for non-specialist audiences (Jucan & Jucan, 2014). It is more common for scientists to learn how to communicate research to peers and focus on explaining hypotheses, executed methods, data analysis, and technical results (Baron, 2010; Baram-Tsabari & Sharon, 2014). Although many scientists engage in science communication voluntarily, other scientists believe that sharing the implications of their research outside of their professional circles carries risk and could damage their credibility (Allen, 2018; Poliakoff & Webb, 2007). This belief is likely due to the potential for highlighting their own bias, overstating claims, or making imprecise statements (Allen, 2018). Specifically, there is a need for scientists to learn how to present research to non-specialists in an engaging manner (Green et al., 2018; Zimmer 2018). Despite notable new directions, many communication efforts continue to be based on ad-hoc, intuition-driven approaches, paying little attention to several decades of interdisciplinary research on what makes for effective public engagement. (Nisbet & Scheufele, 2009).

In teaching the content of science curriculum and the values that often go with it, we sometimes unwittingly, perpetuate a certain harmful mystique of science. That mystique tends to make science seem dogmatic, authoritarian, impersonal, and even inhuman to many students (Dupree & Fiske, 2014; Jucan & Jucan, 2014). Science can also be portrayed as being much more difficult than it is, turning scientists into geniuses with whom students cannot identify and increasing the potential for alienating students from science (Lemke, 1990). Poor communication is contextually characterized by the action of withholding scientific knowledge, thus making it unavailable (Fischhoff, 2013). Poor communication or a lack thereof contributes to lasting damage between scientists and the public by eroding trust and creating a disconnect. As a result, the general populace sees scientists as insensitive to their needs, while scientists see civilians as incapable of grasping fundamental knowledge (Fischhoff, 2013).

Science Communication Efficacy A Growing Area of Study

Science communication interest has drastically increased over the past several years. For example, a network of informal educators (e.g., park rangers, zoo and museum docents) promotes effective scientific communication through interpretive programs for millions of public visitors each year (Allen, 2018). These interpreters propagate scientific stories where they are most meaningfully told, in the places where members of the public are open to learning (Allen, 2018). Still, there is a need for scientists who are subject matter experts to learn how to communicate with or collaborate with communication experts to develop an accurate and compelling narrative (Fischhoff, 2013). Science educators and organizations have even explicitly identified communication skills as a requisite competency for scientific literacy in the twenty-first century (Chung et al., 2016). Efforts to increase scientist engagement in dialogue and participatory forms of communication are most likely the cause of this real and lasting behavioral change (Monroe et al., 2008)

Effective science communication informs people about the benefits, risks, viability of future outcomes, and other costs of their decisions, allowing the recipient audience to make more informed decisions (Fischoff, 2013). As the rhetoric of outrage surrounding controversies over science and policy increases, there is an urgent need for credible, trusted voices that frame science issues in ways that resonate with a diverse public (Allen, 2018). However, even the most effective communication cannot guarantee that people will agree about what those choices should entail regarding decision-making (Fischoff, 2013; Lackey, 2007).

Storytelling and narrative

Scientific pursuits are integral to critical thinking and growth within the scientific community. Science is used to identify problems, understand their extent, systematically seek solutions, and help shape many aspects of our societies (Green et al., 2018). Researchers are privy to witnessing discoveries and changes that most people will never be able to experience (Green et al., 2018). As such, scientists must learn how to share their research in engaging ways through effective communication strategies such as storytelling (Green et al., 2018). Storytelling, in its essence, takes one of three approaches:

- **Shape 1: Discovery -**Discovery is at the very essence of science and good stories. As scientists, our methods revolve around asking questions and discovering answers.
- **Shape 2: Rescue** - Science in service to society operates on the core tenet that the research outcomes should be solutions to significant challenges that we face as individuals, communities, nations, and as a global community.
- **Shape 3: Mystery -** Often, phenomena occur that we cannot readily explain, and there is much at stake–often for society–by not understanding how, why, and what has transpired. Part of what drives science is the desire to solve mysteries and uncover a new understanding of the world, leaving us at a story high (Green et al., 2018).

Human beings know story structure implicitly (Bruner, 2003), making storytelling a type of universal language that connects our communities together. Using stories helps audiences remember communicated themes as they evoke the need for resolution (Orgborn et al., 1996). Stories act as a vehicle through which experiences and events are communicated across audiences. Stories even have the potential to influence people's understanding and beliefs, as well as promote societal and cultural change (Schank & Berman, 2002; Brock et al., 2002). Additionally, the use of story-telling should be integral in both science and environmental education as using narrative strategies may be more appropriate for representing science than expository textual practices (Avraamidou & Osborne, 2009; Gough, 1993). Such an idea is not a large stretch when considering that current 3MT presentations have been found to use a higher rate of positional stances compared to science shared through written communication (Hyland & Zou, 2021).

Framework

Our study was guided by the idea that 3MT presentations provide a way of sharing research through a storytelling or narrative lens. As these presentations are intended for wide generalist audiences representing diverse backgrounds in content knowledge, it is critical that speakers use accessible language to tell their research story (Sugimoto & Thelwall, 2013). The use of professional scientific jargon can create a cognitive gap causing what is being presented by a speaker to not be accurately understood by listeners (e.g., Otoshi & Heffermen, 2008; Rakedzon et al, 2017; Willoughby et al., 2020). Presenters are encouraged to offer an academic narrative that helps to demystify scientific concepts and promote the outcomes of their projects (Jiang & Qui, 2022; Qui & Jiang, 2021). Furthermore, 3MT presentations are intended to be shared in a manner that does not require a high degree of subject-matter knowledge on the part of listeners (Qui & Jiang, 2021). As such, one aspect of 3MT presentations we looked at included verbal characteristics of each talk such as the use of jargon: whether the presenter used ample professional jargon, took time to define included jargon for the audience, or found ways to communicate their science without the need for professional jargon.

Effective 3MT presentations must be structured in a way that captures and holds the interest of a typically non-scientific audience (Qui & Jiang, 2021; Taylor & Toews, 1999). One way a speaker can connect to an audience is by supplementing traditional academic thinking with emotionally connected storytelling (Copeman, 2015). Another way speakers can appeal to an audience is through persuasive interactions and the use of discursive strategies construing immediacy, affectivity, shared goals, and social support (Carter-Thomas & Rowley-Jolivet, 2020). Given the importance of using a communication structure that engages the audience, we looked at how successful speakers framed their 3MT presentations. This element included considerations of how presenters crafted their research narrative in terms of who was presented as the story protagonist, the shape (Green et al., 2018), the context of a story created to facilitate emotional appeal and intellectual impact (Copeman, 2015), and how the presenter framed their overall pitch. The pitch aspect cannot be overlooked, as academic interactions are widely acknowledged to be persuasive. Academics do not just report neutral facts, but instead take a novel point of view when discussing their findings as they anticipate and attempt to react to the views of their intended audience (Deroey, 2015; Hyland, 2001; Hyland, 2004).

Effective presentations require developing both verbal and non-verbal elements to support a performance presence that connects with an audience (Copeman, 2015; Otoshi & Heffemen, 2008). For example, elements such as the clarity of speech and voice quality (e.g., audible volume, a steady pace, organized structure, confidence of the speaker), the correctness of language (e.g., proper pronunciation, correct use of grammar), and how presenters interact with the audience (e.g., use of eye-contact, expressive body language, use of presentation space, visual enhancements) can increase communication effectiveness (Copeman, 2015; Otoshi & Heffemen, 2008). As such, in addition to presentation framing and verbal characteristics, we also took into consideration the non-verbal characteristics of each observed 3MT presentation.

Research questions

The purpose of our project was to investigate communication characteristics of successful 3MT presentations and test those parameters by observing a local university 3MT competition based on how student presenters used those characteristics. The aim of which is to help researchers in all science disciplines increase their communication skills and efficacy for interacting with generalist audiences. Specifically, we focused on the following research questions:

1. What combination of communication elements leads to effective parameters for presenting research to generalist audiences during a 3MT presentation?
2. To what extent do applied communication elements lead to predictably effective presentations?

Methods

Participants

We used a qualitative approach to explore the presentation structure and communication approach for 60 first and second place 3MT presentations over six years from five official 3MT competitions across the globe. Of these observed presentations, 70% focused on science, engineering, or medical topics, while 30% focused on other topics such as applied arts, social sciences, or education. Then we tested the extent to which the identified communication parameters from these prior winners were followed by 15 presenters competing at a local 3MT competition and their resulting success. We then developed implications for scientists to consider when building effective talks for generalist audiences.

Data Sources

We created a communication element protocol to collect observation data from 3MT presentations. This protocol included 19 communication criteria drawn from our framework and organized into three categories: presentation framing, verbal communication, and non-verbal communication.

Presentation Framing.

The presentation framing category of our observation protocol focused on the presentation structure itself and included seven communication criteria: the main character, type of hook, presentation of the problem, resolution, shape of the story, approach, and consistency between approach and resolution. For the main character criterion, we recorded who was presented as the primary focus of the talk. We identified the main character as the audience or as someone else including the presenter themselves. For example, we identified the audience as the main character when the presenter referenced statements such as, “Consider this, you have stumbled upon an…” or, “Let’s say that you decided to explore…” Whereas, we identified the main character as someone else or the presenter when the speaker referenced a hypothetical person doing the research or used first-person voice to share their own role in the story. We described the opening sentence or phrase that the narrator used as the type of hook. We coded the type of hook used as either using a statistic, sharing an opening story or anecdote, making a factual statement, posing a rhetorical question to the audience, describing an analogy, or not using a hook and instead proceeding directly into the body of the presentation. We also coded presentations according to if the presenter posed a problem that they were addressing or not and if that problem was resolved, not resolved, or if their work was in the process of finding a potential resolution by the end of the presentation. We used our guiding framework (Green et al., 2018) to identify the shape of the stories presented. Presentations shaped as Discovery stories involved the presenter taking the audience on a journey of ups and downs ending with a problem solved or definitive actions being taken and the story ending on a positive note. Rescue stories involved the presenter starting out on a high note, such as an exciting event, but then having the story take a negative turn, such as a discouraging event or disaster before ending the story on another positive note or resolution. In Mystery stories, the presenter began with a problem presented but not solved. However, in mysteries, the speaker also mentions a positive direction for the future when wrapping up the presentation. We focused on if the presentations used any of these defined story shapes versus presentations with no defined shape, wherein the presentation did not fit into the three prior defined classifications. For the approach criteria, we coded presentations on if they took a storytelling or cheerleading strategy or a reporting or marketing pitch strategy. With storytelling, the presenter used a narrative to share their thesis results. As a cheerleader, the presenter used positive vocabulary to get the audience on board with the project. For example, using this strategy a presenter may use language such as, "We can do this," or, "Let's go, team!" With the marketing pitch strategy, the presenter made it a goal to get the audience interested in a tool or object used in their daily lives. With the reporting strategy, the presenter was more likely to use unbiased facts with no clear storyline (e.g., an engaging lecture). For the consistency criterion, we looked at if the presenter’s approaches and resolutions were consistent with literature expectations. For example, we expected that presentations using the cheerleading and marketing pitches included resolved problems while reporting strategies offered resolved problems or potential resolutions in process, and we expected stories to be about potential resolutions in process. We recorded these interactions as either consistent with expectations based on prior published communication theory (Green et al., 2018), partial to what would be expected (i.e., when a story offered a fully resolved problem), or not consistent.

Verbal Communication.

The verbal communication element of our observation protocol focused on the qualities of oral delivery of the 3MT and included five criteria: cadence, tone, volume, use of jargon, and verbal emphasis. For the cadence criterion, we coded the pace at which the presenter used as slow, naturally rhythmic, or fast. We coded the presenters' tone as fluctuating, normal, or monotonous. We coded the volume criterion based on the level of projection the presenter used as clearly audible or too quiet. The jargon criterion encompassed the amount of subject-specific language the presenter used during the 3MT and the care given to defining the jargon used. We recorded if presenters avoided jargon or explicitly explained the technical jargon included in the presentation versus presenters who used jargon without providing explanations for the terms. The final criterion in this category, verbal emphasis, focused on the different ways the narrator chose to add emphasis to their story be it through purposeful pauses or explicit emphasis on targeted words, conversational narration, or no noticeable emphasis.

Non-Verbal Communication.

The non-verbal communication element of our observation protocol focused on describing the physical actions of the presenter as well as the visual composition of the presentation slides. This category included seven criteria: presenter blocking, eye contact, posture, facial expression, hand placement, types of visuals used, and the size of supplemental visual content. We coded presenter blocking, or how the stage was used by the presenter, based on if the presenter gave their entire presentation from a single location, or if they made purposeful or constant movement across the stage. We coded the eye contact criterion on whether the presenter focused on a single, outward point or if they made eye contact with multiple audience members. We coded presenter posture on whether they carried themselves in a normal or relaxed stance or if they were more rigid or slumped in stature. Presenters varied in their facial expressions with some maintaining a similar expression throughout the 3MT, while others included explicitly animated facial expressions in order to emphasize points made. The hand pavement criterion described where the speaker placed their hands when not gesturing. We coded presenters that held both of their hands in front, similar to a basketball stance as normal versus other resting hand positions, including if presenters clasped their hands in front or behind them, used one hand to move while the other stayed still, or kept their hands at their sides of the body and not moving. We also coded the type of visuals on the single slide used to support the presentation as either a picture, collage (i.e., multiple visual types used in combination), diagram, graph, text, or no visual used. Then we coded the size of the visual content as being legible and easy to see or too small/missing.

Analysis

We used a deductive approach to code the 60 prior winning 3MT presentations for which characteristics they used according to the described criteria included in the observational protocol. We then compared implemented criteria across the winning presentations in search of communication patterns. Then, we reviewed observations of presentations from a local 3MT competition to map emergent patterns and explore to determine how accurately we could predict the winners in a local 3MT competition as evidence of successful communication.

To complete this predictive investigation, we first observed and analyzed the 15 local 3MT presentations in the same manner as the prior winners coding the communication criteria in the same manner described prior. We then compared our tested outcomes from the current 3MT competition results to our prior expected means to determine the accuracy of the predictive power for both the preliminary and final competition rounds. To test successfulness of these local presentations, we compared individual communication patterns across each category to the established presentation patterns recorded from prior winners. We record participants with communication patterns that most overlapped the prior presentation profile patterns and were mostly like to be judged highest in the competition, therefore we predicted them as being the mostsuccessful communication strategies. If participants majorly deviated in which communication criteria they used in comparison to prior winners (e.g., major pauses in presentation, lack of observable structure), we eliminated them from consideration as predicted round winners. Then, in order to determine the likely winners across each round of the local 3MT competition, we ranked qualified participants based on which presentation profile most overlapped established representative profiles from prior winners in each category: we weighted ranking on Presentation Frame mean as the strongest category, followed by Non-Verbal Communication, then Verbal. We predicted competition success by averaging the rank scores across categories to determine the overall rank scores for each participant. In the event of a tied rank, the participants received the same rank score, and we skipped places until reaching the next rank score (i.e., if there was a 2nd place tie, we ranked participants, 1st, 2nd, 2nd, and 4th). Given the nature of the local 3MT competition, in the event that more competitors were eliminated than preliminary awards available (four winners from each preliminary round moved on to the final competition for a total of 12 finalists), we included previously disqualified competitors until we were able to make predictions about the rank the top four speakers in each preliminary round. We systematically requalified presenters by selecting individuals that qualified in at least two categories and matched at least partial profile patterns with prior winners. We only predicted the ranking of the top two speakers in the final round of the competition as there were only two final awards presented, first and runner-up. We did not attempt to test models of prediction for the 3MT people's choice award winners as this award was largely decided based on which participant drew the most attendance for support and votes rather than on communication composition and skill. Thus, the people's choice award is not dependent upon the identified communication criteria and cannot be predicted using our model.

Results

Using our observation protocol, we found that prior winning talks (n=60) were similar in composition across three criteria of presentation framing, all five criteria affiliated with verbal communication, and four criteria of non-verbal communication.

Similarities Across Successful Presentations

We found that all presentations (100%) introduced their thesis as a problem that needed to be solved and most presenters (96.7%) offered a complete or partial resolution to the presented problem. All (100%) of the winning presenters used a storytelling frame although the nature of the story slightly varied (Mystery 71.7%, Discovery 20%, and Rescue 8.3%).

We found that winning speakers were consistent across all five criteria observed within verbal presentation skills. The speakers talked with a rhythmic cadence (91.7%), maintained a loud enough volume projection for all audience members to easily hear (98.3%), used verbal fluctuations in their speaking tone (100%), and included purposeful verbal emphasis (85%) to draw home main talking points. Furthermore, we found that the successful presentations used limited to no professional jargon usage or limited jargon was well explained when included (90%)

We found that all (100%) successful presenters maintained eye contact with the audience as they talked and most (95%) maintained a natural and relaxed posture during the talk. We also found that the majority (75%) of successful presenters kept their hands placed in front of their bodies in an open position while talking. The remaining speakers tended to keep their hands clasped (21,7%) or to their sides (3.3%) during the presentation. Successful presenters also were consistent in including easily legible text size or providing no text on their supplemental slides (96.7%). In all cases of successful 3MT presentations, the presenters explicitly addressed the images presented on their slides as part of their talk.

Differences Among Successful Presenters

The main differences among prior 3MT presentation winners were recorded primarily within the remaining seven criteria (four criteria connected to presentation framing, and three criteria connected to non-verbal communication). For example, while all but five (8.3%) winning presenters used a type of hook, we found variation in the nature of the hooks used. Of the successful presenters, 26.7% began their talk with a personal story or an anecdote; 21.7% used a call to action; 21.7% asked a question of the audience; 18.3% provided a relevant statistic; and 3.3% shared an analogy connected to their topic. And, while we found that all winning presenters used a storytelling approach to frame their talk, speakers varied in their selected storytelling approach. While all winning presenters framed their talk as a story, 40% acted as reporters, 35% gave a generic story narrative, 23.3% used a marketing pitch approach, and 1.7% acted as a cheerleader. Likewise, we also found that every presentation used a person as the main subject of the story presented, but differentiated in whom they chose to serve as the main character of the presentation with 36.6% putting the audience or "you" and the focal person, 31.7% placed themselves as the focal person, and 31.7% created a fictional entity to tell their story about. We found larger differences when comparing how the presentation shapes used matched the approach and resolutions offered during the presentations. We anticipated that the successful talks would offer consistency to the expected outcomes, but instead, we found that only 61.7% of the winning presentations were consistent in the structuring of their selected storytelling framework with the expected shape and resolution. We found that 13.3% of presenters structured their talk in a way that offered a partial match and 25% of presenters were not consistent across their storytelling structure. This particular finding led us to believe that many of the presenters may be skilled storytellers for these competitions but have not developed sophisticated communication techniques aligned with research-support practices.

The variability across presentations also helped define each talk in a personalized manner. For example, presenters varied in their use of visualizations (pictures 48.3%, collages 30%, diagrams 15%, graphs 3.3%, text only 1.7%, or nothing 1.7%) to best showcase their research. These visualizations ranged from cute cartoons to detailed representations of their data, with the slide often matching the personality and story choice of the presenter.

Likewise, successful presenters used blocking and facial expression in different manners, but in ways that emphasized the intended message and enhanced the story they presented. The winning speakers tended to stay in one place on the stage or move at most to one new position during their presentation (75%). However, some (18.3%) used purposeful blocking to drive home talking points, and others (6.7%) constantly moved around the stage. Also, 63.3% of the presenters were very facially expressive or animated during their presentation, while 30% of speakers could be described as maintaining a normal facial expression and 4.7% held a flat expression throughout the talk.

Testing Our Criteria Model

Using our described observational protocol, we were able to successfully predict nine of the 12 preliminary participants who advanced to the final competition as well as both of the final 3MT winners (Table 1). More interestingly, we were able to successfully predict the accurate rank of the three preliminary finalists and both final competition winners. We found that the 3MT presenters who purposefully developed their presentation's story shape in accordance with their intended message, combined with an appropriate approach, advanced further in the competition. While framing science messages through a storytelling lens was the most compelling similarity across successful 3MT presentations, we found that no single criterion outweighed any others in terms of importance. Still, the combined use of best communication

Table 1. Predictions on presenter advancements through 3MT competition.

Participant	Predicted Rank	Official Rank	
Preliminary Competition			
Group A			
Qualified Presenter 1	4	1	*
Qualified Presenter 2	3	3	*
Qualified Presenter 3	1	PC	
Qualified Presenter 4	1	2	*
Qualified Presenter 5	NR	NR	*
Group B			
Qualified Presenter 1	4	3	*
Qualified Presenter 2	3	NR	
Qualified Presenter 3	2	2	*
Qualified Presenter 4	1	1	*
Group C			
Qualified Presenter 1	2	2	*
Qualified Presenter 2	4	1	*
Qualified Presenter 3	2	3	*
Qualified Presenter 4	1	NR	
Final Competition			
Qualified Presenter 1	1	1	*
Qualified Presenter 2	2	2	*
Qualified Presenter 3	NR	NR	*
Qualified Presenter 4	NR	NR	*

*_Successful prediction based on weighted observational protocol. (NR = No Rank, PC = People’s Choice Winner)_

practices is what resulted in the highest-ranking presentations by competition judges.

Our model does not recommend a single communication style or stance combination that is unilaterally appropriate for sharing science stories with a generalized audience. Rather, our data suggest that potential presenters can follow our general communication model guidelines to develop a successful presentation. We noted that most successful 3MT presentations began with a strong, related hook, used a lead-in in which the speaker introduced themselves and their research problem, and included three main speaking points with evidence that supported their primary take-home point. Furthermore, successful while 3MT presenters showed some variability in jargon usage, none of the observed 3MT winners gave jargon-dense talks.

Implications for Practice

Exploring ways to reach community members that may view science with skepticism is an important step toward increasing scientific literacy in the community, and events like the 3MT provide one such avenue researchers can use to communicate scientific information (Allen, 2018; Schmitt, 2008). Additionally, building a scientifically literate populace is essential for taking steps toward passing science-based policies and making publicly supported positive environmental impacts. To build this populace we need audiences to understand the messages we convey. Prior research (Schmit, 2008) claims that audiences need to understand at least 98% of the words used in order to fully comprehend a message. This notion is consistent with the notion that presenters should use accessible language to tell their research story (Sugimoto & Thelwall, 2013) and the approach of successful 3MT presenters during our investigation. We can further aid science communicators by teaching them how to avoid jargon-heavy language typically associated with science presentations by providing them with tools like the De-Jargonizer to identify potentially problematic terms to avoid in order to improve language comprehension of intended messages (Avraamidou & Osborne, 2009; Rakedzon et al., 2017). Furthermore, scientific storytelling can encourage non-scientists to be more open to learning (Allen, 2018; Fischhoff, 2013) and possibly help reduce skepticism by building transparency, improving trust, and reducing the potential mystique around research that can alienate the discipline from non-scientists. Storytelling can increase accessibility to sometimes inapproachable and complex science topics (Fischhoff, 2013) through the personalization of science messaging, allowing scientists to be viewed as more human to their audience. By selecting a purposeful narrative to shape a scientific message (discovery, rescue, or mystery) (Green et al., 2018), successful 3MT presenters were able to share their research in an engaging and effective way. And even within the short three-minute time limit, taking a moment to explain the link between the provided visual and the presented verbal message can support audiences' attention to the intended message and illustrates best practices for building representational competence (Daniel, 2018; Qiao & Hullman, 2018). Reconsidering science communication as a form of storytelling with visual aids can help audiences connect with scientists as characters and increase buy-in to the presented problem as a theme that needs a resolution (Avraamidou & Osborne, 2009; Gough, 1993; Orgborn et al., 1996).

Overall, effective science communication serves to help create an informed audience that can understand and apply scientific ideas as they make informed decisions within their community (Fischoff, 2013). The 3MT is one option we can support to help early career scientists build their essential communication skills and become trusted voices listened to by generalist audiences.

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References

Allen, W. L. (2018). Visual brokerage: Communicating data and research through visualisation. *Public Understanding of Science, 27*(8)*,* 906-922.

Avraamidou, L., & Osborne, J. (2009). The role of narrative in communicating science. *International Journal of Science Education*, *31*(12), 1683–1707.

Baram-Tsabari, A. & Osborne, J. (2015). Bridging science education and science communication research. *Journal of Research in Science Teaching*, *52*(2), 135–144.

Baram-Tsabari, A., & Sharon, A.J. (2014). Measuring mumbo jumbo: A preliminary quantification of the use of jargon in science communication. *Public Understanding of Science*, *23*(5), 528–546.

Baron, N. (2010). *Escape from the ivory tower: A guide to making your science matter*. Island Press.

Becher, T., & Trowler, P. R. (2001). *Academic tribes and territories* (2nd Ed). Society for Research in Higher Education/Open University Press.

Brock, T. C., Strange, J. J., & Green, M. C. (2002). Power beyond reckoning: An Introduction to Narrative Impact. In M. C. Green, J. J. Strange, & T. C. Brock (Eds.), *Narrative Impact: Social and Cognitive Foundations* (p. 1–15). Lawrence Erlbaum Associates Publishers.

Bruner, J. (2003). *Making stories: Law, literature, life.* Harvard University Press, Cambridge MA.

Carter-Thomas, S., & Rowley-Jolivet, E. (2020). Three Minute Thesis presentations: Recontextualisation strategies in doctoral research. *Journal of English for Academic Purposes, 48,* 100897.

Chung, Y., Yoo, J., Kim, S.-W., Lee, H., & Zeidler, D. L. (2016). Enhancing students' communication skills in the science classroom through socioscientific issues. *International Journal of Science and Mathematics Education*, *14*(1), 1–27.

Cooke, S. J., Gallagher, A. J., Sopinka, N. M., Nguyen, V. M., Skubel, R.A., Hammerschlag, N., Boon, S., Young, N., & Danylchuk, A.J. (2017). Considerations for effective science communication. *FACETS*, *2*(1), 233-248.

Copeland, P. (2015). Three minute theatre: Principles and practice for scripting and performing Three Minute Thesis presentations. *International Journal for Researcher Development*, *6*(1), 77-92.

Daniel, K. L. (Ed.). (2018). *Towards a framework for representational competence in science education* (Vol. 11). Springer.

Davidson, P. M., & Ferguson, C. (2014). The importance of communicating your research: The 3 Minute Thesis. *Advances in Nursing Doctoral Education and Research, 2*(1), 11-14.

Deroey, K.L.B. (2015). Marking importance in lectures: Interactive and textual orientation. *Applied Linguistics, 36*(1), 51–72.

Dupree, C., & Fiske, S.T. (2014). Gaining trust as well as respect in communicating to motivated audiences about science topics. *PNAS, 111,* 13593–13597.

Fischhoff, B. (2013). The sciences of science communication. *PNAS*, *110*(3), 14033-14039.

Gough, N. (1993). Environmental education, narrative complexity and postmodern science/fiction. *International Journal of Science Education, 15*(5), 607-625.

Green, S. J., Grorud-Colvert, K., & Mannix, H. (2018). Uniting science and stories: Perspectives on the value of storytelling for communicating science. *Facets*, *3*(1), 164-173.

Hu, G., & Liu, Y. (2018). Three Minute Thesis presentations as an academic genre: A cross-disciplinary study of genre moves. *Journal of English for Academic Purposes*, *35*, 16–30.

Hullman, J., & Bach, B. (2018, June). Picturing science: Design patterns in graphical abstracts. In *Diagrammatic Representation and Inference: 10th International Conference, Diagrams 2018, Edinburgh, UK, June 18-22, 2018, Proceedings 10* (pp. 183-200). Springer International Publishing.

Hyland, K. (2001). Bringing in the reader: Addressee features in academic articles. *Written Communication, 18*(4), 549-574.

Hyland, K. (2004). *Disciplinary discourses, Michigan classics ed.: Social interactions in academic writing.* University of Michigan Press.

Hyland, K. (2006). *English for academic purposes: An advanced resource book.* Routledge.

Hyland, K., & Zou, H. J. (2021). “I believe the findings are fascinating”: Stance in three-minute theses. *Journal of English for Academic Purposes, 50,* 100973.

Jiang, F., & Qiu, X. (2022). Communicating disciplinary knowledge to a wide audience in 3MT presentations: How students engage with popularization of science. *Discourse Studies, 24*(1), 115-134.

Jucan, M. S., & Jucan, C. N. (2014). The power of science communication. *Procedia - Social and Behavioral Sciences, 149,* 461-466.

Lackey, R.T. (2007). Science, scientists, and policy advocacy. *Conservation Biology*, *21*(1), 12–17.

Lee, J. J. (2016). "There's Intentionality Behind It...": A Genre Analysis of EAP Classroom Lessons. *Journal of English for Academic Purposes*, *23*, 99–112.

Lemke, J. L. (1990). Talking Science: Language, Learning, and Values. Cambridge University Press.

Mezek, S., & Swales, J. M. (2016). PhD defenses and vivas. *The Routledge Handbook of English for Academic Purposes, 361,* 375.

Monroe, B. L., Colaresi, M. P., & Quinn, K. M. (2008). Fightin'words: Lexical feature selection and evaluation for identifying the content of political conflict. *Political Analysis, 16*(4), 372-403.

Nisbet, M. C., & Scheufele, D. A. (2009). What's next for science communication? Promising directions and lingering distractions. *American Journal of Botany*, *96*(10), 1767.

O'Donovan, P., Agarwala, A., & Hertzmann, A. (2015, April). Designscape: Design with interactive layout suggestions. In *Proceedings of the 33rd annual ACM conference on human factors in computing systems* (pp. 1221-1224)

Ogborn, J., Kress, G., & Martins, I. (1996). *Explaining science in the classroom.* McGraw-Hill Education (UK).

Otoshi, J., & Heffernen, N. (2008). Factors predicting effective oral presentations in EFL classrooms. *Asian EFL Journal, 10*(1), 65-78..

Poliakoff, E., & Webb, T.L. (2007). What factors predict scientists' intentions to participate in public engagement of science activities? *Science Communication*, *29*(2), 242–263.

Qiao, X., & Hullman, J. (2018, October). Translating scientific graphics for public audience. *IEEE VIS,* 1-4.

Qui, X., & Jiang, K. (2021). Stance and engagement in 3MT presentations: How students communicate disciplinary knowledge to a wide audience. *Journal of English for Academic Purposes, 51,* 1-12. https://doi.org/10.1016/j.jeap.2021.100976

Rakedzon, T., Segev, E., Chapnik, N., Yosef, R., & Baram-Tsabari, A. (2017). Automatic jargon identifier for scientists engaging with the public and science communication educators. *PLOS ONE, 12*(8), e0181742.

Schank, R. C., & Berman, T. R. (2002). The pervasive role of stories in knowledge and action. In M. C. Green, J. J. Strange, & T. C. Brock (Eds.), *Narrative impact: Social and cognitive foundations* (p. 287–313). Lawrence Erlbaum Associates Publishers.

Schmitt, N. (2008). Instructed second language vocabulary learning. *Language teaching research, 12*(3), 329-363.

Shaikh-Lesko, R. (2014). Science speak. *Scientist, 28*(8), 62–64.

Sugimoto, C.R., & Thelwall, M. (2013). Scholars on soap boxes: Science communication and dissemination in TED videos. *Journal of the American Society for Information Science and Technology, 64*(4), 663-674.

Taylor, K.L., & Toews, S.V.M. (1999). Effective presentations: How can we learn from the experts? *Medical Teachers, 21*(4), 409-414.

University of Queensland (n.d.). Three minute thesis. https://threeminutethesis.uq.edu.au/

Willoughby, S. D., Johnson, K., & Sterman, L. (2020). Quantifying scientific jargon. *Public Understanding of Science, 29*(6), 634-643.

Yang, W. (2020). A keyword analysis of stance and engagement in Three-Minute Thesis (3MT) presentations. *GEMA Online Journal of Language Studies, 20*(2).

Zimmer, C. (2018). Science and scandal: Reporting on biology in an age of controversy. *Integrative and Comparative Biology*, *58*, 45.

A Framework for Scaling-up Community-Engaged Research Experiences in Introductory General Biology Laboratories

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Abstract

In this paper, we describe the transition of all five course-sections of General Biology Laboratory I from "cookbook" surveys of taxonomic domains and kingdoms to course-based undergraduate research experiences that champion inquiry-based learning in "real world" environments. We achieved this by scaling-up lessons from a research-focused pilot section refined over three years to blend instruction with collaboration with community partners seamlessly. In terms of outcomes, students share data analyses directly with community partners, present posters at research conferences, publish research findings, and use project findings to successfully compete for placement in advanced summer research programs. This course structure benefits the students, the community partners, and the instructor. The community partners, in turn, are provided with free scientific consultations that advance data-driven strategies and empower adaptive management of localized environmental issues. The instructor benefits from the opportunity to contribute their unique disciplinary expertise toward the collaborative design and shared success of a modular course.

Key words: community engaged CURE labs, undergraduate, introductory biology, implementation, scaling up

Introduction

Most introductory biology laboratories are taught using direct instruction, where students are given predetermined answers after following procedures (Dolan, 2016; Indorf et al., 2019). This is the case with the introductory general biology laboratory courses for all first-year students at University of Detroit Mercy (UDM) which are all taught using direct instruction except for one pilot Course-Based Undergraduate Research (CURE) laboratory. At most universities, an introductory biology laboratory course is a required class for all students (biology majors and non-majors) (Baker, 2004; Gasiewski et al., 2012; Patchen et al., 2014; Robinson, 2012). For many students, an introductory biology laboratory course fulfills a credit requirement for their degree, and these may be the only science courses they will take in college (Gasiewski et al., 2012; Patchen et al., 2014; Seymour & Hewitt, 1997). For other students, these introductory biology courses serve as gateways to more advanced biology courses. Whatever the case, these introductory biology laboratory courses often lack engaging pedagogy as they heavily rely on teaching using the direct instructional approach, and this is considered one of the reasons why students switch out of biology majors (Gasiewski et al., 2012; Robinson, 2012; Garcia & Rahman, 2015). It is within the first two years of taking these courses that the majority of attrition in the sciences occurs in college (Chang et al., 2008; Seymour & Hewitt, 1997). Many students are challenged by introductory biology laboratory courses and struggle to understand and apply the content (Ateh & Charpentier, 2014; Gasiewski et al., 2012; Patchen et al., 2014). These introductory biology courses may be a critical barrier to students' progress toward their degree aspirations (Ateh & Charpentier, 2014).

Both the Vision and Change in Undergraduate Biology Report and the American Association for the Advancement of Science advocate the reform of undergraduate Science, Technology, Engineering, and Mathematics (STEM) curricula to focus on developing analytical skills instead of memorizing content

(Brewer & Smith, 2011; National Research Council, 1996, 2003; Olson & Riordan, 2012). These scientific organizations and committees have called for institutions to teach science the way it is performed by professional scientists, with an emphasis on inquiry, autonomy, and discovery-based experiences (Brewer & Smith, 2011; National Research Council, 1996, 2003; Olson & Riordan, 2012). Some of the attributes of undergraduate programs that have met this goal include experience with authentic research, active learning, collaborative learning communities in which students share an intellectual experience, and involvement in research that directly impacts their scientific or local communities (Seymour & Hewitt, 1997; Estrada et al., 2011; Graham et al., 2013; Provost, 2016; Toven-Lindsey et al., 2015). Moreover, researchers have shown that including undergraduates in faculty-supervised research has several benefits (Werth et al., 2022)**.** Unfortunately, such opportunities are typically available to only a few undergraduates pursuing independent research projects under the guidance of research faculty.

One approach geared toward making research opportunities available for ALL students involves incorporating CUREs into the existing gateway laboratory courses that are part of the undergraduate curriculum (Brewer & Smith, 2011; Olson & Riordan, 2012, Indorf et al.,2019; Wei & Woodin, 2011; Miller et al., 2022; Werth et al., 2022). CUREs in the natural sciences (e.g., biology, chemistry, physics, math, and earth science) constitute (1) presenting an element of discovery so that students are engaged in novel exploration; (2) incorporating iteration into the course; (3) promoting collaboration among students and faculty members; (4) training students in scientific practices and critical thinking; (5) addressing research questions that are of interest to a scientific or local community (Dolan, 2016; Patchen et al., 2014, Hatfull et al., 2006; Olson & Riordan, 2012; Corwin et al., 2015; Spell et al., 2014). CUREs also present marked benefits for instructors, departments, and institutions, including student retention and the creation and collection of research data which are publishable (Brewer & Smith, 2011; Govindan et al., 2020; Jordan et al., 2014; Miller et al., 2022).

Specifically, scaling-up of existing CUREs has the potential to make research opportunities available to ALL students who do not typically access research, including those with lower GPAs and underrepresented students in STEM (Miller et al., 2022; Hydorn, 2005). CURE courses have demonstrated positive impacts on undergraduate students, including increased knowledge and skills, more engagement in active learning, improved student achievement, improved preparation and persistence for STEM careers, and greater inclusion of underrepresented minorities in undergraduate research (Harrison et al.,2011 Miller et al., 2022; Freeman et al., 2014; Goodwin et al., 2021; Kuh, 2008; Hunter et al., 2007; Kardash et al., 2008; Lopatto, 2004). The more students participate in hands-on, authentic research experiences, the more likely they are to maintain their interest in science and begin to think of themselves as scientists (Mraz-Craig et al.,2018; National Academies of Sciences, Engineering, and Medicine, 2015; Archer & DeWitt, 2016; Carlone & Johnson, 2007; Dolan, 2016). Thus, the implementation of authentic CUREs may facilitate students' development of a scientific identity (Garcia et al., 2015; Chen & Soldner, 2013; Wong, 2015; Chemers et al., 2011; Hauwiller et al., 2019; Clark et al., 2016; Archer & DeWitt, 2016; Brownell et al., 2012). Several studies have shown that students who consider themselves scientists or who have a scientific identity are more likely to remain in STEM fields (Brownell et al., 2012; King et al., 2016; Lopatto, 2004; Beck, 2012; Domin, 1999; Indorf et al., 2019). The primary educational literature clearly shows that early exposure to STEM research is critical for developing and cultivating STEM interest among undergraduates, ultimately diversifying the community of students gaining access to post-graduate programs and the STEM workforce (Indorf et al., 2019). This is critical because many undergraduate students leave STEM programs within the first two years of college, with underrepresented students leaving at higher rates (Jordan et al., 2014; Carlone & Johnson, 2007).

Current biology laboratory curriculum

The UDM has been trying to improve the Introductory Biology Laboratory Curriculum General Biology Laboratory I for over 20 years (Baker, 2004). But the laboratory activities that were implemented were direct instruction confirmatory laboratory models (Batzli, 2005; Bolsenga & Herdendorf, 1993; Renkly &Bertolini, 2018). A common perception of direct instruction laboratories is that the instructor introduces the topic, presents the theoretical aspects of procedures, and identifies the laboratory objectives. The typical laboratory manual explicitly states the experimental goals of the experiment and provides instructions for data collection and analysis (Domin,1999). Within the laboratory manual, there are questions and suggestions that enable students to consider the concepts relevant to their investigations and to evaluate their experimental procedures. The students follow the procedures given by the instructor or from the laboratory manual to obtain the predetermined outcomes. Sometimes the students are unaware of the expected outcome, and the teacher directs or helps them obtain the desired outcome (Hiemstra & Van Yperen, 2015; Stufflebeam, 1983). Such direct instruction laboratories are highly criticized for a number of reasons: the focus of students is obtaining the correct results of the experiment though they may fail to understand the concept of the laboratory experiment (Batzli, 2005; Stufflebeam, 1983). One barrier for resource-challenged private undergraduate institutions, such as the UDM, is the prioritization of an institution-wide analysis of all programs and facilities.

To address these challenges, we (Carmona, Nyutu, and Polanco) developed a collaborative project to transition all five course-sections of General Biology Laboratory I from “cookbook” surveys of taxonomic domains and kingdoms that utilize rote-memorization (National Research Council, 1996) to that of course-based undergraduate research experiences that champion inquiry-based learning in “real world” environments (Renkly & Bertolini, 2018). We would achieve this by scaling-up lessons from a pilot-section that for three years has been cultivating best practices with community partners in Detroit amidst unprecedented interruptions to Higher Education brought-on during the SARS-Cov-2 pandemic. Each Fall, General Biology Laboratory I services 180 (predominantly first year) undergraduate students from multiple departments across the College of Engineering and Science. The pilot community engaged CURE curriculum also includes exercises in reading and understanding primary literature, using various data analysis, and communicating science to different audiences. The community engaged CURE course is intended for undergraduates in their first year who are pursuing majors such as biology and pre-health. Here, we describe our collaborative model as a widely implementable curricular framework to scale up a one-semester introductory General Biology Laboratory I curriculum to employ techniques of CUREs.

Purpose

Each laboratory section of the community engaged CURE starts with a novel issue the community partners face. The students then work on how to design an experiment around that issue so that each group of four students are working on a different issue. The community engaged CURE has been designed to not only address particular research questions but also expose students to a variety of research techniques and topics. Upon completing the community engaged -CURE, students should achieve the following learning objectives.

- Students will be able to formulate biologically relevant questions, make empirical hypotheses, design experiments that employ independent/ dependent variables as well as controls and treatments, as well as interpret patterns in data through basic statistical analyses.
- Students will be able to make quantitative measurements of cell morphologies using a microscope and image analysis.
- Students will be able evaluate differences in the morphology of bacteria and fungi that grow on nutrient agar plates, as well as use molecular tools for the quantification of fecal-indicator bacteria in field conditions.

- Students will have a greater appreciation for the linkages between science and society.
- Compose and revise scientific manuscripts and make oral presentations that effectively communicate the findings of their research.
- Gain an increased appreciation and understanding of how hypothesis-driven research is conducted.

Our semester-long General Biology I laboratory pilot community engaged CURE course comprises two modules that build upon the preceding module's experiences. During the summer of 2021 we reimagined on how to scale up the pilot to two other sections each with 36 students. Weekly requirements included students developing a hypothesis, designing and setting up an experiment, collecting data, recording results, and forming conclusions that highlighted how they applied scientific methodology (see Appendix 1). Using an empirical, experimental approach (i.e., hypothesis testing), the first module project empowers students to select the independent variables, the second module allows both dependent and independent variables to be selected by students. The first module we partnered with Cadillac Urban Gardens to focus on photosynthesis and climate change. For the second module, we worked with Lake St. Clair Metro Park on microbial diversity, addressing green stormwater infrastructure. Benefits include ease of getting to the locations which are close to campus, many of the students live in the communities where our partners are based, and students experience using their STEM degree to cultivate change in their community. Students participate in a project that follows the typical topics/concepts covered in the lecture, from photosynthesis to central dogma, scientific method, microbial diversity, and classification systems in one semester, providing a strong connection between the topics discussed in the introductory biology lecture and the hands-on aspect of the research experience.

In module one, students learn the basic principles of the compound microscopes (see Appendix 1). Calibration of ocular micrometers, measurements of microscopic structures and preparation. Once students have mastered these skills they will collect two leaves from an oak tree and two leaves from the cherry trees outside the biology department. The students measured the stomata length, stomata density, and percentage of stomata open and closed. The students typed in their data in a shared excel file and then calculated, mean, standard deviation and run a T-test. Then graphed their data using excel and recorded their data in their electronic OneNote notebook. The following week, students sampled stomatal densities of plants at Cadillac Urban Gardens Southwest Detroit Environmental Vision. Cadillac Urban Gardens is a one-acre urban garden located in, Southwest Detroit, on the former grounds of the Cadillac Clark Street Plant’s Executive parking lot. In 2012 as a community collaboration between Southwest Detroit Environmental Vision (SDEV), the Ideal Group, General Motors (GM), residents, non-profits, businesses, schools, and other local community organizations, Cadillac Urban Gardens was developed with and for the community in mind. This garden since 2012 has been able to repurpose 331 shipping containers from GM and utilize them as raised beds to grow fresh produce the community can harvest without cost. The garden provides food security for residents with little access to garden space and fresh produce. It has become a model for sustainable gardening practices as residents grow and harvest produce within walking distance of their homes. Thus, students developed a research project responding to an environmental issue that Cadillac Urban Gardens Southwest Detroit Environmental Vision had identified as affecting their plants. For example, is there a difference in the stomatal density of companion plants and plants grown alone without companion plants in raised beds. The students recorded their data in their OneNote electronic laboratory book. Students analyzed their data and prepared their scientific poster which they presented at the College of Engineering and Science Undergraduate Research Symposium at UDM.

In the second module students learned about microbial diversity and richness (see Appendix 1). In the prior week students prepared 12 tryptone soya agar (TSA) and

12 Lennox broth (LB) agar petri plates. As students waited for their liquid agars to solidify they went over the Shannon Diversity Index. The students went around campus and compared faculty and student's car diversity (car type and car color) on campus to practice calculating and analyzing data using the Shannon Index Diversity. The following week students chose two creative places to swab for bacteria and inoculated them in the TSA and LB agar plates they had prepared and incubated the agar plates for a week. The subsequent week. students made a photo library of different bacterial morphotypes they identified on their LB and TSA agar plates and saved them in their electronic OneNote notebook. The students used Acrobat reader image analysis tool to digitally measure the area of all bacterial colonies and then record their data in excel. The students then used EstimateS to rarefy their data, and use excel to make graphs of their data, and prepared their scientific posters.

In the third module, students collected data from Lake St. Clair Metropark. Central to this process was having students experience an impaired watershed in multiple ways by physically touring and observing environmental impacts in the watershed, sampling, and testing different sites for physical/chemical parameters, and quantifying *Escherichia coli* and coliform colony forming units (CFUs). In this module students also developed a laboratory project connecting student learning to real-life challenges, specifically a local water-quality project. This module will focus on water quality issues which are important community concerns in metropolitan Detroit (Renkly & Bertolini, 2018).

The Lake St. Clair "green scaping" project is a solution to stormwater pollution that residents have been concerned about for years. The ponds and vegetation bioswales collect the rainwater as it falls and naturally filter out the contaminants before the water flows back into Lake St. Clair. The Lake St. Clair Metro Park project is a great starting point for further green infrastructure development in Macomb County. Students collected water samples from different points on Lake St. Clair to test for levels of *Escherichia coli* and total coliform. After collecting their water samples in 100ml disposable sterile sampling vials. The students put one packet of the colilert reagent in each water bottle and mixed it until the colilert reagent dissolved. The students then poured out the mixture in Quanti tray sleeves and sealed each sleeve using the Quanti-tray IDEXX sealer. The sealed trays were placed in a 35°C incubator for 24 hours. The students counted the number of positive wells for *Escherichia coli* and coliform and used the table provided with the IDEXX sealer to obtain a Most Probable Number (MPN) and recorded their results in a shared excel file. The students then ran a correlation analysis between the Most Probable Number and the physical properties of water (Total Suspended Solid, Temperature, pH, and Conductivity), T-test to compare the means of the two different sites those with invasive Phragmites and those without Phragmites. The students recorded their data in their OneNote electronic laboratory book. Students prepared their scientific poster and presented to the class and the community partners.

Conclusions

Scaling-up the piloted community engaged CURE best-practices across all the General Biology I laboratory sections resulted in informative experiences for first-year undergraduates in the college stemming from an "asset-based" STEM culture (i.e., strengths driven), which celebrates inclusive excellence by placing all introductory biology students (e.g., language skills, cultural backgrounds, etc.) at the forefront of scientific exploration and innovation (Olson & Riordan, 2012). For example, while many of the students in the pilot courses lived in the communities where our partners were based, student evaluations showed it was the first time most of them experienced using their STEM degree to cultivate change. These community-engaged research experiences stand in sharp contrast to the "deficit-based" approach (i.e., needs-driven) students experienced throughout high school, wherein STEM contributions were reduced to memorization of facts detached from students' personal sphere of influence or interest (National Research Council, 2003). This collaborative project piloted course structure allows faculty to mentor short-term field projects (i.e., student explorations) that serve as a research strategy for the long-term study of diverse biological phenomena in an urban context. As teacher-scholars in a Primarily Undergraduate Institution, this collaborative project will sustain vibrant and academically productive scholarship with student co-authored contributions and cultivate grantsmanship by advancing pilot data primed for competitive federal and foundation grants. This collaborative project also democratizes research mentorship for a broader segment of the student community, many of whom may not have approached a professor on their own to seek out research opportunities in a faculty laboratory. Another significant result from these community engaged CURES is that more diverse group of undergraduate students can now advance highly competitive dossiers when applying to graduate and professional programs. This community engaged CURE laboratory provides an affordable option for colleges of all sizes to provide students an off-site course-based research experience. One feature of the community engaged CURE is the adaptability of the project into a semester schedule.

In terms of outcomes, students share data analyses directly with community partners, presented posters at research conferences (e.g., College of Engineering & Science), will publish research findings (e.g., Michigan Academy of Sciences, Arts, and Letters), and use project findings to successfully compete for placement in advanced summer research programs (e.g., Biology Summer Internships). This course structure benefits the students, the community partners, and the instructor. It grants students access to independent research and opportunities to publish authentic scientific papers as undergraduates. The community partners, in turn, are provided with free scientific consultations that advance data-driven strategies and empower adaptive management of localized environmental issues. The instructor benefits from the opportunity to contribute their unique disciplinary expertise toward the collaborative design and shared success of a modular learning structure. Advancing hands-on research explorations that tackle real-world problems affecting diverse Detroit-area communities, our proposed course model has the potential to tap diverse perspectives in solving local environmental challenges as well as identifying innovative new directions of STEM research. By enhancing early participation and removing barriers to research experiences, community-engaged CUREs at the introductory level also help students enter upper-division courses with a greater understanding and expectation of research experiences and its transformative role in society. Additionally, by empowering undergraduates in the design and scope of STEM explorations that address environmental issues affecting Detroit-area communities, we feel a community engaged CURE model serves as an effective strategy for improving the recruitment and retention of underrepresented students in STEM disciplines.

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References

ARCHER, L., & DEWITT, J. (2016). Understanding Young People's Science Aspirations: How students form ideas about ‘becoming a scientist’. Taylor & Francis.

ATEH, C. M., & CHARPENTIER, A. (2014). Sustaining student engagement in learning science. The Clearing House: A Journal of Educational Strategies, Issues and Ideas, 87(6), 259-263.

BAKER, S. S. (2004). Using transgenic Arabidopsis in cold acclimation experiments is an effective tool in teaching the process of science. 26th Annual Association of Biology Laboratory Educations Conference. Bowling Green, OH.

BANGERA, G., & BROWNELL, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. CBE—Life Sciences Education, 13(4), 602-606.

BATZLI, J. M. (2005). Points of view: A survey of survey courses: Are they effective? A unique approach? Four semesters of biology core curriculum. Cell Biology Education, 4(2), 125-128.

BECK, K. 2012. The Effect of Guided-Inquiry Chemistry Labs on Student Engagement. Master Thesis, Carroll University WI

BOLSENGA, S. J., & HERDENDORF, C.E. (Eds.). (1993). Lake Erie and Lake St. Clair Handbook. Wayne State University Press.

BREWER, C. A., & SMITH, D. (2011). Vision and change in undergraduate biology education: a call to action. American Association for the Advancement of Science, Washington, DC, 81.

BROWNELL, S. E., KLOSER, M. J., FUKAMI, T., & SHAVELSON, R. (2012). Undergraduate biology lab courses: comparing the impact of traditionally based “cookbook” and authentic research-based courses on student lab experiences. Journal of College Science Teaching, 41(4), 36-45.

CARLONE, H. B., & JOHNSON, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 44(8), 1187-1218.

CHANG, M. J., CERNA, O., HAN, J., & SAENZ, V. (2008). The contradictory roles of institutional status in retaining underrepresented minorities in biomedical and behavioral science majors. The Review of Higher Education, 31(4), 433-464.

CHEMERS, M. M., ZURBRIGGEN, E. L., SYED, M., GOZA, B. K., & BEARMAN, S. (2011). The role of efficacy and identity in science career commitment among underrepresented minority students. Journal of Social Issues, 67(3), 469-491.

CHEN, X. (2013). STEM Attrition: College Students' Paths into and out of STEM Fields. Statistical Analysis Report. NCES 2014-001. National Center for Education Statistics.

CLARK, T. M., RICCIARDO, R., & WEAVER, T. (2016). Transitioning from expository laboratory experiments to course-based undergraduate research in general chemistry. Journal of Chemical Education, 93(1), 56-63.

CORWIN, L. A., GRAHAM, M. J., & DOLAN, E. L. (2015). Modeling course-based undergraduate research experiences: An agenda for future research and evaluation. CBE—Life Sciences Education, 14(1), es1.

DOLAN, E. L. (2016). Course-based undergraduate research experiences: Current knowledge and future directions. Natl Res Counc Comm Pap, 1, 1-34.

DOLAN, E. L. (2016). Course-based undergraduate research experiences: Current knowledge and future directions. Natl Res Counc Comm Pap, 1, 1-34.

DOMIN, D. S. (1999). A review of laboratory instruction styles. Journal of chemical education, 76(4), 543.

ESTRADA, M., WOODCOCK, A., HERNANDEZ, P. R., & SCHULTZ, P. W. (2011). Toward a model of social influence that explains minority student integration into the scientific community. Journal of educational psychology, 103(1), 206.

FREEMAN, S., EDDY, S. L., MCDONOUGH, M., SMITH, M. K., OKOROAFOR, N., JORDT, H., & WENDEROTH, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the national academy of sciences, 111(23), 8410-8415.

GARCIA, R., RAHMAN, A., & KLEIN, J. G. (2015). Engaging Non–Science Majors in Biology, One Disease at a Time. The American Biology Teacher, 77(3), 178-183.

GARCIA, R., RAHMAN, A., & KLEIN, J. G. (2015). Engaging Non–Science Majors in Biology, One Disease at a Time. The american biology Teacher, 77(3), 178-183.

GASIEWSKI, J. A., EAGAN, M. K., GARCIA, G. A., HURTADO, S., & CHANG, M. J. (2012). From gatekeeping to engagement: A multicontextual, mixed method study of student academic engagement in introductory STEM courses. Research in higher education, 53, 229-261.

GOODWIN, E. C., ANOKHIN, V., GRAY, M. J., ZAJIC, D. E., PODRABSKY, J. E., & SHORTLIDGE, E. E. (2021). Is this science? Students’ experiences of failure make a research-based course feel authentic. CBE—Life Sciences Education, 20(1), ar10.

GOVINDAN, B., PICKETT, S., & RIGGS, B. (2020). Fear of the CURE: a beginner’s guide to overcoming barriers in creating a course-based undergraduate research experience. Journal of microbiology & biology education, 21(2), 50.

GRAHAM, M. J., FREDERICK, J., BYARS-WINSTON, A., HUNTER, A. B., & HANDELSMAN, J. (2013). Increasing persistence of college students in STEM. Science, 341(6153), 1455-1456.

HARRISON, M., DUNBAR, D., RATMANSKY, L., BOYD, K., & LOPATTO, D. (2011). Classroom-based science research at the introductory level: changes in career choices and attitude. CBE—Life Sciences Education, 10(3), 279-286.

HATFULL, G. F., PEDULLA, M. L., JACOBS-SERA, D., CICHON, P. M., FOLEY, A., FORD, M. E., ... & HENDRIX, R. W. (2006). Exploring the mycobacteriophage metaproteome: phage genomics as an educational platform. PLoS genetics, 2(6), e92.

HAUWILLER, M. R., ONDRY, J. C., CALVIN, J. J., BARANGER, A. M., & ALIVISATOS, A. P. (2019). Translatable research group-based undergraduate research program for lower-division students. Journal of chemical education, 96(9), 1881-1890.

HIEMSTRA, D., & VAN YPEREN, N. W. (2015). The effects of strength-based versus deficit-based self-regulated learning strategies on students' effort intentions. Motivation and Emotion, 39, 656-668.

HUNTER, A. B., LAURSEN, S. L., & SEYMOUR, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. Science education, 91(1), 36-74.

HYDORN, D. L. (2005). Community service projects in a first statistics course. MAA NOTES, 66, 111.

INDORF, J. L., WEREMIJEWICZ, J., JANOS, D. P., & GAINES, M. S. (2019). Adding authenticity to inquiry in a first-year, research-based, biology laboratory course. CBE—Life Sciences Education, 18(3), ar38.

JOHNSON, T. R., & CASE, C.L. (2013). Laboratory experiments in microbiology. 10th ed. Benjamin Cummings; San Francisco, CA: 2013.

JORDAN, T. C., BURNETT, S. H., CARSON, S., CARUSO, S. M., CLASE, K., DEJONG, R. J., ... & HATFULL, G. F. (2014). A broadly implementable research course in phage discovery and genomics for first-year undergraduate students. MBio, 5(1), e01051-13.

KARDASH, C. M., WALLACE, M., & BLOCKUS, L. (2008). Undergraduate research experiences: Male and female interns' perceptions of gains, disappointments, and self-efficacy.

KING, N., VAN DER TOUW, T., SPOWART, L., & LAWLOR, C. (2016). A scoping study investigating student perceptions towards inquiry-based learning in the laboratory. European Journal of Science and Mathematics Education, 4: 305-314.

KUH, G. D. (2008). Excerpt from high-impact educational practices: What they are, who has access to them, and why they matter. Association of American Colleges and Universities, 14(3), 28-29.

LOPATTO, D. (2004). Survey of undergraduate research experiences (SURE): First findings. Cell biology education, 3(4), 270-277.

LORD, T. (2006). Moving from didactic to inquiry-based instruction in a science laboratory. The American biology teacher, 68(6), 342-345.

MILLER, D. M., NATALE, A., MCANULTY, T. K., SWOPE, R. D., MCNAUGHTON, E. A., BECKETT, A., ... & XIONG, S. (2022). The Design and Implementation of an Interdisciplinary CURE as an Alternative Option for the General Chemistry Laboratory Course. Journal of Chemical Education, 99(7), 2530-2540.

MRAZ-CRAIG, J. A., DANIEL, K. L., BUCKLIN, C. J., MISHRA, C., ALI, L., & CLASE, K. L. (2018). Student identities in authentic course-based undergraduate research experience. Journal of College Science Teaching, 48(1), 68-75.

NAGDA, B. A., GREGERMAN, S. R., JONIDES, J., VON HIPPEL, W., & LERNER, J. S. (1998). Undergraduate student-faculty research partnerships affect studen retention. The Review of Higher Education, 22(1), 55-72.

NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE. (2015). Integrating discovery-based research into the undergraduate curriculum: Report of a convocation. National Academies Press.

NATIONAL RESEARCH COUNCIL. (1996). National science education standards. National Academies Press.

NATIONAL RESEARCH COUNCIL. (2003). BIO2010: Transforming undergraduate education for future research biologists.

OLSON, S., & RIORDAN, D. G. (2012). Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the president. Executive Office of the President.

OLSON, S., & RIORDAN, D. G. (2012). Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the president. Executive Office of the President.

PATCHEN, A. K., DEBAY, D. J., BARNETT, M., & STRAUSS, E. (2014). Engaging students in scientific inquiry: successes and challenges of engaging non-science majors in scientific inquiry. In Inquiry-based learning for faculty and institutional development: A conceptual and practical resource for educators (Vol. 1, pp. 271-289). Emerald Group Publishing Limited.

PROVOST, J. (2016). Research for all: a CURE for undergraduates. ASBMB Today, 15, 30-31.

RENKLY, S., & BERTOLINI, K. (2018). Shifting the paradigm from deficit oriented schools to asset based models: why leaders need to promote an asset orientation in our schools. Empowering Research for Educators, 2(1), 4.

ROBINSON, N. R. (2012). An evaluation of community college student perceptions of the science laboratory and attitudes towards science in an introductory biology course (Doctoral dissertation, University of Alabama Libraries).

SEYMOUR, E., & HEWITT, N. M. (1997). Talking about leaving (Vol. 34). Westview Press, Boulder, CO.

SPELL, R. M., GUINAN, J. A., MILLER, K. R., & BECK, C. W. (2014). Redefining authentic research experiences in introductory biology laboratories and barriers to their implementation. CBE—Life Sciences Education, 13(1), 102-110.

STUFFLEBEAM, D. L. (1983). The CIPP Model for Program Evaluation, in Evaluation Models. Viewpoints on Educational and Human Services Evaluation, 1983.

TOVEN-LINDSEY, B., LEVIS-FITZGERALD, M., BARBER, P. H., & HASSON, T. (2015). Increasing persistence in undergraduate science majors: A model for institutional support of underrepresented students. CBE—Life Sciences Education, 14(2), ar12.

TRAVIS, H., & LORD, T. (2004). Traditional and constructivist teaching techniques. Journal of College Science Teaching, 34(3), 12.

WEI, C. A., & WOODIN, T. (2011). Undergraduate research experiences in biology: alternatives to the apprenticeship model. CBE—Life Sciences Education, 10(2), 123-131.

WERTH, A., WEST, C. G., & LEWANDOWSKI, H. J. (2022). Impacts on student learning, confidence, and affect and in a remote, large-enrollment, course-based undergraduate research experience in physics. Physical Review Physics Education Research, 18(1), 010129.

WONG, B. (2015). Careers “From” but not “in” science: Why are aspirations to be a scientist challenging for minority ethnic students?. Journal of Research in Science Teaching, 52(7), 979-1002.

Community Engaged CURE Modules

Day	Week of	Module	Recitation/ Online Lecture	Lab Activities	Assignments[+]
T	Aug 29	Climate Change	• Climate Change	• Syllabus • 25 questions	
T	Sep 5	Climate Change	• Autotrophs: Chemosynthesis & C_3/C_4/CAM photosynthesis	• Stomata measurements	
T	Sep 12	Climate Change	Biochemistry of Photosynthesis	• Experimental design • Data collection	
T	Sep 19	Climate Change	• Conservation Biology & Climate Change	• SDEV Cadillac Gardens • Experimental design • Data collection	
T	Sep 26	Climate Change	• Using the electronic resources of the library	• Scientific writing • Poster design	• Env. Justice Assignment Due: Climate Change • OneNote Notebook Check
T	Oct 3	Microbial Diversity	• DNA, Alleles, & Evolution	• Pour agarose gels	• Poster Due: *Stomatal Dynamics*
T	Oct 10	Microbial Diversity	• Central Dogma & Gene Structure	• Pour agarose gels • Experimental design	• PechaKucha: *Stomatal Dynamics*
T	Oct 17	Microbial Diversity	• Organismal Richness, Diversity, & Evenness	• Experimental design • Data collection	
T	Oct 24	Microbial Diversity	• Set up mini project	• Experimental design • Data collection	
T	Oct 31	Microbial Diversity	• Imaging Analysis through Adobe	• Scientific writing • Poster design	• Env. Justice Assignment Due: Microbial Diversity • OneNote Notebook Check
T	Nov 7	Microbial Diversity	• Rarefying Data and Graphing	• Aquaponics • experimental design	• Poster Due: *FIB Dynamics*
T	Nov 14	Microbial Diversity	• Reading Phylogenetic Trees	• Lake St. Clair MetroPark Raingardens • Data collection • Data analysis Data collection	• PechaKucha: *FIB Dynamics*
T	Nov 21	***Thanksgiving Break***		•	
T	Nov 28	Microbial Diversity	• Kingdoms: Features & Clades in Flux	• Data analysis	
T	Dec 5	Microbial Diversity	• Phylogenies & Conservation Biology	• Scientific writing • Poster design	• Env. Justice Assignment Due: • Poster Due • OneNote Notebook Check
T	Dec 14	Microbial Diversity	FINAL EXAM 2:00–3:50p		• Poster Due: Lake St Clair • Oral Presentation: Lake St Clair

***Bioscene*: Journal of College Biology Teaching**
Submission Guidelines

I. Submissions to *Bioscene*

Bioscene: Journal of College Biology Teaching is a refereed publication of the Association of College and University Biology Educators (ACUBE). Bioscene is published online only in May and in print in December. Submissions should reflect the interests of the membership of ACUBE. Appropriate submissions include:

- Articles: Course and curriculum development, innovative and workable teaching strategies that include **some type of assessment** of the impact of those strategies on student learning.
- Innovations: Laboratory and field studies that work, innovative and money-saving techniques for the lab or classroom. These do not ordinarily include assessment of the techniques' effectiveness on student learning.
- Perspectives: Reflections on general topics that include philosophical discussion of biology teaching and other topical aspects of pedagogy as it relates to biology.
- Reviews: Web site, software, and book reviews
- Information: Technological advice, professional school advice, and funding sources
- Letters to the Editor: Letters should deal with pedagogical issues facing college and university biology educators

II. Preparation of Articles, Innovations and Perspectives

Submissions can vary in length, but articles should be between 1500 and 5000 words in length. This includes references and tables but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. Topics designated as acceptable as articles are described above. The formats for all submissions are as follows:

A. Abstract: The first page of the manuscript should contain the title of the manuscript, the names of the authors and institutional addresses, a brief abstract (200 words or less) or important points in the manuscript, and keywords in that order.

B. Manuscript Text: The introduction to the manuscript begins on the second page. It should supply sufficient background for readers to appreciate the work without referring to previously published references dealing with the subject. Citations should be reports of credible scientific or pedagogical research.

The body follows the introduction. Articles describing some type of research should be broken into sections with appropriate subheadings including Materials and Methods, Results, and Discussion. Some flexibility is permitted here depending upon the type of article being submitted. Articles describing a laboratory or class exercise that works should be broken into sections following the introduction as procedure, assessment, and discussion.

Acknowledgment of any financial support or personal contributions should be made at the end of the body in an Acknowledgement section, with financial acknowledgements preceding personal acknowledgements. If the study required institutional approval such as an Institutional Review Board (IRB), the approval or review number should be included in this section. For example, this study was approved under the IRB number 999999. The editor will delete disclaimers and endorsements (government, corporate, etc.)

A variety of writing styles can be used depending upon the type of article. Active voice is encouraged whenever possible. Past tense is recommended for descriptions of events that occurred in the past such as methods, observations, and data collection. Present tense can be used for your conclusions and accepted facts. Because *Bioscene* has readers from a variety of biological specialties, authors should avoid extremely technical language and define all specialized terms. Other than heading titles, the first word in a sentence or a proper noun, authors should not use capitalization, underlining, italics, or boldface within the text. Authors should not add extra spaces or indentations, nor should they use any hidden from view editing tools. All weights and measures must be given in the SI (metric) system.

In- text citations should be done in the following manner:
Single Author:

"… when fruit flies were reared on media of sugar, tomatoes, and grapes" (Jaenike, 1986).

Two Authors:

“…assay was performed as described previously (Roffner & Danzig, 2004).

Multiple Authors:

“…similar results have been reported previously (Baehr et al., 1999).

C. References: References cited within the text should appear alphabetically by the author's last name at the end of the manuscript text under the heading references. All references must be cited in the text and come from published materials in the literature or the Internet. Authors should use the current APA style when formatting the reference list.

D. Example citations are below.

(1) Articles-

(a) Single author:

DeBuhr, L. E. (2012). Using Lemna to Study Geometric Population Growth. *The American Biology Teacher*. https://doi.org/10.2307/4449274

(b) Multi-authored three to seven authors:

Green, H., Goldberg, B., Schwartz, M., & Brown, D. D. (1968). The synthesis of collagen during the development of Xenopus laevis. *Developmental Biology*, *18*(4), 391–400. https://doi.org/10.1016/0012-1606(68)90048-1

(c) Mutli-authored more than seven authors

List the first six authors than an ellipsis followed by the last author.

(2) Books-

Bossel, H. (1994). *Modeling and Simulation* (1st ed.). New York, NY: A K Peters/CRC Press. https://doi.org/10.1201/9781315275574

(3) Book chapters-

Glase, J. C., & Zimmerman, M. (1993). Population ecology: Experiments with Protistans. In J. M. Beiswenger (Ed.), *Experiments to Teach Ecology* (pp. 39–82). Washington, DC: Ecological Society of America. Retrieved from https://tiee.esa.org/vol/expv1/protist/protist.pdf

(4) Web sites-

McKelvey, S. (1995). Malthusian growth model. Retrieved November 25, 2005, from https://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html

E. Tables

Tables should be submitted as individual electronic files in Word (2013+) or RTF format. Placement of tables should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. All tables must be accompanied by a descriptive legend using the following format:

Table 1. A comparison of student pre-test and post-test scores in a non-majors' biology class.

F. Figures

Figures should be submitted as **high resolution** (≥ 300dpi) individual electronic files, either TIFF or JPEG. Placement of figures should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. Figures only include graphs and/or images. Figures consisting entirely of text will not be accepted and must be submitted as tables instead. No figures put together using a cut and past method will be accepted. All figures should be accompanied by a descriptive legend using the following format:

Fig. 1. Polytene chromosomes of *Drosophila melanogaster*.

III. Letters to the Editor

Letters should be brief (400 words or less) and direct. Letters may be edited for length, clarity, and style. Authors must include institution address, contact phone number, and a signature.

IV. Other Submissions

Reviews and informational submissions may be edited for clarity, length, general interest, and timeliness. Guidelines for citations and references are the same for articles described above.

V. Manuscript Submissions

All manuscripts are to be sent to the editor electronically and must comply with the same guidelines for text, figure and table preparation as described above. *Authors must clearly designate which type of article they are submitting (see Section I) or their manuscript will not be considered for publication.* Emails should include information such as the title of the article, the number of words in the manuscript, the corresponding author's name, and all co-authors. Each author's name should be accompanied by complete postal and email addresses, as well as telephone and FAX numbers. Email will be the primary method of communication with the editors of *Bioscene*.

Communicating authors will receive confirmation of the submission. Manuscripts should be submitted either as a Microsoft Word or RTF (Rich Text File) to facilitate distribution of the manuscript to reviewers and for revisions. A single-email is required to submit electronically, as the review process is not necessarily blind unless requested by an author. If the article has a number of high resolution graphics, separate emails to the editor may be required. The editors recommend that authors complete and remit the Bioscene Author Checklist with their submission in order to expedite the review process.

VI. Editorial Review and Acceptance

For manuscripts to be sent out for review, at least one author must be a member of ACUBE. Otherwise, by submitting the manuscript without membership, the corresponding author agrees to page charges. Charges will be the membership fee at the time of submission per page. Once the authors' membership or page charge status has been cleared, the manuscripts will be sent to two anonymous reviewers as coordinated through the Editorial Board. Reviewer names and affiliation will be withheld from the authors. The associate editors will examine the article for compliance with the guidelines stated above. If the manuscript is not in compliance or the authors have not agreed to the page cost provisions stated above, manuscripts will be returned to authors until compliance is met or the page cost conditions have been met. Reviewers will examine the submission for:

- **Suitability:** The manuscript relates to teaching biology at the college and university level.
- **Coherence:** The manuscript is well-written with a minimum of typographical errors, spelling and grammatical errors, with the information presented in an organized and thoughtful manner.
- **Novelty:** The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

Once the article has been reviewed, the corresponding author will receive a notification of whether the article has been accepted for publication in *Bioscene*. All notices will be accompanied by suggestions and comments from the reviewers. The author must address all of the reviewers' comments and suggestions using the original document and **track changes** for any consideration of a resubmission and acceptance. Revisions and resubmission should be made within six months. Manuscripts resubmitted beyond the six-month window will be treated as a new submission. Should manuscripts requiring revision be resubmitted without corrections, the associate editors will return the article until the requested revisions have been made. Upon acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website. Time from acceptance to publication may take between twelve and eighteen months.

VII. Revision Checklist

Manuscripts will be returned to authors for failure to follow through on the following:

A. Send a copy of the revised article **using track changes** for text changes back to the associate editor, along with an email stating how reviewers' concerns were addressed.
B. Make sure that references are formatted appropriately in APA style format.
C. Make sure that recommended changes have been made or a clear explanation as to why they were not.
D. Figures and legends sent separately, but placement in manuscript should be clearly delimited.

VIII. Editorial Policy and Copyright

It is the policy of *Bioscene* that authors retain copyright of their published material.