CURRICULUM DESIGN AND ASSESSMENT: THE DEVELOPMENT OF A NONMAJOR BIOLOGY COURSE-BASED UNDERGRADUATE RESEARCH EXPERIENCES AND ITS EFFECTS ON STUDENTS AND INSTRUCTORS

A Dissertation
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

William Edward Falkner

In Partial Fulfillment of the Requirements
for the Degree of
DOCTOR OF PHILOSOPHY

Major Program:
Discipline-Based Education Research

April 2024

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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DOCTOR OF PHILOSOPHY

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ABSTRACT

The goals of nonmajor science education are to improve scientific literacy and produce pro-science attitudes. Together, these goals are expected to improve an individual's ability to make evidence-based decisions based on newer understandings of the natural world as well as developing technologies. In a post-COVID-19 world, public understanding of science was brought to the forefront for public health but were also challenged by a deluge of misinformation to obfuscate these goals. General education science courses represent the last formal experience for our populace. Following a learning-science-by-doing-science approach, this dissertation describes the development, implementation, and assessment of a course-based undergraduate research experience (CURE) for nonmajor science students. The first objective of this dissertation was to review the outcomes and design elements of published CUREs. Through a systematic review of Biology-based CURE literature, several content, skill, and affective-based outcomes are identified resulting from eight proposed design elements. The second objective was to outline and highlight the decision-making process when designing a CURE for nonmajors. Here, historical perspectives on course design, both general and science-specific, are described and applied along with findings from the first objective to design a CURE for nonmajor biology students. The third objective was to survey graduate teaching assistants (GTAs) that instructed this nonmajor CURE to identify GTA benefits and challenges. Findings indicate that GTAs found CUREs to be beneficial to their current and future works and strongly believed this type of approach to nonmajor education is preferable to expository lab design. The final objective was to assess student scientific literacy and science attitudes after engaging with a CURE. Based on two surveys using a pre/post design, there were no significant differences between different laboratory course designs for neither literacy nor attitudes and only found some support between the association of scientific literacy and science attitudes. This dissertation demonstrates the complexity of cradle-to-grave course design, the difficulty in measuring large constructs such as scientific literacy and science attitudes, and implications for future evidence-based course design.

ACKNOWLEDGMENTS

The following dissertation may be my own words, but it can hardly be considered a solo endeavor. Since I began this journey at North Dakota State University in 2019, I have been graced with an encouraging troop of individuals that have helped me craft my professional and personal development. First, I give thanks to Lisa Montplaisir for her support, guidance, and patience as I stumbled into the program. Lisa and the rest of the DBER faculty and students have helped make NDSU and Fargo my home these last five years. I would also like to thank my committee for their continued interest and guidance in my success and endeavors. A special thanks to Kimi Booth for her willingness to open her classroom up for my wild ideas. I will not miss our meetings discussing new ideas and directions for courses because I firmly believe there are many more to come. I would also like to thank Brent Hill and Kayla Earls for their assistance and guidance on statistics necessary for this work. Additional thanks to my lab mates Melody McConnell, Becky Reichenbach, and Maddie Milbrath. Thanks to my former advisor Deb Linton whose influence on my professional career has been incalculable.

I wish to extend my gratitude to the family I found along the way. First to those in the DBER program who have provided and sought support and companionship along the way. Thanks to Nekeisha Johnson and Emily Hackerson for co-teaching summer camps and wrangling middle school students with me as well as Caitlin Anderson for co-teaching BIOL 272 with me. A second thanks to those from the Biological Sciences program, Brian Springall and Kayla Earls. I wish to think all my Yu-Gi-Oh! friends for providing a sorely missed social outlet outside of academia. Finally, thanks to Carrie Bettencourt for her incalculable support throughout the writing process.

Last but never least, I wish to acknowledge my wonderful wife, Kathleen Dragos. Despite meeting a decade ago in mineralogy class, you have ironically become my rock. With the extent to which she has listened to me rant and rave about my coursework and dissertation, I feel as though she should be awarded at least an honorary doctorate on my behalf. We have challenged each other, learned from each other, and grown with each other that my persistence, motivation, and confidence to complete with work would not exist without her desire to see me be my best.

DEDICATION

I wish to dedicate this work to my students past, present, and future. Teaching has always been a lifelong passion and I would not find it half as fulfilling if it weren't for the plethora of individuals I get to meet, teach, and learn from along the way. The a-ha moment in the classroom. The smile on a student's face when they pass a test they worked hard on. The sigh of relief when a student recognizes you care and are invested in their success. It is for these students and at these moments I love what I get to do and look forward to continuing it.

In loving memory of Yanni Nanos, my tutee of three years and my greatest teacher.

"To laugh often and much: To win the respect of intelligent people and the affection of children, to earn the appreciation of honest critics and endure the betrayal of false friends; to appreciate beauty, to find the best in others, to leave the world a bit better whether by a healthy child, a garden patch, or a redeemed social condition; to know even one life has breathed easier because you lived. This is to have succeeded." -Ralph Waldo Emerson

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Introduction

The Vision and Change initiative call for an emphasis on core biological concepts and core competencies and practices for all undergraduate biology students (AAAS, 2010). Additionally, the call is made to increase the number of authentic activities to engage students in hands-on research, emphasizing that learning science is learning to do science. Students engaged in active learning result in increases in learning gains and a reduction of failure rates (Freeman et al., 2014).

Traditionally, the main method for students to engage in authentic research is to engage in undergraduate research experiences (UREs) which are well-documented in their benefits for undergraduate students. STEM students need work experience in a professional research environment to increase their persistence in STEM and marketability for graduate school or industry (Carpenter et al., 2021; Hernandez et al., 2018). Additionally, learning gains for undergraduate research experiences are long-lasting regardless of a students' interest in a graduate study (Lopatto 2003, 2004, 2007, 2008). However, the availability of undergraduate research experiences vastly outnumbers the amount of STEM students. Another attempt included apprenticeship models wherein students conduct independent research under the guidance of a faculty member or senior lab member. Still, such an approach engages only a small percentage of students in the process of science.

Since lecture courses generally focus on building content knowledge and are often ill-equipped for developing skill-based objectives due to low teacher-student ratios, laboratory courses are an ideal target for modification to align with research-centered competencies (Glaze, 2018). Accordingly, laboratory courses have recently shifted from “cookbook” labs towards student-centered, inquiry-based activities, case studies, and cooperative learning (Sundberg, Armstrong, & Wischusen, 2009). In a survey of Australian and New Zealand research universities, key outcomes of a laboratory education included thinking like a scientist, developing content knowledge, developing technical skills, understanding the process of science, quantitative reasoning, and communication skills (Gibbons et al., 2020). While one approach to accomplishing these goals is to produce courses aimed at specifically developing a variety of laboratory skills (Rowland et al., 2012), the President’s Council of Advisors on Science and Technology’s Engage to Excel report (PCAST, 2012) places a particular emphasis to “replace standard laboratory courses with discovery-based research courses.” This call to develop such classes culminated with the recent push for course-based undergraduate research experiences (CUREs) in the last decade.

CUREs have been historically defined as a laboratory learning experience that incorporates five main structures: the use of scientific practices, discovery, broadly relevant work, collaboration, and iteration (Auchincloss et al., 2014). To this end, CUREs follow the general evolution of the undergraduate laboratory experience from confirming knowledge through demonstrable laboratory experiments, to inquiry-based experiments where results are unknown to students, to finally experiments that are student-designed with results unknown to both student and instructor (Craig, 2020). CUREs can expose students to a variety of biology topics not generally considered, provide more opportunities to underrepresented minority, low-income, and first-generation students, and provide students with more opportunities to use scientific thinking outside of the classroom (Elgin et al., 2016). Students who engage with a

CURE reportedly feel as though they experience a true undergraduate research experience (Staub et al., 2016). Additional findings confirm that CUREs and UREs produce similar gains in thinking like a scientist, preparation for graduate school, communication skills, quantitative reasoning, and technical skills (Olivares-Donoso and González 2019; Smith et al. 2021). Furthermore, UREs may lack components of actual research that CUREs inherently design for such as establishing research goals, defining criteria for suitable evidence, autonomy in experimental design, and construction and testing of experiments beyond collecting data (Holmes and Wieman, 2016). Early in its inception, an attempt to model the outcomes and structures of CUREs have been developed, but analyses within this framework are still in its infancy (Corwin, Graham, and Dolan, 2015).

The purpose of this review is to give evidence to the utility of CUREs and provide ample guidance to instructors looking to adopt, adapt, or create a CURE for their own purposes. A large-scale review of studied CUREs is instrumental in reducing barriers for faculty to increase adoption (Genne-Bacon et al, 2019). It is necessary and important to support ambitious teaching on all fronts to improve undergraduate education (Talanquer, 2014). This review focuses on three essential questions to help increase the adoption of CURE programs and reduce barriers for faculty and departments to develop these programs:

1. What are the cognitive and affective gains of CUREs for students and instructors?
2. What are the reported structural or environmental elements necessary to achieve said gains?
3. What descriptive studies regarding the implementation of CUREs exist and what are the emergent patterns of implemented CUREs?

Methods

Search and Screening

The initial search for articles was conducted on Google Scholar, Web of Science, and the Education Resources Information Center (ERIC). The search strings “biology” and “course-based undergraduate research experience” were used to narrow the search to specifically CUREs conducted in the domain of biology. Additionally, articles were limited to being posted as late as 2014 as this was the first year of concretely defined CURE research. From this initial search, 951 articles were identified from Google Scholar, 129 from Web of Science, and 61 from ERIC. Condensing the article pool, all articles from Web of Science and ERIC were duplicated in the initial 951 pool from Google Scholar.

Since many studies utilize CUREs in either introductions or conclusions, articles were screened on a variety of standards. First, abstracts from various conferences and symposia on biology education were removed due to inadequate information regarding either the CURE studied or the results of student learning. Secondly, abstracts were screened to ensure the article discussed CUREs in a biology setting and either presented a perspective of CURE implementation, described a CURE curriculum, or studied the results of a CURE implementation. After these two screenings, 203 articles remained for inclusion in this study. These articles were then sorted into four broad categories, with overlap, to answer our research question: 1) articles reporting outcomes of CUREs (N=70), 2) articles reporting on necessary pedagogical structures of CUREs (N=27), 3) example of CURE curriculum/modules (N=54), and 4) perspectives on CURE development (N=36).

Data Extraction

To examine the positive effects of CUREs on students and educators, each paper was screened for reported benefits of engaging with a CURE. To categorize benefits, the original categories from Corwin, Graham, and Dolan’s CURE model (2015) were used, including cognitive gains, skill-based gains, and attitudinal gains with additional categories added when needed (Table 1). Then, themes were categorized based on the number of supporting articles as probable (>10), possible (6-10), and proposed (<6). Finally, articles with negative or conditional findings were separated and discussed individually.

To examine the necessary features of CUREs to reach these outcomes, papers that reported important structural or environmental components were coded. Initially, only the original five structures of CUREs were used (scientific process, discovery, relevance, collaboration, and iteration), but more were necessary to explain the outcomes observed. Similarly, structural/environmental categories were classified into probable, possible, and proposed groupings and articles with negative or conditional findings were analyzed individually.

In order to understand the range of biology CUREs, papers with adequate description of the CURE course (at least 3 paragraphs of description) were included. The following is recorded for each CURE described: academic level (Nonmajor, Introductory, Upper Level), subject (Biochemistry, Cellular and Molecular Biology [BCMB], Ecology, Evolution, and Conservation [EEC]), length of CURE (in weeks), and short description of the student projects.

Results

Outcomes for Students and Instructors

Initial attempts to view supported student outcomes were reported by Corwin, Graham, and Dolan (2015) and included sixteen articles that supported nineteen student outcomes. Here, 70 articles are presented and collapsed into 15 student outcomes that were initially informed by the 2015 outcome classification but modified as trends emerged from research over the last seven years (Table 1). Initially papers were considered probable (>3 supporting articles), possible (2-3 supporting articles), and proposed (single supporting article). Given the distribution of articles, outcomes were assigned probable if they contained >15 supporting articles, possible if they contained 5-15 supporting articles, and proposed if they contained <5 supporting articles. As a result, all but two of these proposed fifteen outcomes would be considered probable by the original 2015 standard, but these groupings are conservative to ensure the most supported outcomes are highlighted. Student outcomes for the seventy articles were deduced from a range of approaches (quantitative, qualitative, and mixed methods) and measuring techniques (validated instruments or author-generated self-assessment questions). Therefore, while these results report the number of articles supporting a student outcome, it does not attempt to assess the strength of the support each article individually provides.

Probable outcomes include increased analytical skills (N=21), increased self-efficacy (N=20), and increased content knowledge (N=17). Increased analytical skill refers to any outcomes that obtained a significant gain in problem-solving skills, critical thinking skills, or data analysis skills. An increase in self-efficacy combines studies that examine either student confidence or self-efficacy. Finally, increased content knowledge, which was most supported in the 2015 review, is the least supported of the probable categories likely due to an emphasis on analytical skills over increased content knowledge. All three of these outcomes are also supported as probable outcomes in the 2015 review.

Possible outcomes include enhanced science identity (N=13), increased communication skills (N=11), career clarification (N=10), increased sense of belonging (N=10), enhanced scientific attitude (N=8), enhanced understanding in the nature of science (N=7), enhanced self-determination in science (N=7), increased technical skills (N=6), enhanced experimental design (N=6), and persistence in science (N=5). Of note, sense of belonging, persistence in science, increased technical skills, and career clarification were originally included as probably outcomes in the 2016 review and have experienced a relative equal number of supporting articles, highlighting the probable outcomes as increasingly found outcomes of CUREs in comparison. Furthermore, the enhanced understanding of the nature of science was originally a proposed outcome has now been elevated to possible status in this schema.

Lastly, increased collaboration skills (N=2) and increased tolerance for obstacles (N=1) make up the proposed student outcomes of CURE participation. This is of particular interest as both of these articles received more support in the 2015 review than they do now. Collaboration skills finding little supporting evidence is further interesting as collaboration is chiefly considered a hallmark of CURE implementation, yet students do not seem to gain collaborative skills out of a CURE. This may highlight the need to improve collaboration education within CUREs or that collaboration may not be as necessary as proposed.

Finally, four outcomes have been completely excluded from this revised review of the literature. Project ownership, an original possible outcome, has since been described as a component necessary for student outcomes, and thus has been moved to further discussion in the next section. Increased access to faculty interaction and increased access to mentoring functions have been removed from the list due to a lack of any supporting articles included in this study. This may be due to a lack of interest in these concepts as outcomes or may be due to a lack of findings in search of them.

Table 1. Student outcomes supported by relevant CURE literature. Outcomes are grouped into larger themes and then organized by number of supporting articles. Probable outcomes contain more than 15 articles, possible outcomes are supported by 5-15 articles, and proposed outcomes contain less than 5 articles.

	Outcome	Reference
Probable	Increased analytical skills	Boomer, Kumar, and Dutton 2021; Brownell *et al*. 2015; Cianfrani and Hews 2020; Cianfrani, Hews, and Dejong 2020; Dahlberg *et al*. 2019; D'arcy *et al*. 2019; Delventhal and Steinhauer 2020; Fisher *et al*. 2018; Indorf *et al*. 2019; Jones and Barham 2019; Lo and Le 2021; Malotky *et al*. 2020; Ochoa *et al*. 2019; Olimpo, Fisher, and DeChenne-Peters 2016; Olimpo, Pevey, and McCabe 2018; Ortiz *et al*. 2020; Pavlova *et al*. 2021; Smith *et al*. 2022; Sorensen *et al*. 2018; Staub *et al*. 2016; Waddell *et al*. 2021
	Increased self-efficacy	Chatfield 2014; Cirino *et al*. 2017; Delventhal and Steinhauer 2020; Fisher *et al*. 2018; Gin *et al*. 2018; Harvey *et al*. 2014; Hiatt *et al*. 2021; Indorf *et al*. 2019; Kirkpatrick *et al*. 2019; Kowalski, Hoops, and Johnson 2016; Lo and Le 2021; Majka, Guenther, and Raimondi 2021; Mordacq *et al*. 2017; Olimpo, Fisher, and DeChenne-Peters 2016; Ortiz *et al*. 2020; Pavlova *et al*. 2021; Sorensen *et al*. 2018; Stovall *et al*. 2019; Thu *et al*. 2021; Vater *et al*. 2021
	Increased content knowledge	Cianfrani and Hews 2020; Evans *et al*. 2021; Hiatt *et al* 2021; Ing *et al*. 2021; Jordan *et al*. 2014; Li *et al*. 2020; Lyales and Oli 2020; McDonough *et al*. 2017; Peteroy-Kelly *et al*. 2017; Peyton and Skorupa 2021; Reeves *et al*. 2018; Shapiro *et al*. 2015; Smith *et al*. 2022; Staub *et al*. 2016; Tootle *et al*. 2019; Wolkow *et al*. 2019; Wu 2021
Possible	Enhanced science identity	Baynham 2016; Broussard *et al*. 2021; Cooper *et al*. 2020; D'arcy *et al*. 2019; Esparza, Wagler, and Olimpo *et al*. 2020; Hiatt *et al*. 2021; Kowalski, Hoops, and Johnson 2016; Smith *et al*. 2022; Majka, Guenther, and Raimondi 2021; Mraz-Craig *et al*. 2019; Starr *et al*. 2020; Stovall *et al*. 2019; Waddell *et al*. 2021

Table 1. Student outcomes supported by relevant CURE literature. Outcomes are grouped into larger themes and then organized by number of supporting articles. Probable outcomes contain more than 15 articles, possible outcomes are supported by 5-15 articles, and proposed outcomes contain less than 5 articles (continued).

	Outcome	Reference
Possible	Increased communication skills*	Cirino *et al* 2017; D’arcy *et al*. 2019; Delventhal and Steinhauer 2020; Fisher *et al*. 2018; Li *et al*. 2020; Malotky *et al*. 2020; Mordacq *et al*. 2017; Ochoa *et al*. 2019; Reeves *et al*. 2018; Rodrigo-Peiris, Xiang, and Cassone 2018; Thu *et al*. 2021
	Career clarification	Corwin *et al* 2018; Delventhal and Steinhauer 2020; Harvey *et al*. 2014; Mraz-Craig *et al*. 2019; Overath, Zhang, and Hatherill 2016; Price *et al*. 2020; Sorensen 2018; Starr *et al*. 2020; Tootle *et al* 2019; Turner, Challa, and Cooper 2021
	Increased sense of belonging	Bangera & Brownell 2014; Cianfrani, Hews, and Dejong 2020; Dahlberg *et al*. 2021; D’arcy *et al*. 2019; Gin *et al*. 2018; Majka, Guenther, and Raimondi 2021; Malotky *et al*. 2020; Sorensen *et al*. 2018; Stovall *et al*. 2019; Vater *et al*. 2021
	Enhanced scientific attitudes	Broussard *et al* 2021; Cianfrani and Hews 2020; Delventhal and Steinhauer 2020; Harvey *et al*. 2014; Kowalski, Hoops, and Johnson 2016; Li *et al*. 2020; Lyales and Oli 2020; McDonough *et al*. 2017
	Enhanced understanding of the nature of science	Boomer, Kumar, and Dutton 2021; Brownell *et al* 2015; Cianfrani and Hews 2020; Cianfrani, Hews, and Dejong 2020; Gin *et al*. 2018; Kowalski, Hoops, and Johnson 2016; Rodrigo-Peiris, Xiang, and Cassone 2018
	Enhanced self-determination in science	Starr *et al*. 2020; Esparza, Wagler, and Olimpo 2020; Jordan *et al*. 2014; Kirkpatrick *et al*. 2019; Olimpo, Fisher, and DeChenne-Peters 2016; Overath, Zhang, and Hatherill 2016; Peyton and Skorupa 2021
	Increased technical skills	Cianfrani and Hews 2020; Cianfrani, Hews, and Dejong 2020; D’arcy *et al*. 2019; Harvey *et al*. 2014; Li *et al*. 2020; Lo and Le 2021
	Enhanced understanding of experimental design	Cianfrani, Hews, and Dejong 2020; Kowalski, Hoops, and Johnson 2016; Laungani *et al*. 2019; Li *et al*. 2020; Pavlova *et al*. 2021; Peteroy-Kelly *et al*. 2017
	Persistence in science	Indorf *et al*. 2019; Jordan 2014; Rodenbusch 2016; Stovall *et al*. 2019; Vora *et al*. 2020

Table 1. Student outcomes supported by relevant CURE literature. Outcomes are grouped into larger themes and then organized by number of supporting articles. Probable outcomes contain more than 15 articles, possible outcomes are supported by 5-15 articles, and proposed outcomes contain less than 5 articles (continued).

	Outcome	Reference
Proposed	Increased collaboration skills	Malotky *et al*. 2020; Reeves *et al*. 2018
	Increased tolerance for obstacles	Gin *et al*. 2018

Beyond the above gains for students and the intrinsic benefits they bring to instructors and their departments, twelve studies described specific benefits of using CURE pedagogy for their instructors. Most commonly, articles describe CUREs as ideal teaching steppingstones for developing future faculty as new hires or earlier as graduate teaching assistants (Cascella and Jex 2018; Cirino et al. 2017, Goodwin, Cary, and Shortlidge 2021; Heim and Holt 2019; and Moy et al. 2019). Developing faculty and teaching assistants also includes refining academic goals and improving marketability (Light et al. 2019). Secondarily, teaching a research-based course improves teaching efficacy (Light et al. 2019; Moy et al. 2019), aligns teaching and research sides of an instructor (Shortlidge et al. 2016; Shortlidge et al. 2017), and improves overall enjoyment of teaching (Shortlidge et al. 2016).

Beyond the classroom setting, CUREs also offer several professional goals for their instructors. Most noteworthy occurs when instructors incorporate their own lab or fieldwork into the CURE setting which can improve productivity (Kowalski et al. 2016; Schot et al. 2021; Shortlidge et al. 2016; Shortlidge et al. 2017), increase publication output (McLeod et al 2021; Shortlidge et al. 2017), offer locations to pilot research (Shortlidge et al 2017), and ultimately contribute to promotion or tenure (Shortlidge et al. 2016). Finally, CUREs also offer a time and place for research faculty to train and recruit students to their own research lab that may not have originally considered (Shortlidge et al. 2017; Schot et al. 2021; Tootle et al. 2019).

Necessary Structures and Environments for CUREs

Initial descriptions of necessary structures of successful CUREs included (1) discovery-based work with (2) relevance to the scientific community or other stakeholders utilizing (3) collaborative, (4) iterative engagement with (5) scientific practices (Auchincloss et al. 2014, Corwin et al. 2015). In general, fewer CURE-based articles examine these structural components but instead solicit their importance for student surveys. This helps indicate what students believed to be important and valuable to their learning. Structure and environmental papers discussing these components were coded using the original five necessary structures with three environmental constructs emerging from the data (Table 2).

Of the original five structural elements of a CURE, discovery, iteration, and collaboration were most often cited with scientific practices and relevance receiving less support. Despite these findings, given that CUREs require students to conduct some form of research, scientific practices may either be a necessary component for student outcomes or a necessary outcome for course activities. However, when it comes to scientific practices, one study suggests that using these practices to complete a CURE project may not be necessary (Sommers et al. 2021). Iteration and collaboration have their own roots in other evidence-based practices that promote student learning, improve student attitudes, and promote diversity and inclusivity in the classroom. Given its relatively low prevalence in studies, collaboration needs further clarification whether peer collaboration is necessary or if student-instructor collaboration is sufficient (Goodwin et al. 2021).

Table 2. Structural and environmental elements supported by relevant CURE literature. Design elements are grouped into probable (>5 articles) and possible (≤5 articles).

	Outcome	Reference
Probable	Discovery	Cooper *et al.* 2019; Corwin *et al.* 2018; Corwin *et al.* 2019, Esparza, Wagler, and Olimpo 2020; Goodwin *et al.* 2021; Lo and Le 2021; Sommers *et al.* 2021
	Iteration	Corwin *et al.* 2018; Gin *et al.* 2018; Goodwin *et al.* 2021, Light *et al.* 2020, Lo and Le 2021, Lopatto *et al.* 2020, Wiggins *et al.* 2021
	Collaboration	Corwin *et al.* 2018; Esparza, Wagler, and Olimpo 2020; Gin *et al.* 2018; Lo and Le 2021; Mraz-Craig *et al.* 2019; Olimpo *et al.* 2016; Sommers, Richter-Egger, and Cutucache 2021
	Project Ownership	Cooper *et al.* 2019; Cooper *et al.* 2020; Corwin *et al.* 2019; Kirkpatrick *et al.* 2019; Lo and Le 2021; Mraz-Craig *et al.* 2019; Peyton and Skorupa 2021
Possible	Autonomy	Gin *et al.* 2018; Mader *et al.* 2017; Olimpo *et al.* 2016; Pavlova *et al.* 2021; Sommers, Richter-Egger, and Cutucache 2021
	Scientific Practices	Goodwin *et al.* 2021; Sommers *et al.* 2021; Starr *et al.* 2020
	Relevance	Adkins-Jablonsky *et al.* 2020; Cooper *et al.* 2019; Corwin *et al.* 2019; Lo and Le 2021
	Formative Frustration	Goodwin et al 2021, Lo and Le, Lopatto et al 2020, Rodrigo-Peiris et al 2018

Relevance and discovery often appear together in CURE articles as two sides to the same coin; discovery of new information is usually relevant to some interested party. However, one of the few experimental studies to investigate the effect of removing each of these elements found that discovery and relevance may not be important for student outcomes (Ballen et al. 2018) and that merely the opportunity to make discoveries need be accounted for (Gin et al. 2018). Some authors opt to use the term authenticity when referring to these two components of CUREs (Rodrigo-Peiris et al. 2018), however authenticity's definition makes it difficult to assess the veracity of authenticity as a measurable and plannable element (Rowland et al. 2016).

The three emergent elements (project ownership, autonomy, and formative frustration) refer to the classroom environment in which a CURE is situated, bringing to attention that how a CURE is conducted is as important as how it is structured. Of these, project ownership is a well-established environmental construct that requires students to feel as though their CURE projects are of their own design instead of work that is decided for them. Autonomy, another environmental element, places emphasis on the necessity of student choice in the CURE classroom. Finally, formative frustration describes an environment where failure is not seen as the result of poor work, but part of the process of science. While failure is a possible outcome of any science venture, the stress of these papers is on instilling students with a resilience to obstacles.

Finally, modality of instruction is an emergent theme regarding CURE effectiveness with which modality appears to be an insignificant factor. Student outcomes were no different between a bench-based CURE and computer-based CURE (Kirkpatrick et al. 2019). Similarly, no differences were found between in-person, hybrid, nor online CUREs (Doctor, Lehman, and Korte 2021). However, the difficulty in completing certain technical skills remotely remains a major barrier to several CUREs (Fey, Theus, and Ramirez 2020).

Descriptions of Published CURE Curriculums

To characterize and catalogue published CURE curriculums, fifty-four articles were analyzed for their content track, academic level, and length of implementation (Table 3). This table provides an idea of the trajectory of CURE expansion into different areas of science and provide a jumping-off point for faculty that are looking for similar examples for the CURE they wish to develop. In addition, it provides a snapshot of areas in need of more description or development as we continue to develop CUREs for other Biology disciplines.

In terms of content focus, most CUREs are conducted in biochemistry or cell and molecular biology (BCMB, N=39, 72%) compared to CUREs in ecology, evolution, and conservation. This likely reflects an early adoption of CUREs in BCMB through the SEA-PHAGES initiative from the Howard Hughes Medical Institute that is now implemented in over 100 universities. Nonetheless, this does not reflect the need to develop EEC students' experimental skills and thus calls for an increase in EEC CUREs to be described in the literature for future faculty to adopt and adapt.

CUREs are split between upper level (N=25, 53%) and introductory (N=20, 43%) settings. This reflects an interest to develop students research skills regardless of their content background. CUREs depend on either advancing upper-level students' content knowledge through content-rich CUREs or engaging students with hands-on research experience early in their education. The final categorization includes CUREs used with nonscience majors (N=2, 4%). While CUREs were initially conceived to supplement research experiences students were not receiving outside of the classrooms, the outcomes associated with CUREs align with general science education, leading CUREs to be a potential avenue for nonscience major education. Despite this, there is an obvious dearth of information regarding CURE pedagogy with nonscience major students.

CUREs have typically been described as variable in length, ranging from a single week to multiple years. Nonetheless, 72% of included CUREs were conducted for a full semester as a laboratory class (N=38) while 16% ran for half a semester, or 5-8 weeks (N=9). Only five CUREs described reported a runtime of four or less weeks (9%). One difficulty of assessing CURE length, however, is when one should report the timeframe of the CURE. CUREs are characterized as having an instructional period where students learn relevant skills and content, and a project period where students develop their own project and conduct their research. Some CUREs blend these two periods so that students have longer to complete their own research while others have a clear separation between the two. In the case of separation of instructional and project time, it is difficult to know from the literature if an instructional period predated shorter-run CUREs. As a result, CUREs that describe the week-by-week activities of their course are highlighted in green in Table 3 to highlight articles that show the progression from gaining skills and learning content knowledge to developing and conducting student-led research. Further, if CUREs are to be reported as requiring as little as one week for implementation, further descriptions of these CUREs are required. Finally, it will be necessary to examine whether the student outcomes are similar between partial-term and full-term CURE implementation to assess the fidelity of this pedagogy.

Table 3. Brief list of described CUREs in academic literature. Articles are listed based on track, level, and length. Track refers to either biochemistry, cellular and molecular biology (BCMB) or ecology, evolution, and conservation (EEC) CUREs. Level refers to CUREs implemented in the first two years of study (introductory), latter two years of study (upper), multiple years (variable), or as a nonmajor CURE (nonmajor). Length refers to what portion of a semester the CURE takes place from quarter, half, full, or year corresponding to roughly 4-, 8-, 16-, and 32-week CUREs. Gray rows specify articles that feature a week-by-week syllabus for described CUREs.

Reference	Track	Level	Length	Description
Adkins-Jablonsky *et al.* 2021	BCMB	Introductory	Full	Students use agar art to explore ecophysiology of microorganisms.
Alneyadi, Shah, and Ashraf 2019	BCMB	Upper	Full	Using liquid chromatography-mass spectrometry to quantify folic acid levels in milk.
Ayella and Beck 2018	BCMB	Upper	Full	Exploring consequences of nonconserved mutations in enzyme structure and function.
Baker *et al.* 2021	BCMB	Upper	Full	Students investigate the bacterial community composition between seasons.

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Reference	Track	Level	Length	Description
Bakshi *et al.* 2017	BCMB	Introductory	Full	Students isolate microorganism and extract DNA to identify unknown microorganisms.
Bennett *et al.* 2021	BCMB	Introductory	Full	Drug tolerance development in Saccharomyces cerevisiae
Bhatt and Challa 2018	BCMB	Introductory	Full	Students use CRISPER-Cas9 to observe the target disruption of specific genes in zebrafish.
Boomer, Kumar, and Dutton 2021	BCMB	Upper	Quarter	Students use culture-based bacterial enumeration to compare beef contamination.
Capmbell and Eckdahl 2018	BCMB	Introductory	Full	Students investigate bacterial transcription initiation using rClone Red.
Chaari, Al-Ali, and Roach 2020	BCMB	Introductory	Full	Students purify, quantify, and study a particular enzyme extracted from chicken organs.
Chatfield 2014	BCMB	Upper	Full	Identification of bacterial species sourced from biofilm from tap water.
Copenhaver-Parry 2020	EEC	Introductory	Full	Comparing local leaf characteristics with climate data.
Cotner and Hebert 2016	EEC	Introductory	Half	Students investigate concepts of sexual selection, sperm competition, sexual orientation, and sex ratios with bean beetles.
Dahlberg *et al.* 2021	BCMB	Upper	Quarter	Annotating published data for WormBase.
Davis-Berg and Rafacz 2021	EEC	Nonmajor	Full	Testing animal behavior hypotheses using zoos and webcams.
Delventhal and Steinhauer 2020	BCMB	Upper	Full	Using RNAi knockdown to test the effects of genes on neurodegeneration.
Dorn *et al.* 2021	BCMB	Upper	Quarter	Synthesizing and assaying molecules to develop a compound library.

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Reference	Track	Level	Length	Description
Evans *et al.* 2021	BCMB	Upper	Full	Genomics screening for blood cell development genes.
Fisher *et al.* 2018	EEC	Introductory	Full	Testing environmental effects on a population of Tigriopus
Fuentes and Entezari 2020	BCMB	Introductory	Full	Investigating water quality around the community.
Fuhrmeister *et al.* 2021	BCMB	Introductory	Full	Environmental surveillance of antibiotic resistance.
Garcia *et al.* 2020	BCMB	Upper	Full	Evaluating the effect of chemotherapeutic agents on calcium signaling.
Good 2020	BCMB	Upper	Full	Using in silico methods to characterize a gene of interest.
Harvey *et al.* 2014	BCMB	Upper	Half	Novel gene expression in Python tissues
Hekmat-Scafe *et al.* 2017	BCMB	Introductory	Full	Characterization of mutations in a tumor suppressor gene.
Hesse and Schubert 2017	EEC	Upper	Full	Using focus groups to understand public perceptions of a nutrition topic.
Hiatt et al 2021: Plant Biology	EEC	Variable	Full	Describes four separate botanical CUREs
Li *et al.* 2020	BCMB	Introductory	Year	Catalytic characterization of an unknown enzyme.
Lucas, Nichols, and Boeck 2021	BCMB	Upper	Half	Describes three related CUREs on antibiotic emergence
Lyles and Oli 2020	BCMB	NA	Half	Investigating health benefits of fermented products
Marsiglia *et al.* 2020	BCMB	Upper	NA	Using NMR Spectroscopy to study protein-protein interactions.
Martin 2021	EEC	Introductory	Full	Quantifying microplastics in local surface water and substrates.

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Reference	Track	Level	Length	Description
McDonough *et al.* 2017	BCMB	Upper	Half	Identifying and determining gene regulation at multiple levels.
Mills *et al.* 2021	BCMB	Introductory	Half	Using a reverse genetic approach to characterize developmental genes.
Ochoa *et al.* 2019	BCMB	Upper	Full	Identifying, analyzing, and cloning genes involved in tissue regeneration
Olimpo *et al.* 2016	EEC	Introductory	Full	Environmental effects on T. californicus egg production
Ortiz *et al.* 2020	EEC	Upper	Half	Studying bird activity through birdwatching
Oufiero 2019	EEC	Upper	Full	High speed cinematography of insect form and movement
Pedwell *et al.* 2016	BCMB	Upper	Full	Yeast-focused beer brewing and/or bionfuel synthesis
Peyton and Skorupa 2021	BCMB	Introductory	Full	Culturing biodegrading thermophiles
Procko *et al.* 2019	BCMB	Upper	Full	Transcriptome analysis to investigate plant responses to light
Ramirez *et al.* 2021	EEC	Introductory	Full	Understanding coral response to environmental fluctuations
Roberts *et al.* 2019	BCMB	NA	Full	Flexible CURE focusing on analysis of unknown function
Sewall *et al.* 2020	BCMB	Upper	Full	Effect of high-fiber diets on gut microbiomes
Shameka 2019	BCMB	Variable	Full	Identifying interaction sites between proteins
Shanle, Tsun, and Dtrahl 2016n	BCMB	NA	Half	Investigating p300 Bromodomain mutations
Sharma. Hernandez, and Phuong 2019	EEC	NA	Full	Scientific computing with predicted effects of climate change

Table 3. Brief list of described CUREs in academic literature. Articles are listed based on track, level, and length. Track refers to either biochemistry, cellular and molecular biology (BCMB) or ecology, evolution, and conservation (EEC) CUREs. Level refers to CUREs implemented in the first two years of study (introductory), latter two years of study (upper), multiple years (variable), or as a nonmajor CURE (nonmajor). Length refers to what portion of a semester the CURE takes place from quarter, half, full, or year corresponding to roughly 4-, 8-, 16-, and 32-week CUREs. Gray rows specify articles that feature a week-by-week syllabus for described CUREs (continued).

Reference	Track	Level	Length	Description
Sorensen *et al.* 2018	EEC	Variable	Quarter	Modeling ecosystem interactions using camera trap data
Tawde and Williams 2020	BCMB	Upper	Full	Isolate and identify antibiotic-resistant microbes from diverse environments
Waddell *et al.* 2021	EEC	Nonmajor	Full	Using behavioral assays to study pain and addiction in Drosophilia
Werby Cegelski 2018: Biofilms	BCMB	Upper	Quarter	Assaying microbial biofilms
Wu et al 2021: Ecology	EEC	Introductory	Half	Using camera trap data to answer ecological and behavioral questions
Zelaya *et al.* 2020	BCMB	Upper	Full	Characterizing culturable and unculturable gut-microbial community
Slee and McLaughlin 2019	BCMB	Introductory	Full	Testing substances' effects on inflammatory response to foreign materials

Discussion

Course-based undergraduate research experiences (CUREs) are a growing trend in the preparation of undergraduate STEM majors, particularly in biology and allied health professions. Since the common objectives and outcomes of CUREs align well with nonscience major science education (which places much more emphasis on the process of science than content knowledge), there has been a call for CURE development for nonscience major students (Ballen et al. 2017). In total, this study found fifteen supported student outcomes that likely are the result of seven course structural elements. In order to improve understanding of CURE course construction, this article briefly accounts fifty-four published CUREs, eighteen of which have published week-by-week schedules and instructions for implementation.

Currently, CUREs support a variety of cognitive and affective elements. In particular, cognitive components such as content knowledge, analytical skills, technical skills, communication skills, and understanding of experimental design are well-supported in the CUREs. Affective components such as self-efficacy, scientific identity, sense of belonging, science attitudes, and persistence in science are equally well supported in the literature. The correlation between these elements are as yet poorly understood. Establishment of a CURE-based framework such as (Corwin, Graham, and Dolan, 2015) or implementation in other well-established theoretical frameworks, such as self-determination theory or expectancy theory, may help disentangle these structures from outcomes and predictors (i.e. enhanced self-efficacy may be necessary for improving students' persistence in science).

Similarly, while CURE articles point towards several important design elements, the connection between these elements and outcomes are as of yet unexplored. Discovery, iteration, and collaboration remain to be well-supported elements in CURE design. Despite this, contradictory evidence towards these remains an unsolved issue as to whether these elements are necessary or only sufficient for student success (Ballen et al. 2018). More backwards elimination designs of these courses may aid in revealing the necessity of each of these design elements. In addition, a clearer focus of these design elements may help lower the bar for research faculty to get involved with CURE development.

Limitations

Comparing dozens of research articles' results into a cohesive consensus is challenging. Presented results here only represent the reported results of each of the papers but is agnostic to their collection method or strength of results. As a result, while student outcomes such as content knowledge and analytical skills may be referenced by over a dozen articles each, the nature of these results are somewhat incomparable. Since data is often self-reported from students or collected from individualized researcher-developed surveys, currently, summing the articles supporting outcomes and design structures only provides an overview of the research conducted and not an in-depth analysis of the strength of these results.

Significance

One of the main challenges postsecondary science education faces is offering adequate research experience for a student body that outnumbers the amount of available undergraduate research positions. To meet these needs, CUREs offer a promising solution to his problem. Collected here are the emerging outcomes students may expect as a result of engaging with a CURE course. Despite these numerous outcomes, however, a larger theoretical framework has been proposed (Corwin, Graham, and Dolan, 2015), but few studies have implemented nor tested this model. Therefore, to investigate the connections between pedagogical decisions and student outcomes, CURE studies must go beyond testing a collection of cognitive or affective measures. Much of the academic work on CUREs fall into practitioner or research articles. Typically, practitioner articles either offer small modules, advice on CURE construction, or describe in detail an implemented CURE. Research articles typically follow a pre/post experimental design to examine the shifts in students cognitive or affective structures. In an effort to understand how CUREs advance student understanding of research principles, there are several avenues to produce such results: 1) development of validated instruments to use in a variety of CURE studies as opposed to researcher-developed surveys, 2) longitudinal studies in particular for introductory CUREs and how these experiences informed students’ academic trajectory, 3) more intermediate reporting throughout a CURE experience as opposed to at the start and end to understand where changes occur within a CURE, 4) more comparison groups between CUREs and other evidence-based laboratory pedagogies, and 5) correlational studies that show the relationship between either two student outcomes or outcomes and structural elements.

CHAPTER 2: SHIFTING PARADIGMS: CURRICULUM EVOLUTION FROM GUIDED INQUIRY LABS TO COURSE-BASED UNDERGRADUATE RESEARCH EXPERIENCE FOR NONMAJORS

Introduction

Early science pedagogy viewed science as a body of discrete facts to be memorized. Major science reform occurred after the 1957 launching of Sputnik. Following this historic event, a greater emphasis was placed on critical thinking. Despite this, nonmajor science education remained focused on discrete facts. The 1960 Biological Science Curriculum Study commission assessed discrepancies between what ought to be taught and what is currently being taught. A follow-up study twenty years later found that only 20% of secondary teachers were instructing using BSCS materials (Shymansky, Kyle, and Alport, 1982). Inherent difficulties in teaching nonmajor students thus were determined to come from two deficiencies: 1) insufficient prior experience in critical thinking and 2) inadequately planned courses that do not remediate nor engage students in critical thinking (Scharmann and Harty, 1986). During this time, much of nonmajor science education fell into four course goals: 1) preparing students to utilize science for improving their own lives; 2) inform citizens to deal responsibly with science-related issues; 3) prepare students academically to acquire science knowledge appropriate for their needs; and 4) give students an awareness to the scope of science and technology-related careers (Harms and Yager, 1981).

Call for action: teaching science for societal action. More than 75% of college students are not science majors (National Center for Education Statistics, 2021), but are future leaders: lawyers, politicians, business owners, etc. Global, complex scientific issues (climate change, pandemics) are affecting our daily lives and require people to make decisions based on scientific information. Misinformation is continually spread to obfuscate the ability of people to make informed decisions. Therefore, a new focus for nonscience major education should be placed on scientific literacy through socioscientific issues, opportunities for students to impact their community, and provide students with the skills to engage with science outside of the classroom (Gormally and Heil, 2022). As such, several studies have been conducted on student interest in differing socioscientific issues finding that these issues differ based on several demographic factors including age, gender, and geographical location (Blankenburg, Hoffler, and Parchmann, 2015; Swarat, Ortony, and Revelle 2012; van Griethuijsen et al. 2014). While further research must be conducted on an educator's specific audience in regards to what scientific content and delivery methods are most engaging to their students, it is clear that the content and delivery methods play an important role in preparing our students to be scientifically literate citizens.

The Next Generation Science Standards provides a framework for K-12 students that emphasize the understanding and application of scientific knowledge and processes to real world scenarios (National Research Council, 2013). Additionally, the understanding of the natural world must be directly tied to the processes of science insofar students are learning science by doing science. The goal of the NGSS is to help produce students that are scientifically literate to engage in a complex, socioscientific environment. Vision and Change is an unrelated, but complimentary initiative that stresses that "undergraduate biology courses are active, outcome-oriented, inquiry-driven, and relevant." (AAAS, 2011). Learning goals should be focused on depth of knowledge as opposed to breadth of knowledge. Biology should be presented less abstractly and related to the real world. Assessment should be viewed as data on course success and used to improve the learning environment.

In summary, the trajectory of the last sixty years of general science education can be described as a repeated attempt to reduce breadth of science knowledge in favor of a depth of understanding; emphasis on the relevance of content to students' daily life; preparing a scientifically literate citizen for evidence-based decision-making and critical thinking regarding socioscientific issues; and that these goals require a deliberate modeling of science and scientific thinking in the classroom. Given the dynamic process of curriculum development, the goal of this chapter is twofold: 1) describe the evolution of laboratory education of the last sixty years in the context of an evolution of curricular goals, education philosophy, developing learning theories, and the emergence of new pedagogical approaches, and 2) to describe the evolution of a single nonmajors Biology laboratory course as a case study of the application of curriculum design philosophy, history, and reflection.

Active Learning and Evidence-Based Teaching

For centuries, the traditional way that information is and still learned today is through large lecture courses. These courses are typified by objectives that are generally content-based, as opposed to skill-based. Learning is viewed as a transfer from a more knowledgeable other to a novice through lecture. This type of instructional strategy, though common, is generally seen as a passive process on part of the student. However, the content-focused goals that allowed expository-based courses to persist had shifted, making lecture ill-prepared to adequately engage students with process-based tasks. Additionally, a change in approach was needed to solve the leaky STEM pipeline experienced nationally (PCAST STEM Undergraduate Working Group, 2012).

Active learning was the proposed solution to concerns that passive, expository lecture was ill-preparing and keeping students in STEM. Freeman et al.'s (2014) meta-analysis helped pave the way to establishing active learning as a gold standard for undergraduate education. This study gave strong initiative to departments to revolutionize teaching, but relatively little in regard to implementation as active learning was seen as any instructional strategy besides lecture. This led to two problems: 1) poorly defined methods of active learning leads to poorly consolidated research and implementation and 2) an abandonment of the positive aspects of expository-based instruction.

More usefully, active learning can be defined as a classroom environment that explicitly provides the learner with agency in the learning process (Lombardi et al. 2021). This agency requires students to set goals, react to classroom activities that help achieve these goals, and reflect on the learning process as a whole (Bandura, 2001). Therefore, while much of the discussion surrounding active learning has been developed as the antithesis of lecture, lecture may still be considered one such option. Rather than a collection of actions an instructor may perform in a given class, active learning is more effectively viewed as deliberate learning processes that maximize student agency in constructing their own knowledge. As a result, it is common to see short lectures connected with several active learning strategies in order to best serve students.

The science laboratory has long been a component of science education since the nineteenth century. While laboratory courses may have initially been utilized as reinforcement for topics learned in lecture, laboratory courses would begin to be viewed as an instructional setting with its own unique instruction, learning, and assessment components (Lazarowitz and Tamir, 1994). While there has been some discussion on what science content topics are best suited for the laboratory environment, much of these objectives are skill- or affective-based such as focusing on thinking like a scientist, developing problem-solving skills, and improving interest, motivation, and attitudes towards science. Given the focus on scientific literacy and student-centered learning, the science laboratory provides an opportunity for students to engage with scientific processes that require students to actively engage in their construction of knowledge. As a result, the development of laboratory courses in the last sixty years have been entwined with concepts of active learning shifting from expository laboratory courses to courses that contribute to the enterprise of science directly.

History and Evolution of Laboratory Courses

Expository Labs

In early laboratory pedagogy, and still seen largely today in physical sciences, expository labs were developed to maximize the transfer of science content to the student. Expository laboratory exercises consist of a predetermined outcome arrived at by deductive reasoning of results obtained from a provided methodology. These labs are commonly called 'cookbook' labs as they require students to complete a step-by-step guide to complete the activity and arrive at the conclusions expected by the instructor. These labs are also called confirmation labs as they often follow a dissemination of an abstract theory beforehand, and through these investigations, the abstract theory can be made more concrete through a highly scaffolded experiment. Alternatively, these labs can also be used to demonstrate the difference between anticipated, theoretical results and experimental results, a commonly seen methodology in chemistry and physics lab exercises.

Expository lab exercises, on the surface, provide a plethora of benefits to its instructors. The labs are often easily conducted in a timely manner, directly target desired learning objectives, and require minimal teacher investment due to the cookbook nature of the experiments. As a result, these lab exercises are also often highly scalable to accommodate many students at a given time. However, these benefits are short-sighted when examining science process objectives as opposed to science content objectives.

Criticisms of expository labs come from philosophical and educational lenses. Philosophically, expository labs do little for the student in depicting an accurate portrayal of science and can lead to misconceptions about how scientific knowledge is constructed. Since students do not have to engage with planning investigations, students can view these experiments as means to an end as opposed to a learning experience in and of themselves. Further development of scientific thinking and science literacy is stunted because of this incomplete engagement with the process of science that compounds when expository laboratory experiences are a student's only engagement with science. As is discussed later in this chapter, expository laboratory experiences often lag any other approaches discussed regarding student outcomes. This lack of positive results can be attributed to the lower amount of time students spend critically thinking about what they are doing and why they are doing it. Additionally, given that these labs are typically content focused, these labs often utilize fewer high-order cognitive objectives, instead focusing on rote memorization and algorithmic problem-solving.

20th Century Shifts in Learning Theories and Philosophy

The focus on rote memorization and breadth of knowledge in a content area would not last long as the prevailing philosophy for science education. During the first half of the 20th century, education philosopher John Dewey was attempting to shift the focus of science education from memorization to scientific thinking and science-informed decision-making (National Research Council, 2000). This would later compound with the development of Bloom's Taxonomy that would further emphasize the differentiation, and later prioritization, of higher-order cognitive skills as the goal of education with lower-order cognitive skills as fundamental building blocks to reach these higher skills.

To support the desire for higher aspirations for science objectives while recognizing the utility of memorization and understanding, three learning theories developed in the 20th century all point to prior knowledge as a commonality at the heart of constructing new knowledge. While expository laboratory experience hinges on rote learning, three cognitive theorists in the last century have helped pave the way to understanding the importance of prior knowledge in assimilating new knowledge. According to Piaget, new knowledge must be interpreted in relation to prior knowledge or experiences (Piaget, 1978). Ausubel added that information is held in connected networks (Ausubel, 1963). Together, these ideas give us a greater understanding that information that can be more easily understood by or adapted to these pre-existing networks of information would be more readily learned. Finally, Vygotsky's zone of proximal development purports that a learner's capacity to learn is based on their current information (Vygotsky, 1978). Therefore, expository laboratory experiences will fail to deliver intended learning objectives should the prior knowledge of the students be ignored.

These three learning theories helped give rise to constructivism as a model for driving conceptual change. Constructivism can be defined by three guiding principles: 1) knowledge must be actively constructed by an individual, 2) social interaction is a key component of building knowledge, 3) cognition is both functional and adaptive, and 4) cognition serves as a method of organizing experiences, not objective reality (Von glasersfeld, 1993). The culmination in this change of science education philosophy and adoption of new learning theories resulting in an inquiry-based learning movement in the 1960s that have continued to evolve and inform curriculum design for science education today.

Open Inquiry-Based Labs

Open-inquiry laboratory courses are defined as an activity of variable length (from a part of a course meeting to multiple weeks in sequence) where students generate methodology for an undetermined outcome and use inductive reasoning to come to some understanding about a natural phenomenon. In doing so, students are tasked with hypothesizing, explaining, criticizing, analyzing, judging evidence, inventing, and evaluating arguments. Through this more authentic, investigative process, students are not only learning the principles and concepts of science, but also the processes in which those principles and concepts are founded.

Early studies of open-inquiry effectiveness found that the transfer of knowledge was improved under inquiry-based methods, but retention of material was lagging expository methods (Bittinger, 1968). Bittinger also found that inquiry-based laboratory courses were more effective than inquiry-based lecture courses. Discrepancies in the effectiveness of different inquiry-based courses were largely attributed to the amount of student guidance provided during the learning process, suggesting that there is a goldilocks effect of guidance on the effectiveness of inquiry-based techniques (Hermann, 1969). Such guidance provided students that do not necessarily limit the openness of the inquiry-based exercise include providing overviews of progress to help students keep track and plan their inquiry trajectory; prompting students to perform certain tasks; suggesting how a task may be completed; explaining or completing more demanding tasks (De Jong and Lazonder, 2014). Regardless of the level guidance, even minimal guidance can fair better than similar laboratory exercises using expository methods (Furtak, Seidel, Iverson, and Briggs, 2012).

Despite positive outcomes of these labs, several challenges emerged because of expecting students to rediscover principles of science. Initial criticisms came about from placing too much demand on students’ short-term memory by asking them to juggle new subject matter, unfamiliar lab equipment, and novel problem-solving tasks (Linn, 1977; Kirschner, Sweller, and Clark, 2006). Other criticisms include poor implementation by not giving students adequate time to tackle inquiry-based activities (Herron, 1971; Tamir and Lunetta, 1981; and Lunetta and Tamir, 1979), not enough time spent on content (Friedl, 1991), and incorrectly equating inquiry with unguided student discovery (Hegarty-Hazel, 1986). Lastly, implementation of open-inquiry laboratory experiences were stunted by the lack of teacher training on how to run these types of investigations at different levels of education and the amount of time open inquiry took compared to the amount of content covered. While breadth of content was still considered preferable over depth of knowledge, open inquiry labs would remain rarely adopted.

Guided-Inquiry Labs

Since the 1960s, the importance of scaffolding and student guidance continued to grow in prominence (De Jong and Van Joolingen, 1998; Alfieri et al., 2011; De Jong, Linn, and Zacaharia, 2013; D'Angelo et al., 2014). In response to developing education research and to the criticism that open inquiry made it difficult to disseminate specific learning objectives as well as the increased class time required for open inquiry compared to expository labs, guided-inquiry laboratory exercises attempted to minimize these issues while retaining the modeling of scientific knowledge construction. Here, inductive reasoning is still the main mode of knowledge construction, but instead of student generated questions and outcomes, the expected outcomes and methodology and prepared for students by the instructor. Typically, these exercises are conducted prior to direct instruction on a given subject matter to provide students with the foundational knowledge to build a stronger understanding of natural phenomenon. While providing students less autonomy in the decision-making process of scientific investigations, guided inquiry allowed students to model and develop a variety of problem-solving techniques in a manner more fitting of a course time frame (Bruner, 1961).

One such theory that can help explain the effectiveness of guided inquiry labs is information processing theory. Information processing theory suggests that learning occurs best with the activation of prior knowledge and elaboration. Activation of prior knowledge in the case of all constructivism-based learning strategies, helps bridge the gap between what is known and what is to be learned by facilitating the assimilation of new information (Schmidt et al., 1989). One common implementation of guided inquiry is in the second stage of the 5E (engage, explore, explain, elaborate, and evaluate) instructional model. This exploration stage and its coordinating elaboration stage provide students an implicit (when conducting their initial investigations) and explicit (elaborating on their understanding following some expository instruction) serve as a basis for elaboration to occur numerous times.

Critics of guided inquiry came from both camps of open inquiry and expository labs. From the open inquiry critics, while guided inquiry may assist with a follow-up lecture, students are not prepared to discover information in which they are conceptually unaware. Further, the more an instructor provides for a student, the less a student must problem solve on their own leading to less robust learning gains from a student for the sake of specific content-based knowledge objectives (Hodson, 1996). Worse yet, guided inquiry could actively reduce a student’s natural inquiry by preventing student interest from driving their own education.

Nonetheless, guided inquiry faired better in student learning outcomes in comparison to open-inquiry methods. The discrepancy between the effectiveness of open- and guided-inquiry can largely be attributed to the increase in student guidance that is likely to reduce extraneous cognitive processing during the learning process (Hmelo-Silver, Golan Duncan, and Chinn, 2007; Lazonder and Harmsen, 2016).

Problem-Based Learning

Problem-based learning (PBL) is not explicitly a laboratory-style pedagogy, however it is analogous to the inquiry-based learning in objectives and methodology. In PBL, the instructor provides students with an authentic problem and acting as a mentor in helping students generate their own problem-solving methodology. PBL is typified by four primary characteristics: 1) knowledge acquisition is contextualized by a central problem, not a list of objectives, 2) student-centered insofar as providing students opportunities to make decisions, encourage self-directed learning, and interest students, 3) students reflect on their understanding and adjust for further learning, and 4) instructors are seen as facilitators of tasks rather than lecturers (Marra et al. 2014). Marra et al. also propose several curriculum design components to complement these characteristics suggesting that PBL experiences be of suitable clarity and difficulty for students, utilize prior knowledge in application of an interesting problem, and stimulate elaboration.

Initially, PBL was developed in the 1950s to enhance the traditional education of medical students with the experiential side of problem-solving in a desired setting to provide an avenue for authentic learning (Savery and Duffy, 1995). With the rise of inquiry-based learning and constructivism, particularly the concept of ‘learning by doing,’ PBL found a foothold in a variety of subjects beyond medical schools and science classrooms. While early PBL lessons used simulated problems and patients for medical students to interact with, PBL today can vary from simulated environments to solving real-world problems, typically ones found in the local community.

Regardless of implementation, PBL effectiveness is rooted in theories of situated learning and mixed practice as well as elaborations on other theories already discussed, such as constructivism, information processing theory, and self-determination theory (Hung, 2002, Onyon, 2012). Situated learning purports that learning best occurs when it is taught concurrently within the social and physical landscape that such knowledge would be applied (Brown, Collin, and Duguid, 1989). Importantly, the environment in which learning takes place may be simulated, as is often the case in case based PBL. Here, students engage with a given problem through a case study that can be utilized as either reflective, analytical experiences or as problems for students to solve in a more traditional PBL sense (Jonassen, 2010). Mixed practice is defined as a deliberate act of mixing content learning or skill training together as a form of interleaving to improve retention as opposed to block practice, the act of teaching contents one subject at a time (Norman and Schmidt, 2000). Whereas inquiry-based practices may be, thought not necessarily, designed to be heavily block-based (i.e. a series of inquiry-based investigations that while mixed in their approaches of scientific practices, are still block-based in science content), problem-based learning by its nature of approaching complex, real-world problems increase the amount of mixed practice required of students. In addition to prior knowledge activation and elaboration, PBL includes another component of information processing theory: context matching. Context matching purports that recall occurs best when the environment in which information is recalled matches that context in which the information was learned (Schmidt, 1983). Given that the design goals of PBL is to have students engage with situated learning, the task of PBL should improve recall particularly when such information is desired.

A meta-analysis of 82 studies found that problem-based learning effectiveness differs by discipline and assessment level (Walker and Leary, 2009). Science and engineering faired worse than teacher education and medical education fields in terms of learning outcomes as compared to expository methods. As for level of assessment, students in PBL classrooms consistently outperformed expository-taught students in application-level assessments and performed generally better on knowledge and understanding of concepts. Gijbels et al. found similar findings in their meta-analysis, finding that PBL has a more positive effects on understanding the link between concepts as well as the application of knowledge, but no improvement on the understanding of base concepts (2005). On the affective side of learning, a meta-analysis of 47 students found that PBL has a small, but positive effect on student attitude compared to expository methods (Demirel and Dagyar, 2016).

Course-Based Undergraduate Research Experiences

Course-based undergraduate research experiences (CUREs) can be described a type of problem-based learning approach that replaces a given problem with a teacher-generated or student-generated research question. Over the last two decades, laboratory curriculum design has moved away from expository laboratory methods in favor of courses that more appropriately mimic the nature and practice of science. CUREs attempt to take the next step and provide students with the experience of generating scientific knowledge through research in a course setting. While drawing on influences from constructivism, inquiry-based learning, and problem-based learning, CUREs also draw upon research on undergraduate research experience. While undergraduate research experiences have a variety of benefits for students including educational and career development, these experiences are not widely accessible to most undergraduate science students. Therefore, CUREs attempt to solve both calls for learning environments that focus on engaging students with the process of science as well as calls to increase the availability of undergraduate research experiences.

CUREs have also developed their own conceptual framework that attempts to explain learning gains and shape future course assessment. These five critical components for CURE assessment are 1) the use of science practices, 2) collaboration, 3) iteration, 4) discovery, and 5) broadly relevant work (Brownell and Kloser, 2015). Initially, discovery and broadly relevant work had been described in the strictest sense that students were investigating questions that did not yet have an answer in science literature and such work in CUREs is relevant to stakeholders outside of the classroom (not unlike some implementations of problem-based learning). Conducting replication studies in CUREs as well as CUREs focused on literature reviews have shed light that only focusing on constructing new knowledge is also a narrow view on science. Moreover, constructing new knowledge as we know from constructivist theories is a largely personal action and thus constructing new knowledge for the self may be more important than generating science for science's sake. Additionally, conducting work of interest to other stakeholders may be a motivating factor, since their inception project ownership and student autonomy have emerged as important design constructs for CURE effectiveness. Simply put, it is not sufficient for CURE work to be of interest to some other entity; instead, the work ought to be important to the student conducting the work. As a result, CUREs have moved from large multi-institutional collective experiments like SEA-PHAGES into smaller, student-directed projects where instructors widen the options for students allowing for more autonomy in the CURE classroom.

Despite generally having rigid definition by its critical components, CURE implementation in the literature is relatively lax. CUREs do not neatly fit into a form of inquiry as any component of CUREs can be instructor- or student-generated. While many inquiry-based laboratory experiences are one- to four-week investigations, CUREs have been described in as little as a single instance in a course and up to two-semester models for investigation. While shorter CURE implementations may be used to give an overview of the process of science not unlike citizen science participation, longer CUREs are conducted to provide longer opportunities for iterative research cycles for student projects. Most commonly, CUREs are single semester courses split into two halves: the first half mimics expository or guided inquiry laboratory exercises to provide students with the background knowledge and skills necessary to conduct research on an instructor-provided topic while the second half focuses on investigations of student-generated questions using student-generated methodologies. Generally, CUREs are assessed on the final product of said research project which may be a formal lab report, communication brief, or some other form of science communication.

Regardless of the developing understanding of CURE design, implementation, and assessment components, it is evident that CUREs provide a plethora of benefits to students. On the cognitive side, CUREs generally lead to increased content knowledge, analytical skills, communication skills, and increased technical skills. On the affective side, CUREs provide students with an enhanced science identity, self-efficacy in science, sense of belonging, and science attitudes. Though CUREs may have been developed out of a desire to offer more undergraduate research experiences to their science majors, the outcomes of CUREs and the philosophy of learning by doing science aligns well with our current goals of nonscience major education.

Development of a Nonmajor CURE

Factors Influencing Transition

The transition from a guided inquiry-based laboratory course to a course-based undergraduate research experience was influenced by a plethora of factors, including student, teacher, technological, and societal factors as well as alignment with current overarching K-12 and collegiate science standards. On the student front, motivation and engagement play a large role in learning course material and persistence in adverse settings that a research course might produce. Under a self-determination theory framework, intrinsic motivation is best fostered through supporting autonomy, competence, and relatedness. Given the ability of CUREs to provide students with choice in their individual projects, autonomy to some degree is more supported in a CURE approach than by repeated inquiry-based activities. Competence is well supported through guided practice and just-in-time teaching, which should be present in any guided inquiry or CURE. Relatedness to students will be a continually moving goalpost to strike the right balance of topics that students will find interesting, important, or fulfilling.

From the teaching perspective, there was also a desire to change the experience for graduate teaching assistants to provide a more robust experience in the classroom. Working with students in a CURE switches the mindset of an instructor from being a teacher to a mentor. In an inquiry-based classroom, this mentor position is typically non-existent. However, given the multitude of career goals of our graduate student teaching team, it is desirable to offer different environments to graduate students to experience working with novices. These mentoring portions of a CURE can help prepare graduate students for more advisory positions that they otherwise would not get out of an inquiry-based lab.

The Covid-19 pandemic triggered a necessity in distance learning and the integration of online platforms for education. This shift also put accessibility and flexibility into the spotlight of course design principles. One such difficulty that may arise in a laboratory course is the difficulty of students who miss class meetings. Since many experiments require specific equipment and set-up time, making up lab experiments in full is not always possible. The culmination of all these factors influenced the decision to find a computer-based project students could work on that felt authentic to the spirit of CUREs without requiring the difficulties of wet-lab work when students had to miss meeting in person (pandemic or otherwise). Lastly, with the rise of online education at this institution, it was beneficial to develop a long-term online form of a general education course, particularly one such as a lab that can be difficult for online students to find and schedule.

In alignment with Visions and Change and the Next Generation Science Standards (NGSS), introductory labs need to address how laboratory courses should be conducted differently. NGSS places an equal emphasis on content as it does disciplinary practices meaning that we should expect new students to be more accustomed to the process of constructing knowledge in science as opposed to passively receiving it. Likewise, Vision and Change also places a larger emphasis on disciplinary practices than past initiatives. Regardless of students major, it is evident that disciplinary practices need be a greater focus.

A CURE approach, while striking a balance of content and disciplinary practices by design, may incur some negative reactions from nonmajor students that need be considered. First, CUREs breach the hidden contract that students have come to expect from science courses and lab-based courses which is to say that following directions and getting the right answer is the desired action by the student (Kahle and Li, 2011). Students can therefore be hesitant to engage with the more open, answer-less nature of a CURE and will require more scaffolding in assisting them with being comfortable with uncertainty. To account for this, while CURE projects require students to generate their own questions and methodologies, we can design individual work to feel more task-based to guide students through the project development portion. Similarly, instructors will additionally need to be supportive of students as they navigate the trials and trepidations of science work. Graduate teaching assistants may be more than appropriately equipped for this as they are also currently undergoing their own projects and aware of the messiness of science firsthand and can assure students that failure is part of the process, reinforcing formative frustration as a necessary component of not just science, but also learning.

In addition to discipline-based practices, societal and economic factors have also placed emphasis on aligning educational practices with 21st-century skills and workforce demands. Given the suspected link between CUREs and critical thinking, problem solving, and collaboration; CUREs and the evolving needs of the job market align well. Thus, a CURE may help contribute to a more adaptive and dynamic workforce as well as enhance student employability.

Essentially, curriculum development is a multifaceted process that requires attention to a variety of stakeholders including students, teachers, technological advancements and availability, broader developing curricular goals, and societal and economic goals. Through considering these factors individually and comprehensively, CUREs made the best sense to best serve each of these factors, particularly to best serve our students.

Design Process

Design of this new laboratory course drew heavily from previous course design, inquiry-based design philosophy, and CURE-specific methodology utilizing a backwards design process (Wiggins and McTighe, 2005). In accordance with backwards design, six objectives were settled at the onset: (i) ask questions and define hypotheses, (ii) plan and carry out investigations, (iii) analyze and interpret data, (iv) construct explanations, (v) engage in argument from data, and (vi) communicate information. These objectives also existed for the previous course model, and we opted to keep the objectives the same as they aligned with our goals of improving scientific literacy and understanding of the nature of science.

Next, assessments were designed per topic per week. Due to the nature of a CURE, the first half of the semester was dedicated to building foundational knowledge and skills and the latter half to conducting independent research. As a result, the assessments must reflect these activities and therefore shift in use during each process. During the first half, guided lab reports were used per lab. In accordance with constructivist theories, guided lab reports included questions to prompt student prior understanding, checks for learning as they progress through the activity, elaborative questions that required knowledge retained from previous weeks, and finally reflective questions to activate student's metacognition. Emphasis at this stage was placed on asking questions, developing hypotheses, and engaging in scientific argumentation using the "claim, evidence, reasoning" model (McNeill and Martin, 2011). During the second half, weekly lab reports were still utilized, but their use was more to structure students' scientific investigations. These latter lab reports included questions regarding a student's progress on their project, areas they needed help on, and preparation for their final infographic. The second half of the course was also bookended by two different assessments. At the start of the project phase, students were tasked to develop a project proposal that walked through their project. This served not only to structure student's thinking regarding project planning but also served as a guide for students to use as they entered class each week; in essence students were writing their future lab directions. Lab reports during the project phase still included reflective questions for students to comment on how their current work is progressing as well as how their project had changed since they initiated it.

Finally, weekly lab activities were planned to follow this course outline. The initial plan had been to simply offer a truncated version of the original three unit inquiry-based lab to make room for students to extend one of the three experiments into their own project. Due to the COVID-19 pandemic and the shift to online and then hyflex teaching, we opted to use projects that could be conducted remotely. As such, one of the three units used in the previous version of this course used data sourced online to conduct an analysis. This served as the basis for our initial run of the CURE wherein students would download data from digitized natural history collections to analyze data. These collections serve a lot of purposes in terms of authentically portraying science: these data are used by scientific investigations already, the data is often messy and challenges student perception of how data is collected, and offers a large variety of variables that students can select to investigate among many different taxonomic groups over large geographical areas. From this, the first iteration of the CURE focusing chiefly on biogeography was developed, introducing students to concepts of Allen’s rule, Bergmann’s rule, and Foster’s rule. As we continued to iterate on the lab exercises and classroom restrictions were lifted, we were able to test out introducing other forms of research including microbial and science education research.

Implementation Strategies

To develop a CURE tailored for nonmajor students, several key implementation elements contributed to the success of this transformative approach. First, a critical aspect of success in the classroom and surrounding student assessment is teaching assistant (TA) training. TAs met once a week for 1-2 hours to discuss the following week’s material, course expectations, and reflections on previous weeks’ teaching and mentoring. Emphasizing course expectations was instrumental in helping TAs understand not just what is expected of them for the next week, but to see the larger picture and how each week in a CURE progressed to help building students up to developing and carrying out their independent projects. Reflection also played a large role in any course correction that needed to take place in the midst of the semester or as an opportunity for change in the following depending on the severity or the creativity of the TAs when brainstorming solutions or other options we might explore.

Another developing trend at our institution is the shifting paradigm from assessments focusing solely on correctness and more towards an iterative, reflective process. Given the iterative and reflective processes in science (as well as our TA preparation meetings), it was paramount to have this mindset trickle down to what we expect from our students. As a result, students were allowed and encouraged to resubmit work to better reflect their developing understanding of the content. This was particularly important during the independent project phase of the course where students were on their own for decision-making and often made mistakes. Shifting from correctness to revision for assessments allowed our students to feel more comfortable in their process of learning research practices rather than fearing punishment for unsuccessful first attempts.

While utilizing online learning practices were considered before a global pandemic, Covid-19 nonetheless prompted a reevaluation and adaption of laboratory courses to online learning environments. As stated previously, online components of this course allowed for easier make-up labs to be conducted by students and naturally progressed into increasing the availability and ease of the course by allowing students to attend physically or virtually. Given that nonmajor students juggle a variety of commitments to their own home major as well as unforeseen circumstances, the ability to make up these missed sessions online is crucial to improving the flexibility of our course. A shift to a blended or online-only implementation may have started as a health precaution in the wake of a pandemic but ended up improving the availability of research experiences to students without being limited by geographical or time constraints.

The last holistic philosophy of the course was developing a supporting learning environment. Such a learning environment for CUREs includes fostering a collaborative and inclusive community where students feel empowered to ask questions, share ideas, and engage in scientific discourse. TAs and peers play pivotal roles in creating these environments where nonmajors can feel welcomed, supported, and motivated to engage in scientific research. Engaging with small groups as well as hosting whole-class discussions were implemented to increase the amount of time expected from students to discuss with their partners, their TA, and between groups.

As for specific semesterly implementations of this CURE, from Spring 2020 to Spring 2023, four unique layouts of the course were developed and described in full below. These layouts increased from providing students with a single biological topic to investigate (biogeography) and sequentially adding additional topics (microbiology and biology education) for students to investigate during their project phase. Two pilots were developed to be run in Spring 2020 and Summer 2021. The first pilot, intended to be a three-topic CURE as conducted in Spring 2023, was interrupted by the COVID-19 pandemic, which also delayed attempts to implement CURE courses outside of summer courses as online and hyflex learning for nonmajor biology laboratories took precedence. The Summer 2021 CUREs were accelerated 8-week programs that were then elaborated upon for the Spring 2022 CURE.

Course Overviews

Pre-Spring 2020: Three-Topic Inquiry-Based Laboratory Course

BIOL 100L began as a nonmajor, in-person laboratory course offered as general education requirement course and was initially developed around three inquiry-based experiments showcasing three different branches of Biology. These units included genetics, microbiology, and ecology. Each of these units scaffolded the inquiry experience for students utilizing a four-week model. In the first week of these iterative modules, students were provided background information on a topic, tasked to construct an hypothesis, and develop methods to test their hypothesis. The second and third week were used to collect and analyze data respectively. Finally, students would construct presentations or infographics to communicate their results with their peers.

Table 4. Repeated process inquiry-based course with objectives. Objectives are as follows: ask questions and define hypotheses (Q), plan and carry out investigations (I), analyze and interpret data (D), construct explanations (E), engage in argument from data (A), and communicate information (C).

Week	Topic	Q	I	D	E	A	C
1	Nature of Science	x				x	
2	Genetics of Taste: Background and Methodology	x	x				
3	Genetics of Taste: Data Collection		x				
4	Genetics of Taste: Data Analysis			x	x		
5	Genetics of Taste: Communication					x	x
6	Skin Microbiome: Background and Methodology	x	x				
7	Skin Microbiome: Data Collection		x				
8	Skin Microbiome: Data Analysis			x	x		
9	Skin Microbiome: Communication					x	x
10	Biogeography: Background and Methodology	x	x				
11	Biogeography: Data Collection		x				
12	Biogeography: Data Analysis			x	x		
13	Biogeography: Communication					x	x

Spring 2022: Single-Topic CURE

For the first iteration of the nonmajor CURE, a single-topic approach was implemented based on the ecology unit from the previous guided inquiry laboratory course. In this iteration, students were tasked to select a biogeographical principal to investigate using species of their choice and sourcing data from digitized natural history collections. The learning goals for this first CURE iteration and all future iterations described use the identical learning objectives from the inquiry-based course. The assignments during the first eight weeks of class (henceforth referred to as the training period) introduced concepts of the scientific method, data analysis, and guided students through two different online databases that they may use for their CURE projects. The last five weeks of course (henceforth referred to as the project period) required students to design their own experiment and scaffolded steps of experimental design each week to assist students in completing their projects. Alignment of learning goals and weekly laboratory activities are shown in Table 5.

The student-designed project was broken down into a scaffolded five-week sequence to provide clear direction for students and serve as a guideline for conducting a scientific investigation. For the first week, students completed a modified Open Science Framework preregistration form (Appendix A). This form requires students to define their hypothesis, describe their methodology including data generation and analysis, and provide a brief review of literature. Then, this completed preregistration form is used as a guideline for students to use during weeks two through four of the project period. Week two tasks students to download, clean, and visualize their data as well as to begin drafting artifacts for the infographic made during week four. Week three tasks students to conduct a statistical analysis of their data and write their conclusions of their study. Week four requires students to complete an infographic based on their study including all of the elements described in their preregistration form. Finally, week five give students a chance to review their peers work and reflect on their own study through a digital poster session.

Table 5. Single-topic biogeography CURE with objectives. Objectives are identical to Table 4.

Week	Topic	Q	I	A	E	A	C
1	Nature of Sciences	x				x	
2	Scientific Sources		x				x
3	Biogeography: Background and Methodology	x	x				
4	Biogeography: Data Collection		x				
5	Biogeography: Data Analysis			x	x		
6	Biogeography: Using GBIF		x	x	x	x	
7	Biogeography: Using Arctos		x	x	x	x	
8	Data Presentation						x
9	Independent Project: Outline	x	x				
10	Independent Project: Collecting and Visualizing Data		x	x	x	x	
11	Independent Project: Data Analysis			x	x	x	
12	Independent Project: Communication Preparation						x
13	Independent Project: Presentation and Peer Review	x					x

Graduate teaching assistants served a dual role as instructor and mentor during the course providing students with feedback through both instructional and project periods. Throughout the project period, students were repeatedly given opportunities to revise and modify their projects based on feedback and guidance from their teaching assistants.

Fall 2022: Dual-Topic CURE

After the implementation of the single-topic CURE, a dual-topic CURE was developed based on student feedback that much of the first iteration required computer-based work and not as much diverse laboratory experiences as was expected (Table 6). To accommodate this interest in differing experiences, the inclusion of the microbiome project from the inquiry-based course replaced the second module of biogeography labs to provide students with ecology/computer-based work as well as microbiology/wet-lab work. Then, students were able to choose between these experiences when developing their experiments in the project phase.

Table 6. Dual-topic microbiome and biogeography CURE with objectives. Objectives are identical to Table 4.

Week	Topic	Q	I	A	E	A	C
1	Nature of Science	x				x	
2	Science Sources		x				x
3	Skin Microbiome: Methodology and Data Collection	x	x				
4	Skin Microbiome: Data Analysis			x	x	x	x
5	Biogeography: Background and Methodology	x	x				
6	Biogeography: Data Collection	x	x	x			
7	Biogeography: Data Analysis			x	x	x	
8	Data Presentation						x
9	Independent Project: Outline	x	x				
10	Independent Project: Collecting and Visualizing Data		x	x	x	x	
11	Independent Project: Data Analysis			x	x	x	
12	Independent Project: Communication Preparation						x
13	Independent Project: Presentation and Peer Review	x					x

Spring 2023: Revised Dual-Topic CURE

The final implementation of the CURE included a new module with which students could choose to use during their project period (Table 7). This last instructional module introduced students to the public understanding of science and guided them through the process of collecting survey data and conducting qualitative, descriptive statistics and the basics of thematic analysis for short response questions. Whereas the removal of the microbiome experiments removes the wet lab experience for students, the introduction of short-response survey data introduces qualitative data for students to experience different types of data. Additionally, the switch from working with microbes to working with survey data again reduces the cost of running the laboratory course while still offering students more experiences and exposure to different types of scientific research.

Table 7. Dual-topic microbiome and biogeography CURE with objectives. Objectives are identical to Table 4.

Week	Topic	Q	I	A	E	A	C
1	Nature of Science	x				x	
2	Science Sources		x				x
3	Public Understanding of Science: Methodology and Data Collection	x	x				
4	Public Understanding of Science: Data Analysis			x	x	x	x
5	Biogeography: Background and Methodology	x	x				
6	Biogeography: Data Collection	x	x	x			
7	Biogeography: Data Analysis			x	x	x	
8	Data Presentation						x
9	Independent Project: Outline	x	x				
10	Independent Project: Collecting and Visualizing Data		x	x	x	x	
11	Independent Project: Data Analysis			x	x	x	
12	Independent Project: Communication Preparation						x
13	Independent Project: Presentation and Peer Review	x					x

Troubleshooting and Future Directions

Challenges and Mitigations

While implementation of a CURE offers valuable opportunities and experiences for students and teaching assistants, a few challenges arose unique to a CURE approach. First and foremost is an uneven background in research experience. While this is expected for our nonmajor students and varying levels of background knowledge is a persistent issue in education, the variety in experiences with conducting and mentoring research in TAs can hinder their ability to support students at different skill levels. Some of this inexperience can be a positive insofar as novice mentors can work harder to overcome their inexperience when first mentoring students (Leary *et al.* 2013). Beyond this, TA reflection and iteration was used to turn mentoring into a learning experience.

Access to resources and time constraints also brought challenges to our students and TAs. The ability of students to have access to the software required for conducting their projects as well as required tech support for online students made troubleshooting a very common occurrence and expectation of TAs. Training TAs on not just conducting procedures correctly, but also on common errors and pitfalls students may experience and how to remedy these situations became equally important. Video tutorials were implemented to help mitigate some of these issues, but these cannot foresee every potential issue a student may encounter, especially during distance learning. Likewise, access to time is a new constraint on online iterations of this course even more so than the in-person iteration of these CUREs. Students outside of the classroom may struggle to find the time to meet project deadlines and TAs may struggle to find the time to provide timely feedback to students so they may continue their projects. Should a TA not provide quick feedback, students may, to best handle their time, move on to future parts of their projects without waiting for feedback on parts of their project that need revision first, resulting in lost time for the student and prolonging projects even further. Providing more rigid timelines for students to adhere to can help students keep on track, but with flexible enough due dates that allow for unforeseen circumstances limiting student success. As for TAs, additional streamlining should be considered to allow for quicker turnaround times on feedback. This can include, especially after multiple iterations, introducing a code system so that TAs can quickly express common issues that require corrective feedback to students.

One of the most glaring issues in the course design from a CURE perspective is the lack of peer collaboration. While some students may choose to complete their CURE project as a pair, the majority of students did not in the in-person iterations of the course, and even less completed the project in the online iterations. More research into fostering collaboration in an online environment must be investigated, especially in methods that allow for flexibility to still be a key design feature.

Lastly, as described in any pedagogical approach that requires students to create their own project, students can feel uneasy in such environments. The training portion of the CUREs match more closely with student expectations of how a laboratory course is conducted: clear objectives, methods provided to complete their work, and relatively straightforward conclusions. One of the main goals of the independent project is to show students that science is rarely so clear and straightforward. Such a change halfway through the semester can be challenging for students and many struggle during the project planning than any other part of the CURE process. On student end-of-semester surveys, students repeatedly say that the training portion prepared them well to conduct their independent project. It is apparent that students do not seem to have lingering negative feelings over their initial troubles getting started with an independent project, we can still modify instruction to mitigate some of these issues. Introducing more project formulation questions sooner in the semester, particularly ones that can focus on projects students could conduct would help give students some experience with what they can research when they reach the project phase. Such questions could simply be reflective questions at the end of each training session on what students would do next or what questions they have over the biological principle learned. Rather than reflective questions at the end of a lab report, pre-emptive brainstorming or warm-up questions could be introduced to laboratory courses. This may serve a dual purpose in not just reinforcing previous content, but bringing forth students' prior knowledge which is an important component of conceptual change and knowledge assimilation.

Reflections

The challenges of developing, transitioning to, and implementation of course-based undergraduate research experiences requires a multifaceted approach drawing from associated pedagogical literature; relevant science goals and objectives that are both downstream (from employers and scientific decision making) and upstream (K-12 science standards); and consideration of both student and instructor interests and abilities. This chapter aimed to describe the complexity of curriculum development and show its evolution over the course of a few years and evolution from inquiry-based methods to student-led research projects. In the spirit of the importance of reflection and continual modification and elaboration on curriculum five avenues of future directions, developments, and concerns were raised during the implementation of these CUREs.

Expanding Research Scope

We investigated three different topics regarding biology spanning biogeography, microbiology, and biology education. Given that student interest can drive motivation in the classroom, a continued investigation in topics that appeal to a general science audience to help leverage this intrinsic motivation further. Additional investigations could identify if certain sub-disciplines of biology are conducive to delivering course objectives. Similarly, many CUREs during the pandemic switched from conducting experiments to conducting literature reviews or meta-reviews. Having students conduct meta-reviews may offer students more freedom in what they choose to research and provide experience with primary literature and synthesis, but at the cost of spending more time working with primary literature than is typical of a nonmajor science laboratory course.

Beyond modification course content and projects, another potential dimension is examining how nonmajor CURE implementations differ based on institutions or grade level. While CUREs are typically prohibitively expensive, the advent of review-based CUREs or CUREs revolving around online databases or educational studies, these CUREs could be easily adapted not just for research-intensive universities, but also liberal arts colleges or community colleges. Similarly, CUREs were typically only a technique used for upper level biology students. Since those origins, they have trickled down to introductory biology students, and now to nonscience majors. Moving forward, such experiences could be adapted to a K-12 students, which would align well with the emphasis on disciplinary practices in current K-12 science standards.

Enhancing Pedagogical Strategies

As seen through the repeated modifications of the CURE as it currently stands, further revisions are necessary. While initial design and development can be based on prior research and understanding of student learning, incorporating feedback from students and graduate teaching assistants are important to best fit this CURE for our current environment. Currently, when asked what could be improved with this course design, many students cite their own procrastination or disengagement from the course as the main negative factor. Therefore, finding better ways to guide students to keep students from procrastinating or proposing and offering more attractive topics to students may keep engagement higher. Similarly, finding better ways to streamline the course for teaching assistants so they can spend more time providing corrective feedback to students should also be considered.

Availability of data is one of the most important aspect to conducting research in the classroom, but also provides a large amount of frustration for students and teaching assistants.

B. Integration of Technology: Explore how incorporating emerging technologies or virtual platforms can enhance the pedagogical aspects of the Biology CURE. Currently, the website we use as an online database, Arctos, is continually changing their website layout making tutorial videos and documents repeatedly out of date. Continual mid-semester modification of course materials can be exhaustive to teaching staff and frustrating to students. Finding better online repositories or methods to provide students with data to work with would be beneficial for all involved in the CURE process.

Faculty and TA Development

Further from course revision based on student and teaching assistant feedback, continual revisions to our development and training of faculty and teaching assistants are needed. For faculty, finding ways to streamline the CURE development process and improve visibility of low-cost, introductory CUREs are instrumental in generating new course offerings to students of all levels. Similarly, more complete training regiments for teaching assistants to help them navigate the mentoring role required in CUREs are needed to reduce anxious feelings novice teaching assistants may feel when engaging with students in a CURE. Interviewing and condensing the experience of previous CURE teaching assistants would be beneficial for new teaching assistants in preparing them for the difference between teaching and mentoring.

Assessment and Evaluation

For proper evaluation of a CUREs success, holistic assessments examining the short-term and long-term impacts of engaging with a CURE are needed. Holistic assessment tools here refer to identifying assessment tools that can properly capture the multidimensional outcomes of

CUREs including content information, disciplinary practices, science attitudes, problem-solving skills, and evidence-based decision making. Short-term impacts would examine how well these objectives are transferred to students within the semester and between differing iterations of the course. Given that nonmajor biology laboratory courses typically enroll hundreds of students each semester at this university, such a sample size would provide an exceptional look at the effectiveness of each CURE between semesters. Similarly, looking at the long-term impact may shed light on the pervasive components of a nonmajor CURE. While the goal of a nonmajor CURE is not to increase enrollment in future science courses, understanding what students ultimately took away from the CURE is important for further revisions of the course. A similar assessment could take place for teaching assistants to examine what teaching assistants take away from their time mentoring a CURE and whether such an experience impacts their own professional trajectory.

Diversity, Equity, and Inclusion

The development of these CUREs has always had the expressed goal of improving the effectiveness of nonmajor science courses to students that best serve their interests and develop their understanding of science. To further this goal, it is necessary to investigate potential disparities in participation and success among a diverse student population. Additionally, while student flexibility was an initial design component, as this course continues to develop and change, more exploration is needed for methods to make the CURE and content more responsive to diverse student backgrounds.

Conclusion

General science education has pivoted away from learning a large swath of content knowledge as well as learning it in an expository fashion. Instead, more emphasis is placed on interdisciplinary practices and understanding the process of science. Described here is the development and implementation of a course-based undergraduate research experience for nonmajor biology students. The continual revisions of this course were presented along with numerous ways to continue to assess, reflect, and modify the course for future iterations. CUREs offer an avenue to improving scientific literacy in a post-Covid-19 society where the importance of scientific literacy has come to the forefront. It is necessary to develop new learning experiences for our general audiences to help improve scientific literacy and positive attitudes towards science for all students.

CHAPTER 3: QUALITATIVE GRADUATE STUDENT TEACHING EVALUATION OF A NONMAJOR BIOLOGY CURE

Introduction

The current shift to active learning strategies and inquiry-based learning in the undergraduate biology curriculum reflects a paradigm shift from a breadth of knowledge focused largely on content to one of developing deeper understanding of fundamental biological concepts, disciplinary skills, and critical thinking. Active learning is a collection of diverse techniques that situate the student in the center of the learning process through collaborative, reflective, and hands-on applications of content material to real-world scenarios. Inquiry-based learning, on the other hand, is the emphasis on student-led problem-solving and knowledge construction that tasks students with formulating research questions, developing methodologies, and analyzing and interpreting results. These ideas taken together capture a dynamic, participatory learning environment that cultivates scientific inquiry and gives relevance to the content learned. Traditionally, such scientific inquiry was left to two components: laboratory classes and undergraduate research experiences. Whereas laboratory classes have evolved over the last 60 years to become more inquiry focused, undergraduate research experiences remain to be elusive apprenticeships that are only available to some students, leaving out an authentic avenue for developing one’s scientific inquiry. As a result, course-based undergraduate research experiences have been developed to bring research into the laboratory classroom setting to provide research experience for all students.

As is often described, course-based undergraduate research experiences (CUREs) are iterative and collaborative learning experiences wherein students work with novel data to discover new information with some real-world relevance (Dolan, 2016). In practice, CUREs are typically a semester-long course that instructs students on some given biological principle, guides students through the research process, and provides students time to conduct their own research in said given field. These courses generally begin with a series of modules or exercises that teach students, step-by-step, the research process (e.g. reading scientific articles, developing hypotheses, conducting statistical analyses). The latter portion of the class is then dedicated to collaborative, student-led investigations as they apply their skills learned through modules into a cohesive research project. In general, these courses are either extensions of the instructing faculty member's research or a network of faculty working collaboratively on a large-scale research project (Lopatto et al., 2020, Jordan et al. 2014).

While the initial purpose of CUREs was to increase the availability of research experiences for undergraduate students, there are a plethora of positive outcomes for students engaging with CUREs. These can include disciplinary-based outcomes such as increased content knowledge, understanding of the nature of science, and technical or discipline-specific skills. Additionally, numerous attitudinal or behavior outcomes include enhanced self-efficacy, science identity, sense of belonging, science attitudes, and self-determination. Finally, CUREs offer many benefits in soft skills such as increased communication skills, collaboration skills, and tolerance for obstacles.

The effectiveness of CUREs is largely understood in a variety of learning theories. Most foundational of these learning theories is constructivism, the theory that knowledge is constructed by the learner through a reconciliation of past and present experiences. When encountering new ideas or experiences, the learner must understand what they currently know, investigate how these new experiences conflict, explain, or coincide with this prior understanding, and then modify our new understanding or discard the new information.

However, knowledge is generally understood through language and frameworks that only exist through human language and culture. Thus, social learning theory purports that knowledge is socially co-constructed in each cultural environment (Vygotsky, 1978). It is not just knowledge students construct, but also where and with whom they construct this knowledge, both peers and instructors. Further, this cultural environment lends itself to situated-learning theory which suggests learning is best done through the relevant actions, context, and culture of said learning (Brown, Collins, and Duguid, 1989). Given the importance of project ownership and self-efficacy to student learning outcomes in CUREs, self-determination theory (SDT) is another well-fit learning theory to help explain CURE effectiveness. SDT purports that intrinsic motivation is helped or hindered through three avenues: competence, autonomy, and relevance. Given that CUREs are taught through instructional modules to build students competence, provide students with a level of autonomy in conducting their own research, and are situated in information relevant to some group outside of the classroom; SDT would predict that CUREs have the potential to increase a student's intrinsic motivation, which has mediating and moderating effects on student learning.

In the United States it is common to have many introductory and laboratory courses taught by contingent faculty members, such as undergraduate and graduate teaching assistants (Sundberg, Armstrong, Wischusen, 2005). These graduate teaching assistants (GTAs) often perform a wide range of duties which can include attending undergraduate lecture, assisting in classroom activities or demonstrations, conducting lectures for undergraduate courses, proctoring exams, offering office hours or tutoring sessions, and, most commonly, serving as instructors for laboratory or recitation courses. These courses tend to be small class sizes and thus often need more teaching staff to accommodate, thus necessitating the need for contingent staffing.

To the graduate students' benefit, such teaching appointments offer a variety of proposed benefits. Often times, these courses may help a graduate student increase their depth of knowledge in their content area as they relearn fundamentals and find new ways to communicate said knowledge. Relatedly, GTAs also gain teaching experience working in front of a classroom as well as working one-on-one with students in the smaller classroom setting. These experiences can also lead to career clarification for many GTAs as they continue to develop their professional identity and may sway GTAs one way or the other on pursuing teaching as a career option or goal.

However, despite these benefits, GTAs experience several frustrations that may hinder their or their students' growth in the classroom. Worthen (1992) found that GTAs typically feel anxious regarding teaching due to a variety of reasons including uncertainty regarding the overall experience, lack of content knowledge, and lack of teacher training. These issues compound with a following lack of confidence and self-efficacy as a teacher and an inability to motivate their students. Findings by Alhija and Fresko (2020) show that little has changed in the near three decades from Worthen's findings. GTAs still find frustration with poorly defined job definitions, low self-confidence, and a lack of appropriate training. Regardless of this, it should be noted that students often evaluate GTAs on par with their faculty counterparts in most measures, exceeding faculty in relatability, while expectedly rating lower in clarity due to a lack of teacher experience (Alhija and Fresko, 2018).

While many CUREs are taught primarily by a faculty instructor, many are assisted by one or more GTA. With the growing desire to scale up CURE inclusion in undergraduate biology curricula, GTA-led CURE sections may be more common in the future. Given the known challenges that GTAs already face in biology laboratory courses, CUREs offer new challenges as well as benefits for GTAs. First, CURE courses by nature require an instructor that is i) able to deal with uncertainty, ii) proficient in the area of research being conducted, and iii) willing to invest the appropriate time and effort to ensure a successful implementation of the CURE (Shortlidge and Brownell, 2016). Upon interviewing GTAs of CUREs, Heim and Holt (2019) found that GTAs perceived themselves inadequate as research mentors, experienced difficulty in the logistics of running numerous research projects, and found the time commitment to CUREs to be excessive. Additionally, Heim and Holt also found that GTAs had difficulties motivating students to take ownership of their work. This is immediately problematic as GTAs have a direct effect on student motivation, which in turn moderates the effectiveness of a CURE in developing its learning objectives (Goodwin *et al.* 2023). Similarly, student ownership is a well-known construct in mediating CURE effectiveness.

In summary, introductory CUREs are on the rise and these introductory courses are typically staffed by graduate teaching assistants. These students are typically undertrained teachers and in-training researchers that may be ill-equipped to lead a CURE effectively for students. However, GTAs are commonly seen as more approachable and generally comparable to faculty members and have skills that may be uniquely developed by engaging in CURE mentoring. Therefore, this study examines the perceptions of GTAs in a nonmajor introductory biology CURE to i) examine GTAs experienced benefits and challenges in teaching a CURE, ii) evaluate benefits and challenges for students of a CURE as perceived by their instructor.

Methods

Participants and Course Description

This research’s procedures were approved by the coordinating university’s institutional review board (IRB #0004014). This university serves an undergraduate population of just under

10,000 and just over 2,000 graduate students. GTAs that taught the nonmajor biology laboratory class between Fall 2021 and Spring 2023 were recruited for this study via recruitment email. Seven of the eight potential GTAs make up our sample, with the eighth GTA being the author. Four male and three female GTAs participated in this study from either MS (n=5) or PhD (n=2) biological science programs. These GTAs also had differing levels of teaching and mentoring experience with four GTAs teaching for two semesters and three GTAs teaching four, six, and 11 semesters, representing a great diversity in teaching experience among the participants. All participants had taught the nonmajor biology course as a CURE, with two participants teaching the course before the transition to a CURE.

The studied class, BIOL 100L, is a general nonmajor biology laboratory class with weekly, 2-hour meetings. The course is meant to be taken with one of the several nonmajor biology lecture courses, but the contents of this course are not taken from course objectives of the lecture courses students may take concurrently. During the Fall 2021 semester, and previous semesters, BIOL 100L was run using an inquiry-based model that walked students through three extended laboratory investigations over three different biology subdisciplines (genetics, microbiology, and ecology). Spring 2022, Fall 2022, and Spring 2023 were instructed using a CURE model. Here, students spent the first eight weeks on basic research principles and relevant biology content. Each CURE-based semester focused on one or two different content blocks including biogeography (all semesters), microbiology (Fall 2022), and biology education (Spring 2023). The following five weeks tasked students to generate their own research project either furthering a project worked on in the first eight weeks or developing an entirely new study with the tools and techniques they learned. Working collaboratively with their peers and/or their GTAs, students developed their own hypotheses and methodologies. As assessments switched from standard laboratory reports in the first eight weeks to updates on progress in the later five weeks, GTA roles shifted as well from instructor to mentor. Here, GTAs were expected to offer feedback on student project proposals and offer advice as students progressed through their research projects. In general, students were independent at this stage, and GTAs were available largely as a resource for students to use.

At this institution, graduate students are polled on teaching preferences for their placement as a GTA. Placement, however, is often determined by student availability and previous placement (i.e. GTAs that taught a lab class are more likely to teach that lab class again) regardless of preference. Further, we are unaware whether the GTAs that taught this course explicitly wished to teach nonmajor biology or wished to teach a CURE. During the time of interviews, only one GTA had taken courses in education, but all GTAs received training prior to the beginning of the semester and met weekly to discuss pedagogical aims of the course and logistics on running the course. Beyond this, there are multiple voluntary sessions on instructional strategies but the extent to how the GTAs engaged with these is unknown.

Data Collection

We connected one-on-one semi-structured interviews with BIOL 100L GTAs in the summer of 2023. Interviews took place 1 to 3 months after the Spring 2023 commenced based on GTA availability. Interviews were conducted after the end of the semester to allow GTAs to gather their thoughts and reflect on the semester as opposed to capturing their thoughts in the moment of teaching. Each interview lasted between 30-90 minutes via a Zoom meeting. Each interview consisted of a list of demographic questions to understand their experience as a GTA as well as their plans of study to contextualize their responses to the eight interview questions of interest (Table 8). Each interview session was audio-recorded and later transcribed. Pseudonyms are provided to each participant and identifying information has been withheld from transcripts and quotations provided in this study.

Table 8. Graduate teaching assistant interview questions

1. How does serving as a GTA help in achieving your short- and long-term goals?
2. To what extent has this experience with teaching a CURE affected your teaching ability?
   … your mentoring ability?
   … your research ability?
3. What challenges did you face in the teaching and/or mentoring portion of the CURE?
   How could these challenges be avoided for future GTAs?
4. How would you characterize students' engagement with the training portion of the CURE?
   How did this engagement change after starting the independent projects?
5. What challenges did students encounter throughout the independent project?
   How could these challenges be avoided for future students?
6. What do you perceive to be the benefits of a CURE approach for nonmajor students?
7. If you have other experience, how does teaching a CURE differ from other lab classes?
8. How can the CURE design be improved from your perspective as a GTA?

Data Analysis

To characterize the complexity and richness of our GTA participants' experiences, we used a reflexive thematic analysis (Braun and Clarke, 2019). This flexible approach allows researchers to make sense of data in the context of various theoretical frameworks. Since our project draws upon a mix of learning, social, and psychological theories, reflexive thematic analysis allows for the discovery of novel insights, offering a nuanced understanding of the shared and unique experiences in our GTA interviews.

To familiarize myself with the data, I began by re-listening to each interview and then manually transcribing each interview. When interview transcription was complete, both researchers (W Falkner and L Montplaisir) read each transcript numerous times, noting any trends we identified. Then, passages of text were highlighted into three major themes (course structure, GTA experience, student perception) and then further broken down into individual descriptive codes. Our research goals were also to identify the role that GTAs play in adopting and delivering course objectives, goals, and teaching philosophy, interpretative codes were also used to identify implicit ways in which GTAs interacted with the course. Both researchers then shared their interpretations, collapsed codes into five themes and nineteen subthemes, and collaboratively organized these themes and subthemes into an affinity map.

Relevance to Other Theories

Following the inductive coding process, we identify three theories that help interpret our findings: i) constructivism, ii) innovation diffusion theory, and iii) self-determination theory. Additionally, Corwin, Graham, and Dolan's modeling of CUREs (2015) is also helpful to shed light on course design and implementation. Constructivism is a multifaceted learning theory that purports that knowledge acquisition occurs through active, contextual participation in constructing new understandings from previous and novel experiences (Mogashoa, 2014). Given the inquiry-based nature of CUREs and the necessary design requirements that task students with conducting novel research, constructivism was a driving learning theory behind the design of BIOL 100L.

Innovation diffusion theory (IDT) argues the decision to adopt an innovation (idea, practice, or object) depends on the beliefs that potential adopter makes regarding the innovation (Rogers, 2003). IDT breaks these beliefs into five categories: i) compatibility, ii) complexity, iii) observability, iv) relative advantage, and v) trialability. In the context of our study, compatibility refers to how well GTAs believe that CUREs fit their expectations or beliefs regarding nonmajor students. Complexity refers to a GTAs perception regarding the amount of effort required to conduct CURE teaching and mentoring. Observability refers to the visibility of CURE results to

GTAs. Relative advantage refers to the GTAs belief that CUREs are better than a traditional, survey laboratory course. Lastly, trialability refers to the ability of a GTA to experience CUREs before committing to the innovation.

Given that both constructivism and innovation diffusion rest on the motivation of the individuals involved self-determination theory (SDT) is applicable. Self-determination purports that high-quality, intrinsic motivation relies on an individual’s autonomy, competence, and relatedness (Ryan and Deci, 2000). GTAs are not only under these psychological needs, but also have a moderating effect on these needs in the classroom. Through their actions, GTAs can provide more space for student choice in the classroom, build student confidence and efficacy in scientific practices, and foster connectedness with the course, content, and their peers. As a result, we have a hierarchical flow of responsibility in providing an environment that is intrinsically motivating: from course designer to instructor and from instructor to student.

Finally, Corwin, Graham, and Dolan’s CURE model (2015) refers to the relatedness of classroom activities to measurable disciplinary practice skills and science attitudes. These practices and attitudes are broken down into three phases (early, middle, and late) of evaluative hubs that predict student success in CUREs. During the early phase, the main outcome is increased self-efficacy based on increased content knowledge, analytical skills, and technical skills. Under the lens of SDT, this phase intends to build a student’s competence through iterative practice. The middle phase’s outcome of interest is sense of belonging, resulting from increased project ownership and increased communication and collaboration skills. Again, under SDT, this phase hinges on students having autonomy in the research process and this process feeling relevant to their lives. The late phase of CURE outcomes is enhanced science identity which is supported by the previous two outcomes as well as increased motivation in science, increased tolerance for obstacles, and external validation from the scientific community. Given what we know about intrinsic motivation, should the early and middle phase outcomes be met, motivation in science should be elevated resulting in internalization of learning and attitudinal outcomes of the CURE.

Findings

All identified codes were sorted as belonging to either intentional course design features, GTA experiences, and perceived student experiences as described by GTAs. These three themes were then assembled into a theoretical framework (Figure 1). Here, we propose three direct and reciprocal effects and one moderating effect. First, intentional course design has a direct effect on developing students' understanding of the course content. Second, course design also has a direct on GTAs by scaffolding best teaching practices and improving GTA understanding of course content. Third, GTAs have a direct effect on student learning and attitude through interactions in course and through course materials (e.g. providing feedback on assignments, answering e-mails). Through reflective teaching practices, students and GTAs have a reciprocal effect on intentional course design by identifying issues in course content and student learning. Additionally, students have a reciprocal effect on GTAs by providing experience with working with diverse learners in such a way that can modify how a GTA approaches problems in teaching or mentoring. GTAs also have a moderating effect on the effectiveness of course design elements and student outcomes through constructive or destructive means in regard to course delivery and classroom behavior.

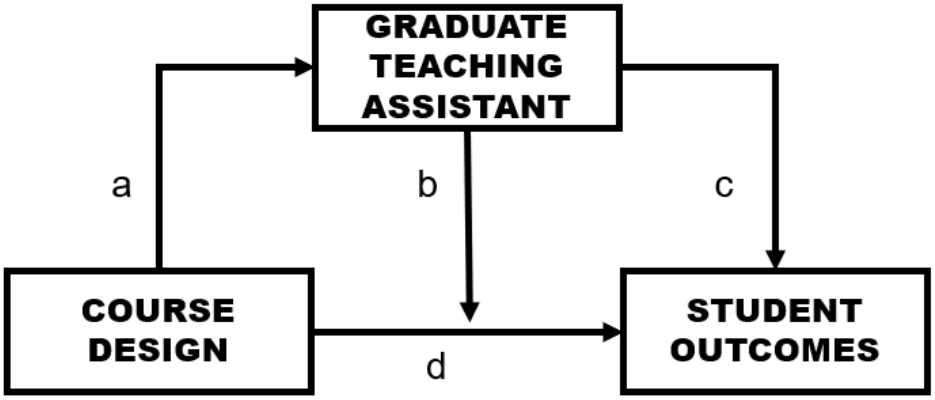


Figure 1. Proposed Framework of GTA-led CUREs

Directional arrows show proposed paths of causality. Arrows a, c, and d are intended in the direction shown but also experience some reciprocity. Arrow b is a moderating process.

What Do GTAs Consider the Essential Elements of BIOL 100L as a CURE?

Student-Centered

Central to an inquiry-based design, all GTAs identified several student-centered practices in the course the differed from previous laboratory courses they either taught or have taken. Four GTAs expressed a de-emphasis of lecture as one form of student-centered approach. This de-emphasis manifest as a belief in how people learn as TA_J purports that “you could stand up there and talk to them all day, but unless they’re actually doing something, they’re not taking anything away.” De-emphasizing lecture was also viewed more as a practical solution to handling students with diverse skillset as TA_E reported “I found it really useful to not spend a lot of time lecturing, but kind of going from group to group and seeing where more people were at.”

In place of lecturing, GTAs found themselves spending more time answering student questions or re-directing student questions. Together with de-emphasizing lectures, TA_A describes their typical approach during the training portion of the CURE:

> I put together kind of a little talk at the beginning of the classes, but [afterward] I would walk around and help the students with any questions they had and I found myself… kind of redirecting questions in a way that they could figure it out themselves.

GTAs were equally vocal about the independent project during the CURE acting as a personalized learning assessment for students. As TA_E described the benefits of a CURE project in terms of personalizing learning for their students:

> The course kind of gives students their own project to work with so they can take it as far as they are able to. I think that’s really important in the course to do that. I think maybe for the students are really struggle… to have a teacher say here’s your space and time for you to learn. I think the course did a good job of giving students their own projects and for them to be able to customize their own experience.

Additionally, four GTAs expressed how working with students in a mentoring capacity allowed for positive interpersonal relationships to form. As TA_W describes “because I’m working more closely with individual projects, it made me feel like a little bit closer to students and form those relationships.”

These same four GTAs also emphasized a positive affect towards nonmajor. This was typically manifest as GTAs described nonmajor students as curious, growing in confidence, and presenting ideas they found creative or ambitious. TA_W describes a unique experience from working with students during the CURE:

> I would say that it was almost like, a little bit inspiring. It kind of lit a fire under me a little bit in a way like, seeing students do their own research kind of made me excited to do mine in a way.

Autonomy and Independence

When asked how BIOL 100L differed from other laboratory courses they instructed, all GTAs found that BIOL 100L provided more space for students to have autonomy in the classroom and, by the end of the semester, acted independently. This autonomy is most expressed through students generating their own research questions and methodology. In turn, GTAs felt that this autonomy was not just a feature of the class, but purposeful for student learning. TA_N summarizes the value of providing students with autonomy and independence in the CURE:

> I felt like it made more sense to them when they were doing their own project. I guess either that or they finally were at the point where they got the hang of [it]. You know what the claim, evidence, reasoning meany because they did it multiple times but there were definitely some people I could tell that the reason it became easier was because now it’s their own project, and it’s in their mind, you know, they’re thinking about it. It’s not something that was just given to them. So they have to dig for that information.

At the same time, GTAs felt that students did not just have autonomy in the classroom, but also acted more independently as well. While many GTAs described an initial busyness during the first week of the CURE when students were formulating hypotheses and drafting methods, TA_A describes the following weeks:

> [Students] knew for the most part what they were doing, so definitely less interaction from me. But that’s a… I like to think a good thing they know what they’re doing. I’ve taught them well, so yeah, they were pretty engaged with their projects.

This autonomy also extended to GTAs as well. Two GTAs discussed feeling in control of the course they were teaching in contrast to other laboratory instruction they experienced.

Additionally, while GTAs were trained on each week's topic the week before instructing, several GTAs would modify teaching strategies based on what they felt was best for their students. TA_E explains the influence of this autonomy:

> It could have been terrible to teach the classes, it could have felt like this is the opposite of what I want to do in classes but I have to, and I didn't have that experience. Instead, I felt like I had creativity in terms of how I can teach the class without deviating too much from what I should be teaching them.

Valuable Experience

Four GTAs identified BIOL 100L as a course that is valuable to students. This manifests in two main ways: i) explicit ideas regarding transferable skills are valuable and ii) implicit emphasis on process is just as valuable as product. As for transferable skills, GTAs typically referenced either 21st century skills (i.e. critical thinking, creativity, technology literacy, collaboration) or scientific literacy skills (i.e. asking questions, understanding statistical inference, constructing arguments from evidence). TA_B summarizes how these skills were a direct outcome of students engaging with the CURE:

> Everyone encounters science in their lives whether they like, see it or not and having some kind of respect for the process, I think, is important. I think nowadays especially, it's really common to see skepticism of science and kind of a lack of understanding of just, you know, like what goes into research and stud, and so doing their own projects gives them a sense of the structure of science, and how data comes about, and how information should be produced and spread for daily life. I think it's valuable to see that whole process, but also in their own lives, like, you know, the scientific method is pretty applicable in any problem you're trying to solve. It's just kind of like a systematic

> approach to solving a problem that, yeah, I think just the context of giving them context for like, where science comes from and where information comes from is very important.

Objectives and Assessment of the Course

Three GTAs expressed two unique qualities of the course objectives compared to other laboratory courses they have experienced. First, BIOL 100L is described as focusing more on higher-order cognitive skills as compared to a more superficial survey of multiple topics within a lab curriculum. Contrasting with many years of GTA experience, TA_B believes that BIOL 100L goals are “much more related to those higher-level thought processes like being able to construct knowledge.”

Speaking on assessment, TA_N noted previously these objectives are iteratively addressed in the course as students repeatedly revisit the courses objectives multiple times during the training phase and the objectives are assessed in their final project. Finally, one GTA expressed that this project-as-assessment highlighted a growth mindset since student projects had a spectrum of sophistication based on the individual students’ ability level and the GTA was able to gauge a student’s ability and guide their projects accordingly.

What Benefits and Challenges Do GTAs Perceive for Themselves?

Benefits

Improved Teaching Ability

All GTAs believed that teaching this course helped improve their teaching ability, which is not uncommon among first-time teaching assistants, however even the most experienced GTAs of our sample echoed these sentiments. All GTAs expressed an improvement in communication skills talking in front of an audience. Additionally, two GTAs elaborate that talking in front of a general audience is important to their long-term career goals.

TA_W shares a similar sentiment with three other GTAs regarding her self-efficacy: “my number one challenge was probably just not feeling adequate enough to teach them…” However, each of these GTAs ended the semester feeling confident in their teaching ability because of the class. As TA_W continues: “It was in the CURE portion that I felt like I was really able to connect… feel like I was almost like, providing them my expertise a little bit more.”

Lastly, two GTAs, one first-time GTA and one long-time GTA expressed the course as helpful in developing their teaching philosophy, particularly about emphasizing the growth of a student’s abilities, and generating a student-centered classroom environment. TA_E describes this formative experience: “I think like, trying to figure out what my own teaching philosophies are and if they mesh with the curriculum, I’m trying to teach… and like, figuring out how can I teach this make it my own but still make sure that I’m teaching this so that all the students in all the classes are kind of learning the same thing.” TA_S describes their takeaway from CUREs as making leaning objectives actionable for students:

> A CURE does make more clear the idea that you’re trying to get students to these sort of like actionable goals. … Because the semester is then working towards something that also forces you to consider the bigger picture, more of how this week’s individual lesson fits into the broader picture of the course as oppose to like, okay, well this week I want them to learn about plants. Next week I want them to learn about animal diversity.

Improved Mentoring Ability

All GTAs believed that this course also positively influenced their mentoring ability. GTAs classified mentoring as related but separate from teaching. TA_B describes teaching the CURE as: “good practice to kind of take a step back and like let them learn and just kind of like, learn how to guide them through the process without just kind of spilling the beans.”

Additionally, GTAs who had experience working with undergraduate students in their research lab found that advising a project is very different than the training they perform with their undergraduate research assistants. TA_B describes this difference: “With the CURE, you are much more focused on what the student’s goals of it are, whereas, like the mentoring I’ve done for research has primarily been, you know, undergrads who are working to help assist me either for credit or pay.”

The most reported skill GTAs took away as mentors was reassuring or comforting students during periods when students doubted their ability or were frustrated with the research process. TA_A describes this skill and their belief that this is different than the teaching they had done in the first half of the semester:

> I… helped kind of reassure them as well and I think it was help [to] get over the bump because there are those students that are like, Oh I don’t know what to do, like… yes, you do. They’re like, oh yeah. So it kind of helped me set boundaries and helped me near the end. I wasn’t so much teaching, but just kind of going around helping reaffirming, reassuring the stuff that they had already learned.

The second most reported skill was having to think on their feet by helping to solve student problems on the spot in regard to their research project. TA_N describes the journey after completing three semesters of CURE instruction:

> The first semester was a little rough. I felt like I wasn’t doing great, as you know, someone in the mentor’s shoes. But then once I got through that second semester and the other semester… After that it became a little better and was able to come and not panic and try to, you know, think about the students questions in a more calm manner, and how I would tackle things, especially with the proposal component where you have to be, you

> know, thinking on your feet. That got a little easier with each passing semester. So in that way, as a mentor, I guess I’m a little better now.

Improved Research Ability

GTAs were more split on the influence of teaching a CURE on their research abilities with four purporting a positive influence and three purporting no influence. Despite this, GTAs were able to identify many benefits from a research lens. As mentioned previously, all GTAs stated an improvement in communication and public speaking with an additional two GTAs extending this benefit to written communication as well.

Four GTAs believed that CUREs helped reinforce their research fundamentals including technology literacy, statistics, scientific argumentation, experimental design, and organizational and scheduling skills. In general, GTAs found the course to be a sort of refresher course and the requirement to find multiple ways to explain these concepts to students solidified their understanding of science. However, TA_A shares a caveat that these skills are less applicable to graduate students since the course was aimed at nonmajor students: “I feel like there wasn’t a ton translatable [skills], but it’s to be expected with this being a 100 level versus a [majors] Biology class.”

TA_W shares a unique insight where having her students complete their own research project provided her with greater motivation for her own work, “It was almost like, a little bit inspiring. So, it kind of lit a fire under me a little bit in a way seeing students do their own research kind of like made me almost excited to do mine in a way.”

Valuable Experience

In general, all GTAs expressed teaching BIOL 100L as helpful in advancing their short-term and long-term goals. Most GTAs found that instructing this course to be good career experience moving forward and believed that the skills learned instructing the course were transferable to their future careers. Additionally, three GTAs believed that teaching was helpful in clarifying their future career goal as TA_N describes: “If I’m planning to go the academic route, this was definitely one thing that gave me a small taste of what that might be like, so I think that’s how it helps with [long-term goals].”

Challenges

Misaligned GTA Course Expectations

One prevalent implicit theme among several GTAs is a misalignment between course objectives that the expectations of the GTA. This was expressed most in the course when GTAs discussed methods of improving the course. While GTAs felt that some students were interested with the computer-based CURE, they felt as though the course was not meeting expectations of the students. When asked how this can be improved, GTAs often suggested including wet lab work or field work into the course design so that students can experience more sides of science. TA_J describes a preference for a variety of experiences even though they recognize the objectives of the course:

> Really another reason I liked [biology majors introductory lab course] is that it was more wet [lab] work, you’re working with organisms, you’re working with chemicals, you’re working with equipment. Versus [this class] where it’s not as hands-on with that kind of stuff and more hands-on with like, the scientific method rather than different areas of science. …But I feel like one of the main things when it comes to any kind of lab work is that you’re going to be getting some wet work done so I think it would be fun to include something in there wet work related. I think that would be difficult to keep it as broad as it was.

Inexperience with Mentoring and Teaching

Several GTAs in our pool had very little experience teaching, several of which had this CURE as their first introduction to undergraduate teaching. Generally, GTAs found that they struggled to answer student questions in a more guided manner as opposed to simply supplying answers to students. Further, GTAs also struggled with finding new ways to explain the same concept to students that were repeatedly struggling with a concept. TA_E describes this challenge: “Another challenge would be just finding new ways to explain something especially when it makes sense to you…. I don’t know how to keep finding new ways to explain.”

As for mentoring, a few GTAs expressed difficulty in gauging project difficulty. Their unfamiliarity with the scope of the projects students could reasonably complete in the allotted time of the course led to the GTAs feeling unsure if student projects were appropriate. TA_B reports, “Knowing now that I’ve done the lab once, I now have an idea of what stuff is just too much” indicating an initial struggle in assessing student project difficulty.

CUREs are Challenging and Overwhelming

Two GTAs described CUREs as challenging and one qualified this by feeling overwhelmed directly, though many more repeated this sentiment referring to the start of the CURE project. The first week of the CURE project tasked students, within a single class meeting, to generate a testable hypothesis, a methodology to test this hypothesis, and identify three articles that would help them either interpret their results or provide broader context to their scientific principle being explored. Students had initial difficulties identifying a question and then follow-up difficulty when it came time to generating an appropriate methodology to test their hypothesis. This resulted in GTAs constantly moving from student to student evaluating their projects to ensure the work they were doing made sense as a scientific investigation. This constant bouncing around the room was the most challenging component for GTAs whereas the latter parts of the CURE where students were then conducting their proposed methodologies as smooth sailing since students were independently working.

Difficulty with Blended Design

Due to the COVID-19 pandemic and the trepidatious nature of student attendance following positive testing for COVID-19 as well as the interest in designing the course to be flexible for students, the course was run with a blended design. This meant that students may choose to complete the labs asynchronously at home and turn in their work for GTA feedback and grading. This extended to both the training portion of the course and the CURE portion. GTAs articulated that working with students via email correspondence is much more time consuming than working with students face-to-face. GTAs also felt that students working asynchronously did so to their detriment as they perceived students that worked at home had a lower quality of work as opposed to those that attended class in person.

What Outcomes and Obstacles Do GTAs Perceive for Students?

Outcomes

Improved Scientific Literacy

GTAs felt that students left BIOL 100L with a greater understanding of science because they were able to experience a more authentic view of science as compared to other introductory laboratory courses the GTAs had experienced. The direct scientific literacy skills highlighted by GTAs were an improved understanding of statistical inference and improved scientific argumentation. TA_W, when asked what the benefits of a CURE are for nonmajors, explains a trend they found in student reflections regarding trust and science understanding:

> I would say getting a better understanding of science. I know a lot of the students come into it just kind of reflecting on some of their responses to like reflections they were like very not trusting of science. Potentially their family wasn't. So maybe, like taking what they learned in this class, and I think that's strengthened through this class is kind of like understanding it better, because I think a lot of like our distrust comes from not being educated on it or the unknown. So I think that taking this course and kind of going through each section at a time. So you know, like… exactly how to identify like reliable sources is probably a really big one for them that they can take home but I think it like just kind of made it like a little bit personal for them, especially with the CURE portion.

This type of understanding of science is also distinctly different than what GTAs expect for general science education from their own experiences. TA_S explains that traditional nonmajor science education is a misrepresentation of science and that CUREs remedy that gap in science understanding, "I think [CUREs] will hopefully make students more scientifically literate… in their daily lives…how well does the evidence that the person is presenting actually support the claim that they're making rather than just does this line up with the body of facts that I was taught when I was a teenager."

Improved Attitudes towards Science

Equally so, GTAs felt that students left BIOL 100L with an improved attitude towards science. Unlike scientific literacy, several GTAs noted that students began the semester initially hesitant or anxious about taking a science course. However, by the end of the semester, students had developed greater confidence in their ability to do and understand science. Additionally, student curiosity of the natural world also increased as two GTAs describe.

Improved 21st Century Skills

Lastly, several GTAs remark on transferable skills that students developed over the duration of the course. Most described was collaboration wherein students were able to use their peers as a resource, which is of particular interest as students typically worked independently on their final projects. GTAs also described students as engaging in self-teaching practices during the CURE portion of the course where students would re-learn the relevant skills from the training portion as they became important during their project. Similarly, GTAs also described students as having to engage in problem-solving as issues arose during their independent projects that required them to either seek help from their GTA, peers, or modify their own project so that they can continue working.

Obstacles

Initial Course Content Difficulty

As with any course, GTAs articulated several challenges students encountered with the course content during the training portion as well as initial issues starting the independent project. The most common of these stemmed from technology issues. GTAs often discussed issues students encountered with downloading datasets, cleaning and preparing data sets, and conducting analyses and visualizing data.

Engagement, Motivation, and Accountability

Overall, engagement in the course experienced one of two trajectories according to GTA observation. All GTAs believe that engagement in the course was mixed throughout the training phase of the course, describing students engaged with the subject of the course, students engaged with completing the work, and students disengaged with either, all in equal measure. After the start of the independent project, some GTAs felt as though engagement polarized with the disengaged students falling further behind as they no longer had the structure underneath them during the course meeting time whereas the engaged students were working diligently with varying levels of independence based on their earlier engagement with the course. Other GTAs however felt that engagement, overall, increased during the start of the CURE project.

When asked specifically about the driving factors of this engagement, GTAs identified several external and internal motivating factors. Least offered, with three GTAs each, were external factors, stating that student motivation was driven by the desire to finish their work so they may leave early or a desire for a better grade. This can be seen from TA_A's reflection on student engagement, "They know when they get done, they're allowed to leave, so it is nice when doing your work is like its own reward."

Four GTAs believed that motivation for students came from a general interest in either the work they were doing or the content they were working with, somewhat contrasting the statements of other GTAs that the course setting was uninteresting to students. Lastly, five GTAs believed that the greatest motivating factor during the CURE was the ownership students had over their projects to investigate a hypothesis of their own design as TA_W believes, "It was like their own that that maybe like kind of made them a little bit more excited."

Lastly, GTAs felt there was a lack of accountability among the disengaged students. This is described in various ways by GTAs such as students giving up, students not doing thorough work, and most commonly: students not reading lab handouts and expecting GTAs to give them more direction. All of these were captured as TA_B describes:

> And then reading instructions, that's another [challenge]… it seemed weird people just never wanted to read the instructions on their own, and I don't know how you solve that problem, but maybe stricter deadlines. Towards the end of class, I felt kind of bad, but I was like, I feel like we need a little bit more strict deadlines, just because some people,

> you know, they skipped a lot of stuff or they missed a couple [labs]. They basically just kinda gave up and they just, you know, they wouldn't come to class for the whole semester because they're like "well, I already missed 2 labs, it's gonna be too hard to catch up." And I, you know, like all wasn't lost. They could have come back and finished up a lot of them. Just didn't want to put in the effort, and understandably. It's a daunting task to do all at once.

TA_S brings this full circle connecting motivation, engagement, and student learning in their reflection:

> It definitely was a mixed group… there were some students and some groups that were very motivated others that were not, and those ones that were not were also, of course… not be handing in work that was as complete or where they were sort of more likely to be missing some of the fundamental concepts.

Course Setting

BIOL 100L was held in both a biology instructional lab room as well as a computer lab, splitting time between both spaces. According to a few GTAs, students could feel confused or frustrated with switching between locations. As alluded to earlier, TA_N reiterates student voices, "I think students were like, this is not even a biology lab. All I'm doing is sitting in front of a computer". While this reflected student opinions, GTAs also shared this sentiment as TA_J believes "it had the hands-on bit of downloading the data and wrangling it and analyzing it, but I feel like there's a disconnect since you're downloading data, but I think If they collected their own data, I think it would have meant more." Thus, we can identify that while some students may have been less engaged with the computer-focused CURE, GTAs may have had a role in reducing buy-in from students, shedding light on the need to focus on buy-in for GTAs as well.

Diverse Learners

Lastly, though a culmination of many challenges experienced by our GTAs, students were described in various ways as diverse. As for science attitude, GTAs described students as coming in with a well-developed excitement for the subject contrasted with others' fear or apathy. TA_N emphasizes this effect of efficacy on student performance suggesting "the biggest challenge was the students that had a complete mind block… They were already in that thing of I'm bad at this, I cannot do it." While GTAs recognized that part of mentoring is reassuring students that making mistakes is part of the research and learning process, GTAs still struggled to communicate these values to students.

Students were also found to have come in with differing levels of skillsets that made it challenging for them to complete coursework on their own as well as for GTAs to assist them. As TA_E describes their experience with students, "Some students came in with different terms of… with basic things like reading comprehension or even the ability to understand how their computer works and you have other students that are very advanced." These differences found GTAs challenged in spending too much time going over concepts some students were well prepared for whereas others required more constant attention.

How Do GTA Challenges Moderate Course Effectiveness?

Based on the themes identified in course design, GTA experience, and perceived student experience, we propose an implicit moderating effect of GTAs on overall course effectiveness, as described as the direct effects of the course design on student outcomes. First, GTAs described the course as student-centered. At the same time, GTAs described it as challenging to individualize instruction for struggling students. Additionally, GTAs also often began with low teaching self-efficacy that likely stems from a lack of experience as well as feeling that there is a lack of adequate GTA training. Given the plethora of articles describing GTAs as undertrained, the concept that inadequate GTA training undermines the effectiveness of exemplary course design should not be ignored.

Second, GTAs qualified this student-centered approach as focusing on autonomy during the CURE project phase of the class. This is then countered by GTA difficulty in motivating students, inexperience with mentoring, as well as inexperience with identifying project difficulty for students. Therefore, while GTAs easily recognize autonomy and independence as a goal and as a valuable component of the course, they may feel that they are inadequate at mentoring students on independent projects. This is a sentiment that is repeated by one expert GTA that had taught multiple iterations of the course expressing that being able to mentor students evolved after several iterations of the course. As another GTA believes, these challenges are unavoidable for GTAs and experience on the job may be the only proper training.

Lastly, the mismatch between GTA expectations of the course against the course philosophy likely has profound effects on how those GTAs instruct the course as well as how they view student behaviors. This is most evidenced when GTAs believe the course should include a survey of experiences for students (wet lab, field work, computer work, etc.). Such a belief harkens to traditional laboratory experiences that prefer breadth over depth. By focusing on fewer topics, students can be more easily prepped for independent work by building confidence in a few targeted skills rather than more novice experience in a variety of topics. For one novice GTA, they felt that one goal of this nonmajor course was to recruit students to becoming biology students. Under this lens, a GTA may view unenthusiastic students as a failure of the course or their own teaching. Though not expressed in our GTA pool, if a GTA felt that all student-designed projects should be of an identical caliber, they may miss out on the growth aspect of the course design by limiting students from enacting their autonomy and showcasing their interests and abilities.

Discussion

These reflections show the student-centered design of the course was communicated and enacted by GTAs. While GTAs were able to list numerous skills that students learned by the end of the course, they almost always referred directly to the CURE process as opposed to the infographic, the product of the course. Whereas product-focused teaching may provide students with variety and choice of assessment to reflect student understanding, process-focused teaching emphasizes how students make sense of the content being taught. Additionally, the personalization of learning described by GTAs shows that our instructors are identifying gaps in student understanding and finding bridges to get students from their current understanding to one aligned with learning objectives, recognizing constructivism's reliance on student current schema to accommodate new information.

GTAs discussed using a variety of support based on students' needs and used the independent project as more of a growth-based product as opposed to expecting all students to reach identical outcomes. In doing so, GTAs are implicitly describing a flexible teaching approach that is focused on the learning process to help support student competent, belonging in the classroom, and provide students the time and feedback necessary for knowledge to be constructed. This personalization of approaches for students shows a direct effect of instructors on student outcomes (Figure 1, arrow c). This effect is a course nonspecific value that requires specific training of teaching assistants to modify student instruction based on need. This focus is more apparent in courses such as CUREs that require a large amount of student independence but generally fits the notion that no educational approach is 'one size fits all.'

Beyond the actions GTAs performed in the classroom, GTAs also felt that the objectives and structure of the course was valuable to student learning. GTAs felt that course objectives were richer than they expected for a nonmajors, introductory laboratory course. They also felt the course was designed with iterative assessments to emphasize the construction of knowledge through repeated experiences as well as provide numerous opportunities for reflective feedback. Lastly, they felt that the independent project was an opportunity to modify assessments on a student-to-student basis to foster a growth mindset for students. At first, this observation supports the direct effect that course design has on student outcomes (Figure 1, arrow d). However, this also shows that course design can have a direct effect on graduate teaching assistants' mindset about teaching (Figure 1, arrow a), suggesting that motivating course design is not just important for students, but their teachers in training as well.

CUREs have been described as a gateway for graduate students to step into teaching, research, and mentoring roles (Goodwin, Cary, and Shortlidge, 2021). These experiences then help improve teaching and mentoring efficacy, reinforce research skills, and refine academic and career goals for GTAs (Light et al. 2019, Moy et al. 2019). Based on our GTA interviews, our findings concur with these past studies. GTAs also described numerous elements of constructivism, IDT, and SDT. However, the connection between these elements may be hindered by a lack of GTA training in both teaching strategies and CURE-specific pedagogy. Without more direct instruction in pedagogy, GTAs may not be aware of the evidence-based practices nor their importance or proper implementation (Figure 1, arrow b).

Based on their views about the course design, GTAs likely developed some pedagogical content knowledge by engaging with CUREs. This is somewhat evidence in the two GTAs that identified changes in their teaching philosophy. While GTAs did not have the terminology to describe the process of knowledge construction as explained by constructivism, they did describe best practices when describing the course and their actions within it. Previously mentioned, GTAs stressed the student-centered design of the course and iterative course structure meant to reinforce student learning. When discussing gains, particularly as mentors, they focus on the motivating aspects as well as the importance of guiding students to an answer as opposed to telling students their answer. From this, we identify that from a teaching perspective, GTAs rely on course design (Figure 1, arrow d) whereas when discussing mentoring, GTAs rely on themselves as suppliers of support for students (Figure 1, arrow c).

Our findings resonate with previous findings that GTAs are underprepared to mentor students in CUREs (Heim and Holt, 2019). Particularly, the mentorship GTAs have practiced has been more in a training capacity as opposed to the encouraging, motivating, and supervisory role. Nonetheless, GTAs by the nature of the independent projects in CUREs are thrust into this position with very little training and even less experience, likely diminishing both their effectiveness in the classroom and indirectly diminishing the effectiveness of the course design (Figure 1, arrows b and c). Fortunately, like Heim and Holt, while GTAs were underprepared for serving as a mentor, all GTAs felt that this was a valuable component of teaching the CURE.

GTAs believe that students left BIOL 100L with improved scientific literacy, improved attitudes towards science, and improved 21st century skills; all which GTAs felt were relevant to both their daily lives and their future careers. Regarding how students obtained this new knowledge, attitudes, and skills, GTAs reference a combination of course structure and ideas about learning that are relevant to constructivism. Several GTAs reference students' prior knowledge and attitudes. GTAs recognize that students entering the course may view science as a "collection of facts" and many students express their fears regarding being successful in science. GTAs generally believe that engaging with scientific research is an experience that will lend itself to correcting misconceptions about science and that success in the CURE may also elevate student attitudes towards science.

Missing, however, is the approaches that GTAs specifically must take recognizing the prior knowledge of the students to bridge their learning. This is compounded as GTAs describe the vast differences in skillsets of students at the start of class. While GTAs had earlier described that they had to adjust their teaching and mentoring approaches to fit the abilities of individual students, it is clear from GTAs stressing of nonmajor students as diverse learners, there is more training required to address these concerns.

Innovation Diffusion

There is also evidence here that the implementation of the CURE provided some elements of innovation diffusion theory for our GTAs. In terms of compatibility and relative advantage, GTAs found that the course objectives were valuable and appropriate for nonmajor students as opposed to survey-style laboratory courses. Additionally, GTAs discussed the reiterative practice of the course to support these general scientific literacy objectives. As expressed through GTA interviews who taught the course numerous times, the more a GTA engages with this course, the less complex they view the process of instructing a CURE. Finally, through a provided curriculum to GTAs in a nonmajor setting, this CURE provides students a form of trialability with CUREs. CURE courses can be found at all levels of undergraduate education and typically meet several times a week. This nonmajor CURE is a scaled down version of such an approach and thus allows for a less stressful environment that increases the trialability of the course. Again, these teaching appointments for graduate students are important because of their direct effects on the development of future educators.

Based on these findings, we can expect that when course design is explicitly student-centered and structured to help students construct knowledge through iterative practice and feedback, GTAs will identify these valuable experiences and enact them in the classroom. Additionally, after instructing the course, GTAs found the course to be compatible with what they expect for a nonmajors science course, the course has relative advantage over other course models, reduces the complexity of CUREs through a lower-stakes trial. Lastly, GTAs identified all three constructs that contribute to improving intrinsic motivation in the course design. Taken all together, the course design as intended was communicated well to GTAs and those practices were then manifested in the classroom.

From our GTAs experiences, we can identify several characteristics of Rogers' diffusion of innovations theory. Based on the positive influence GTAs experienced because of the CURE as well as the value they found in the course objectives, CUREs appear to be aligned with GTAs' expectations of a course for nonmajor students, but also exceeded their expectations for their own personal gains from instructing the course. Not only did GTAs with other teaching experience find this course to be compatible with their expectations, but also found the course to have relative advantage over other nonmajor biology laboratory courses or introductory science courses. Both also support the observability of CURE pedagogy, again supporting the direct effects of course design on GTA professional development (Figure 1, arrow a).

However, trialability and complexity have a more mixed interpretation from our GTAs. Trialability is the ability of a potential adopter to test an innovation. Arguably, being appointed the instructing position and being given the curriculum does not leave much room for trialability (as opposed to demonstrating the approach before graduate students are appointed teaching assistant positions). At the same time, it can be argued that not being responsible for course development increases the trialability and provides scaffolding for GTAs to develop their own CUREs.

Complexity regarding any teaching assistantship position is entangled with a graduate student’s coursework, research, and teaching. Due to this, GTAs may prefer simpler course design and expectations over more complex courses to reduce the stress teaching may have on their other obligations. Many GTAs described the proposal session of the independent project as challenging and chaotic, some even requesting to have multiple GTAs during this time. Beyond this course meeting, GTAs generally considered the rest of the independent project sessions as low stress. Typically, in CUREs, students work in groups. This can be for a variety of reasons from a desire to implement collaboration and develop collaborative skills, mirror authentic research teams and divisions of labor, or maybe due to limitations in course resources. While our students were given the choice to work independently or with a partner, many students chose to work independently, which greatly increased the number of projects that GTAs must examine. As several GTAs noted, students working independently still depended on discussing course materials with their peers. The intent of allowing students to work on their own was to increase responsibility for one’s project and reduce the inequitable grading of a team project. Additionally, it was suspected that if students work in groups, their own autonomy would be diminished in having to make concessions to their lab partner. More research is needed regarding the project ownership of students in groups versus students working independently.

Further on complexity, GTAs expressed that while teaching the CURE can be challenging on its own, GTAs that taught the CURE during the Fall 2021 and Spring 2022 semester where student absence was higher due to COVID-19 policies on attendance experienced an inclement teaching environment. While asynchronous CUREs of this nonmajor lab have been conducted at this institution, only the course designer at the time of interviewing these GTAs has taught this course. Indeed, a preprint from Plaisier et al. (2023) suggests that not only were asynchronous CUREs as effective as in-person CUREs, but also had surprising outcomes for students in terms of science identity, engagement, and motivation. Similarly, effective asynchronous course design differs greatly from in-person courses to take advantage of the benefits of asynchronous work as well as mitigate its unique challenges. This was not the case for our course where instead, the asynchronous activities were identical to in-class assignments without modification. While this approach may have benefited some students, it likely hindered more, particularly those that took the opportunity to take the course asynchronously out of a lack of interest or motivation for the course. Similarly, constructivism purports to have a social component that requires interactions with peers to assist in knowledge acquisition, which if improperly implemented, as it is in this course iteration, is lacking from the student experience and would predictably lead to lower student success. Therefore, given the novice nature of GTAs that are struggling to learn teaching, mentoring, research, as well as the tasks of graduate school, providing students the option to attend synchronously or asynchronously, while appreciated by students who need flexibility, may be too much a burden for GTAs, ultimately moderating the effectiveness of the course (Figure 1, arrow b).

GTAs also reinforce characteristics of innovation diffusion through their observation of students in the CURE. As reiterated from GTAs valuation of course design, they find observable results from the students they have instructed. Second, GTAs find the course compatible with their expectations of nonmajor laboratory course goals. Third, CUREs are preferable to complete these goals over traditional survey laboratory courses. Through this lens, we can identify GTAs observing a direct connection between course design and student outcomes (Figure 1, arrow d).

We also find some evidence that student outcomes may have a mediating effect on the direct effect of course design on GTAs (Figure 1, arrow a) as viewable outcomes my improve the adoption of course pedagogies among GTAs.

Again, complexity remains an obstacle for GTAs. Accommodating diverse learners introduces more difficulty for GTAs while instructing the CURE. However, many of these issues such as technology issues, low motivation and engagement, and trouble with initial course content are not unique to the CURE design. Instead, the issues students had in developing their initial hypotheses remains a unique issue that must be addressed in future iterations of the course. Since these semesters, students are tasked with generating new hypotheses in each training meeting to not just practice writing hypotheses but generating their own.

Self Determination Theory

Fostering student autonomy in classroom settings is understood to increase both motivation and proficiency in the subject at hand (Chalupa and ter Haseborg, 2014). Given the nature of CUREs to require students to engage in developing and conducting their own research, it is unsurprising that GTAs found BIOL 100L to support more autonomy than other courses. The independence noted by the GTAs also expresses increased student competency in science practices as well as observability that the course scaffolded this competency for students. This confers with Furtake and Kunter’s (2012) findings that student-centered learning was not sufficient in improving student learning, but instead the autonomy-supportive environment was necessary. Additionally noted, GTAs felt more in control of their classroom, enacting their own ownership of the course they were teaching. This is contrary to the sentiment shared by many graduate students thrust into teaching positions (Slack and Pownall, 2023). Therefore, while the autonomy provided to students is intentional from a design perspective and requires a deeper understanding of what level of autonomy is sufficient for promoting student motivation and learning, more investigations should be done regarding GTA ownership of the course and how to provide more autonomy to GTAs when provided a set curriculum. In accordance with our model, this represents a proposed reciprocal effect between GTA and course design (Figure 1, arrow a), suggesting there may be synergistic effects in allowing courses to be directly influenced by GTAs who teach them. Before such an approach is implemented, however, it is important to have an adequately trained graduate cohort that can make evidence-based teaching decisions as well as the opportunities within a set curriculum for these decisions to be made.

Frymier and Houser (2009) found that developing interpersonal relationships with students as described by our GTAs is important for both student motivation and learning. This can be explained through SDT in that the learning environment in which students are situated is relevant to them as they may feel more included in the learning process. The personalization of the course content and assessment also provides opportunities for competence-building required for intrinsic motivation (Figure 1, arrow d).

Regarding SDT, our findings suggest a greater sense of competence in teaching, mentoring, and research, an elevated feeling of relevance of the course to their expectations, and minorly afforded autonomy towards GTAs' teaching decisions. Above the three constructs of motivation for our GTAs, most GTAs expressed positive teaching and mentoring efficacy. This is important as one of our greater challenges for GTAs was a lack of mentoring and teaching experience and initial low self-efficacy. This suggests that while GTAs may be undertrained to handle a CURE, there is some experiential learning that occurs along the way. As one GTA described: some challenges are unavoidable. Therefore, more research should be conducted in the skills that GTAs need to be sufficient in their role as teacher and mentor that need be trained prior to instruction, the skills to be flexible and deal with the unexpected during class meetings, what skills develop particularly during instruction rather than prior to instruction, and how the CURE process scaffolds this skill-building in GTAs. However as suggested by previous findings here, training may not need to be solely prior to taking on the role as teaching assistant, but also may be coupled with instructing a course.

Autonomy was an often-reported design feature of the course and several GTAs felt that they, too, had some level of agency in their classroom. This level of GTA autonomy was seen most when GTAs were mentoring students. Here, GTAs could modify the projects students were completing not only to fit their expectations of what students could feasibly complete in the time allotted, but also the comfortability of the GTA to mentor the student in that project. In doing so, GTAs were able to modulate their experience with the course to their own personal competency level. Indeed, GTAs that had mentored for several semesters expressed even more competence in mentoring projects and allowed for more complex or difficult projects from their students. From this, we can see that while all GTAs felt that they were conducting hands-on work with their students during the independent project phase, this involvement is directly tied to a GTA's efficacy in assisting with the project and GTAs felt they had the autonomy to work within their comfort level. One future direction gleaned from this is examining this autonomy directly by observing the ways in which GTAs feel they have agency in the course and ways in which they could obtain more agency. Should GTAs be trained adequately in teaching and mentoring, providing more autonomy to a GTA should be desirable to both help match GTA efficacy to their mentoring style. In doing so, we may improve the direct effects of course design on GTA professional development as well as improving the moderating effects GTAs have on course effectiveness (Figure 1, arrows a and b respectively).

Lastly for SDT, GTAs found the course valuable for students and valuable for themselves. This shows that GTAs found the course relevant to numerous parts of their identity. First, the course taught scientific literacy skills that GTAs felt were important for nonmajor students to learn to be educated members of society. Second, the course involved the full process of science from hypothesis generation, data collection and analysis, and argumentation and communication. GTAs felt that this was both helpful as it aligned with their research identity as well as supported this identity through either reinforcing old ideas or teaching new ways to view parts of the research process, particularly in communication. Third, the course assisted with career development through either an increased desire to teach in the future, feeling that the course content was positive career experience, or feeling as though CUREs were positive resume contributions. While some complaints that the research skills were not aligned with a GTAs personal skillset, overall, GTAs found this course relevant to their interests. Besides modifying course biological content to better fit the skills of graduate students, CUREs of any content area offer relevance to GTAs. In the future, these findings should be contrasted with biology major CUREs to identify what the unique contribution the differing demographics play on graduate student opinions of the course.

On the flipside of SDT, GTAs felt that attuning the course to make it more relevant to student interest was an important modification. GTAs seemed to believe that the course would be more beneficial to include numerous different experiences, something more akin to the survey style of labs commonly associated with introductory laboratory courses, especially for nonmajor students. What GTAs fail to mention here is that the course is essentially a data-driven course that focuses heavily on working with large datasets, analyzing said datasets, and condensing data down into some conclusion. When GTAs suggest having a diversity of experiences provided to students, they miss the original intent of the course to focus more on data handling, analyzing, and interpretation. As a result, GTAs may struggle to motivate students when they value the biological content over the broad scientific literacy objectives. Under the lens of SDT, GTAs may struggle to establish the relevance component that is important for intrinsic motivation which may then reduce student learning, another such example of moderating course effectiveness.

Earlier, GTAs found the CURE relevant to their interest in instructing valuable science courses. While we cannot know from interviewing GTAs, it is reasonable to assume this relevance can be communicated to their students, resulting in greater motivation and engagement with the CURE. Additionally, GTAs describe competence-building on part of the students through engagement with the course. These concepts combined with previous discussions of student autonomy in the class would suggest that the course was successful in establishing a learning environment intended to enhance student motivation.

Nonetheless, GTAs expressed difficulties in motivating students to engage with coursework. Engagement generally increased after the start of the independent project as predicted through SDT by increasing student autonomy, yet a notable portion of students enter BIOL 100L with low interest in the subject. While increasing the number of experiences may capture more student interest, it would reduce the depth of knowledge students receive through repeated practice and the increase stress of juggling multiple concepts may increase unnecessary stress considering the goal of the course is scientific literacy as opposed to science content knowledge. Instead, surveying students for what topics feel relevant to their interests or daily lives could be conducted and build a CURE around these highly engaging topics. Regardless of the student learning gains GTAs report from the CURE, the number of students that either stopped attending or dropped the course, however small a margin, is troubling and should be investigated further. On the other hand, computer work is a necessary component of scientific research due to statistical inference or data visualization. Therefore, GTAs must also be prepared to stress the importance of these processes to students when engagement is lower with computer-based work. This highlights the complexity of student motivation in a course which can result from student initial attitudes, GTA direct effects on students, the effect course design has on students, as well as the interactions between any of these constructs.

Recommendations

Further research should be conducted into whether GTAs internalize these values as general best practices for teaching versus paradoxical accommodation, i.e. believing these methods only work for this course and not others. Similarly, further research should be conducted regarding GTAs feelings towards designing or implementing CUREs of their own in the future. However, given the varied career goals of our GTAs, this is not necessarily a relevant question to all GTAs. Based on the GTAs reflections, elements of competence-building, autonomy, and relevance to students are all apparent in course design. Further research needs to be conducted to experience how GTAs in other courses evaluate their course structure through these elements as well as how student motivation in these courses reflect these design approaches. Most importantly, GTA observations may be necessary to fully investigate how well these course design elements, despite being identified and valued by GTAs, are implemented in the classroom setting.

Engaging with CUREs with proper training, GTAs can use best practices in teaching and find motivation through on-the-job efficacy-building, agency to modulate course activities to their skillsets, and find value in the course that they teach. However, much attention must be paid to the essential training required for GTA lab instruction as well as buy-in for CUREs. It is insufficient to design a course and train GTAs to instruct it. GTAs must be explicitly aware of course philosophy so that they may be equipped to motivate students in the classroom as well as prioritize those best practices in teaching. Through this common understanding, GTAs may then be afforded more autonomy in the classroom to enact these course goals and best serve their students. If we purport that teaching appointments benefit graduate students by developing skills they may need in their future career and CUREs offer an avenue for students to practice their teaching, mentoring, and research skills, then we must identify the training required and mindset necessary to assist GTAs in this skill development as well as provide the opportunities in classrooms through CUREs to practice these skills.

From GTAs' perceptions of their students in the course, we identify a transfer of intentional course design to graduate student instruction and to student learning. Regarding constructivism, GTAs identify differing student incoming skillsets and attitudes and struggle to adequately address these diverse students. Continuing our theme of innovation diffusion, CUREs are compatible with GTA values, have advantages over other course designs, and produce observable results. However, due to the different expectations of graduate students from other commitments, complexity remains an obstacle for GTAs insofar as viewing mentoring as an added difficulty to the course as compared to traditional survey courses. Lastly, regarding SDT our GTAs identify a notable number of students with relatively low engagement and motivation within the course. This resulted, as perceived by GTAs, in lower learning gains and attitude gains and resulted in such behaviors consistent with learned helplessness and absence from class. Engagement with the course on the other hand was viewed as motivation through project ownership, consistent with numerous other CURE studies. In summary, we identify shortcomings of GTA training including difficulty working with diverse learners, issues motivating students in the classroom, and leveraging past experiences to assist in learning new information. We also identify potential shortcomings in course design by failing to address biological content that is relevant and interesting to our nonmajor population.

Conclusion

In our efforts to qualitatively evaluate GTA perceptions regarding CURE pedagogy, implementation, and student response, we found a plethora of benefits and challenges. GTAs not only recognize and assimilate pedagogical content knowledge by teaching CUREs, but also value these student-centered approaches. These moves towards more expert-like teaching, however, are hindered by the lack of foundational pedagogical knowledge of GTAs. Therefore, further GTA preparation to understand how people learn and the evidence-based practices we use because of theory and research can help GTAs navigate innovative teaching environments.

We also found that GTAs generally found the CURE to improve students' scientific literacy and science attitudes with some GTAs believing that these changes would influence students' decision-making skills regarding science-based issues. While these beliefs are promising and important for educators to believe, follow-up studies with the students of the course, particularly those entering with low scientific literacy, efficacy, and attitudes, are necessary to complete the loop from curriculum design to student learning outcomes.

We recognize that our findings are limited to only a single nonmajor CURE from three semesters at a single 4-year public university. Further research is necessary to identify if our observed trends are applicable to students in other graduate programs or other institutions to broaden the relevance of our findings.

CUREs have long been recognized as a promising and perhaps integral part of a biology majors' education. However, the purported student outcomes of CUREs, such as improved scientific literacy, heightened science attitude, and experience with real-world problem-solving are not simply goals for majors-only science education, but broad reaching from primary to post-secondary education and even beyond in adult education. These findings show that instructing a CURE, even for nonmajors, had positive influences on graduate students' teaching, mentoring, and research abilities and fostered self-efficacy in each of these domains. Additionally, these findings suggest unique ways in which CUREs for nonmajors require special attention during the design and training processes. Should CUREs be considered as a promising avenue for nonmajor science curricula, special attention must be given to preparing our GTAs for success in the classroom so that our best intentions for students diffuse through our GTAs and into exemplary teaching in the classroom.

CHAPTER 4: QUANTITATIVE STUDENT EVALUATION OF A NONMAJOR BIOLOGY CURE

Introduction

In the last decade, science education has shifted towards a focus on developing scientific literacy and pro-science attitudes for all students (NGSS Lead States, 2013; AAAS, 2011; Feinstein, Allen, and Jenkins, 2013). For science, technology, engineering, and mathematics (STEM) majors, this manifests as preparing future scientists; for nonscience majors, this manifests as developing informed citizens. However, this has historically resulted in content-focused assessment of nonmajor students instead of explicitly developing their scientific literacy skills or examining scientific attitudes. To meet these goals, specific teach strategies should be developed to engage students in science and the scientific literacy skills necessary.

Scientific literacy has a variety of definitions and related skills though all encompass the ability to apply scientific reasoning in real-world situations. The Test of Scientific Literacy Skills (TOSLS) which defined scientific literacy in two broad categories: 1) understanding methods of inquiry that lead to scientific knowledge and 2) organizing, analyzing, and interpreting quantitative data and scientific information (Gormally, Brickman, and Lutz, 2012). Significant differences in scientific literacy skills have been correlated with student aptitude and level of training (Shafer, Ferguson, and Denaro, 2019). Additionally, one study found that explicit activities centered around practicing scientific literacy skills improved students’ ability to make evidence-based decisions and understand what scientists do (Taylor, 2019). In contrast, Ding, Wei, and Mollohan (2016) found no correlation between year of study and scientific reasoning skills. This can be explained by a focus on content knowledge over skill development (Wright, 2005). However scientific literacy was shown to significantly increase after taking one to three one-semester courses (Hobson, 2008).

A second goal of STEM education for nonmajors is to develop a long-lasting interest in the sciences that would lead to more engagement in science-related activities or higher confidence in becoming a lifelong learner of science (Feinstein, Allen, & Jenkins, 2013). Attitudes towards science refer to a set of behaviors including: 1) favorable attitudes towards science and scientists, 2) acceptance of scientific inquiry, 3) enjoyment of learning science, 4) interest in science-related activities, and 5) interest in pursuing a career in science (Klopfer, 1971). As seen with scientific literacy, attitudes towards science do not improve with the number of courses taken by a student alone (Osborne, Simon, & Collins, 2003), but can improve and have sustained effects when students engage in research experiences (Shaffer et al., 2014).

The relationship between scientific literacy and pro-science attitudes is mixed. A survey of scientific literacy and science attitudes over 57 countries found that science attitude and scientific literacy are correlated (Bybee & McCrae, 2011). Yet, attitudes towards science in the United States have remained relatively high (75%) whereas the scientific literacy rate remains around 17% (Miller, 2004). Therefore, while scientific literacy rates are low while science attitudes are high, it is not enough to assume those with a positive view on science are more likely to develop science literacy skills. These scientific literacy skills must be addressed specifically in science curricula as opposed to expecting transfer of these skills to occur after taking a single science course.

One potential method to improving undergraduate scientific literacy and pro-science attitudes is through introducing authentic research opportunities in the classroom (Ballen et al., 2017). These course-based undergraduate research experiences (CUREs) are defined by five dimensions: 1) use of scientific practices, 2) discovery, 3) broader relevance, 4) iteration, and 5) collaboration (Auchincloss et al., 2014). These CURE courses can occur over several weeks to several semesters to engage students in a research project lead by either faculty or a larger CURE initiative. Some examples of CURE labs include a semester-long development of gateway entry vectors in *Chlamydomonas reinhardtii*, measuring the effects of oil spills on Gulf killifish embryos, and investigating the interaction between genetics and reproductive behaviors in *Astatotilapia burtoni* (Bakshi, Patrick, & Wischusen, 2016). The main goals for students in CUREs are to develop a perception of oneself as a scientist through doing science, thinking like a scientist, and communicating science. Nonmajor specific goals for CURE implementation have been to develop an understanding of the nature of science, critical thinking skills, and pro-science attitudes (Alkaher & Dolan, 2014; Caruso, Sandoz, & Kelsey, 2009). One barrier to developing and implementing CUREs is the difficulty of implementing novel research to novice researchers. Despite insistence that all five dimensions are necessary for CURE structure, it has been demonstrated through a backwards elimination model that novelty of results (discovery and broad relevance) may be an unnecessary component of CURE pedagogy (Ballen et al., 2018).

While CUREs are generally thought to prepare STEM students for future research, CUREs have seen a plethora of advantages outside of preparing STEM students for future careers in laboratory settings. Scientific literacy-related gains include improve concepts of scientific thinking and ability to interpret data (Brownell et al., 2015); and improved content knowledge (Olimpo, Fisher, and DeChenne-Peters, 2016); while science attitude-related gains include: better perceived lab experience (Brownell et al., 2012) and heightened interest and self-efficacy in research (Brownell and Kloser, 2015).

Despite these numerous findings, very few have examined these of CUREs effects in nonmajor students. Many of the findings regarding the benefits of engaging in CUREs align with objectives regarding scientific literacy and pro-science attitudes for nonmajor students. Therefore, our goal is to develop and evaluate a CURE implemented in the laboratory section of a large, introductory biology course for nonmajor students to answer the following questions: i) What measurable shifts occur in nonmajor students' scientific literacy after participating in a CURE, ii) What measurable shifts occur in nonmajor students' attitudes towards science after participating in a CURE, and iii) to what extent do pro-science attitudes correlate with scientific literacy skills?

Methods

Research Population

Students at North Dakota State University are required to take ten credits of science and technology courses. These courses include natural science, physical science, and technology. Of these ten credits, four credits must be taken in natural or physical science. Additionally, one of these credits must be taken as a laboratory co-requisite with a lecture course.

Non-Majors Biology Laboratory Curriculum Iterations

Non-Majors Biology Lab, BIOL 100L, is a one-credit laboratory course intended to be taken as a co-requisite with three different nonmajors lecture course: Concepts of Biology, Environmental Science, and Human Biology. Due to this, topics taught each week in the lecture component is not reinforced with a lab aligned with the same content standards. This laboratory course meets for two hours per week. The laboratory course is comprised of a wide range of nonmajor students that take this course at any point during their college career. This course serves over 500 students per year. Each laboratory section contains ≤24 students arranged into six laboratory groups and instructed by a graduate teaching assistant.

Inquiry-Based Labs

Historically, the learning goals of this inquiry-based lab were to engage students in the scientific process to answer questions and construct new knowledge (Table 9). These goals were met by three four-week units (genetics of taste, microbiome of the skin, and biodiversity) where students engaged in the scientific method developing hypotheses and experimental design, collecting data, analyzing data, and presenting results. While the inquiry-based lab featured iterations between units withs its core objectives, iteration does not occur within a unit allowing a student to experience how a project changes with more data and understanding of the subject, as is common in CURE curricula.

CURE Development

Following a backwards design paradigm, the learning goals of this newly developed CURE to be used in the nonmajors Biology lab are two-fold: 1) engage students in an iterative research experience to develop scientific literacy skills and 2) develop pro-science attitudes by engaging in scientific research. Since scientific literacy goals are not at odds with the course objectives for the initial curriculum, the course objectives remain static for all iterations of this course. No additional objectives were written to promote pro-science attitudes so that we may measure how attitudes change after engagement with a CURE. Given evidence that discovery and relevance may be insignificant dimensions; iteration, collaboration, and using scientific practices are also accounted in the design of this nonmajor CURE. Iteration is found between the skill-building and project periods of the course where students will have experience with utilizing scientific practices in a guided format before conducting work on their own.

Collaboration will occur in three forms: instructor-student feedback, peer feedback, and group work during both portions of the course.

Table 9. Comparison of the objectives and assessments in the previous inquiry-based laboratory course and the newly developed CURE course.

Objective-assessment alignment by laboratory pedagogy.		
Learning objective	Assessment (inquiry-based)	Assessment (CURE)
Design a research project using elements of good experimental design	Laboratory reports during the first week of a unit. Presentations at the end of a unit ask students to critique their experimental design.	Laboratory reports during three of the training modules that introduce data repositories. Proposals at the start of the CURE project require students to outline their entire research project. Final week of CURE project tasked students with evaluating the experimental design of their peers.
Collect and analyze data pertinent to a research project	Laboratory report during second week involves data collection. Laboratory reports during the third week involve data analysis.	Laboratory reports during three of the training modules that introduce data repositories. Two laboratory reports followed up two of the three training modules with data analysis. CURE project required students to identify and carry out the appropriate analysis for their project.
Interpret data statistically and/or qualitatively		
Construct a scientific argument using a claim-evidence-reasoning model	Presentations are framed using the claims-evidence-reasoning model.	Every lab report in the skill-building phase required a claim-evidence reasoning statement. Students must identify their claim-evidence-reasoning in the project as well as their peers during peer review.
Communicate research to a diverse audience	Presentations of experiment and results are conducted at the end of each unit.	Infographics are constructed at the end of the skill-building phase and again at the end of the CURE project.

Development of the course structure to meet our objectives began by adapting previous BIOL 100L exercises into a framework for introductory-level CUREs (Bakshi, Patrick, and Wischusen, 2016). Expanding on existing laboratory ideas in the inquiry-based lab, instead of using three smaller units, a single unit was chosen and given an iterative cycle for students to collect preliminary data first, read literature, and modify their experimental design and ask their own questions regarding the topic (Table 10). The first difference between lab structures is a focus on finding, critiquing, and implementing scientific literature (appropriate for an introductory, non-major student) into the students' projects. Additionally, more attention is given to having students examine how science is communicated. Both differences are intended to help students evaluate scientific claims they may experience in their everyday life.

Table 10. Comparison of the weekly activities in the previous inquiry-based laboratory course and the newly developed CURE course.

Week	Inquiry-Based Laboratory		CURE Laboratory	
1		Nature of Science	Skill-Building Phase	Nature of Science
2	Project 1	Experimental Design		Scientific Sources
3		Data Collection		Citizen Science Efforts
4		Data Analysis		WildCam Tutorial
5		Infographics		Statistics and Making Claims
6	Project 2	Experimental Design		GBIF Tutorial
7		Data Collection		Arctos Tutorial
8		Data Analysis		Infographics
9		Infographics	Project Phase	Experimental Design
10	Project 3	Experimental Design		Data Collection
11		Data Collection		Data Analysis
12		Data Analysis		Infographics
13		Infographics		Peer Review

Development of this CURE was modified from a single unit of the inquiry-based lab course (biodiversity). In this unit, students investigate data from a citizen science project involving the identification of animals via trail cameras in the Gorongosa National Park. These data include a variety of variables regarding the camera's location in the park, including season, time of day, habitat, and number of animals sighted. Students use sightings, season, and habitat to answer whether sightings are contingent on season and habitat type in cycle 1 (Table 10). The other variables available in the citizen science project allow students to ask other questions using the databases provided. Additionally, familiarity with working with curated databases have transferable skills to other digitized natural history collections (such as Arctos, iDigBio, or GBIF). The plethora of variables and data that can be used as an extension of this activity make this unit a good candidate for a CURE-based curriculum.

Pilot Study

A pilot study was conducted in the Summer 2021 semester at North Dakota State University in an online, asynchronous format for BIOL 100L to a class size of 38 students. The first half of the course was dedicated to a scaffolded research question, similar to a unit from the inquiry-based laboratory schedule. The second half of the class tasked students with individually developing a question they could answer with the variables available from either the Gorongosa WildCam project or Arctos (one digitized natural history collection that was included as a potential data source). Due to the asynchronous nature of the course, students wrote journals during each week of the independent project portion of the course to keep communication with the instructor to have questions answered or feedback provided.

Each of the five core components of a CURE were addressed at some level during this pilot CURE. Students experienced cycles of iteration through practicing scientific skills in the first half of the course, implementing these skills in the second half of the course, and evaluating their peers' work at the end of the course in a digital poster session. Collaboration between students was limited but instead took the form of weekly student-instructor feedback via journal reflections and office hours. The process of science was interwoven in each cycle of the course with each lab assignment in the first half of the course focusing on one or two science practice(s) and the second half asking for evidence of each of these practices based on students' research projects. Discovery, from the perspective of the student, had students ask questions that they did not know the answer to prior and developed an answer from the available data. Lastly, relevance was relegated to the sharing of research projects among other students in the class and personal relevance through the development of their own research question.

Due to the nature of data available to students through the Gorongosa WildCam project or Arctos, the student projects were mostly aimed at ecological, zoological, or animal behavioral studies utilizing camera trap data or digitized natural history collections. Some project examples include investigating instances of Bergmann's rule, Allen's rule, Foster's rule, sexual dimorphism, and seasonal animal behavior or habitat use. Each of these projects required a proposal at its start and an infographic at its end. These projects were completed from start to finish in three accelerated weeks, or six weeks in a typical fall/spring semester.

A second iteration of this accelerated course design was implemented again during the Summer 2022 semester. This course featured a streamlined course design the provided students with five modules instead of six (dropping a module on citizen science regarding the Gorongosa WildCam project). Additionally, the Gorongosa WildCam project was used as the data source for tutorials in Summer 2021, but due to most students choosing to use Arctos that year, Arctos was chosen as the data source for tutorials in Summer 2022. Despite being given the option and written and video tutorials, students still preferred to use Arctos in Summer 2022.

CURE Lab Implementation

A full-semester, non-accelerated CURE course was implemented during the Spring 2022 semester comprising thirteen sections with a total of 294 students. Like the Summer 2021 pilot, the semester was divided into two phases: skill-building and project. The summer courses only used a single data source for its skill-building phases but to give students a variety of options to choose from, three data sources (WildCam Gorongosa, GBIF, and Arctos) were introduced in the latter half of the skill-building phase. Each of these data sources provide different variables for students to investigate allowing for a large variety of potential ecology/biogeography projects for students to draft in the project phase of the course.

A second iteration of this CURE was implemented during the Fall 2022 semester comprising fourteen sections with a total of 340 students. Since the Spring 2022 iteration of the course focused solely on biogeography due to its data source, this iteration of the course offered two topics during the skill-building phase: microbiome analysis and ecology. During this model, students spent three weeks learning about the skin microbiome, plating bacteria, and learning to count colonies, identify species richness, and visually infer species identity. Students additionally spent three weeks learning about the Gorongosa WildCam project, managing and visualizing large datasets, and conducting statistical analyses. Following the skill-building phase, students then decided whether to extend the microbiome or the WildCam project into their own investigation.

Data Collection and Analysis

To evaluate the shift in students' scientific literacy skills, we used the Test of Scientific Literacy Skills (TOSLS; Gormally, Brickman, & Lutz, 2017). This instrument was initially validated with students in an introductory, general education biology course that used problem-based learning, a demographic like our study. The test uses 28 multiple-choice questions divided into nine scientific literacy skill areas, described in Table 11. All scientific literacy skills described by TOSLS are also included in our CURE design, thus all skill areas are relevant for examination. These nine skill areas collapse into a single scientific literacy score that can be used to compare pre- and post-course literacy skills. Data were collected via Blackboard on the first and last week of the semester when the lab course does not meet in person. Participation in the survey was not tied to course points and is voluntary on part of the student.

To measure shifts in science attitudes, we used the Colorado Learning Attitudes about Science Survey for biology (CLASS-Bio, Semsar *et al*. 2011). This instrument was validated with introductory biology students, both major and nonmajor, and showed a significant difference between these sets of students on initial scores. The CLASS-Bio uses 31 Likert-style questions to determine percent favorable scores in seven areas related to pro-science attitudes, described in Table 12. Like TOSLS, CLASS-Bio is also collapsible into a single science attitude score that can be used to compare pre- and post-course attitudes. This survey was also implemented in the first and last week of the semester and was not tied to course points.

Due to high survey mortality and a low number of students completing both pre- and post- surveys, data were converted into binary variables. For TOSLS data, the average correct responses per subscale, as well as test total, was calculated and given a 1 for a score over 50% and a 0 for a score equal to or less than 50% meaning that a 1 is more correct than incorrect for a given subscale or total. For CLASS-Bio data, the average Likert score per subscale was given a 1 for a value over 3 and a 0 for a score equal to or less than 3, meaning a 1 is a more positive than negative result.

Table 11. Codes, titles, and descriptions of Test of Scientific Literacy Skills

Code	Full Subscale	Description
T1	Identify a valid scientific argument	Recognize what qualifies as scientific evidence and when scientific evidence supports a hypothesis
T2	Evaluate the validity of sources	Distinguish between types of sources; identify bias, authority, and reliability
T3	Evaluate the use and misuse of scientific information	Recognize a valid and ethical scientific course of action and identify appropriate use of science by government, industry, and media that is free of bias and economic, and political pressure to make societal decisions
T4	Understand elements of research design and how they impact scientific findings/conclusions	Identify strengths and weaknesses in research design related to bias, sample size, randomization, and experimental control
T5	Create graphical representations of data	Identify the appropriate format for the graphical representation of data given particular type of data
T6	Read and interpret graphical representations of data	Interpret data presented graphically to make a conclusion about study findings
T7	Solve problems using quantitative skills, including probability and statistics	Calculate probabilities, percentages, and frequencies to draw a conclusion
T8	Understand and interpret basic statistics	Understand the need for statistics to quantify uncertainty in data
T9	Justify inferences, predictions, and conclusions based on quantitative data	Interpret data and critique experimental designs to evaluate hypotheses and recognize flaws in arguments

A binomial logistic regression was conducted on each survey's total binomial score as well as each subscale of both surveys using both semester (Fall, Spring), timing of test (pre, post) and the interaction between semester and timing as independent variables. These analyses would provide the likelihood of students performing better on a scientific literacy test or exiting class with higher scientific attitudes than students entering class as well as differentiate between these effects between treatments (Fall inquiry-based lab and Spring CURE). Survey results are visualized using percentages to show how many students in each treatment and at each time of surveying met the qualifications for meeting a literacy or attitudinal subscores.

Table 12. Codes, titles, and descriptions of the Colorado Learning Attitude about Science Survey for Biology.

Code	Full Subscale	Description
C1	Real world Connection	Characterizes biology as a subject that important to one's everyday life
C2	Enjoyment (personal interest)	Values learning and sharing biological knowledge
C3	Problem solving: reasoning	Values problem solving in biology and receive new ideas and evidence
C4	Problem solving: synthesis & application	Able to organize biological knowledge and interpret it in their own words
C5	Problem solving: strategies	Responds to problem solving with different approaches when faced with difficulty
C6	Problem solving: effort	Values finding a solution to problems through adversity
C7	Conceptual connections/memorization	Characterizes biology as an effort to understand the natural world as opposed to facts to memorize

Finally, to address the association between scientific literacy and science attitude as assessed by our two surveys, phi coefficients were calculated for each pair of subscores values. Phi coefficients are identical to Pearson correlation coefficients but used for two binary variables. These coefficients were then populated into a heatmap and assessed qualitatively for any emerging trends between measures of scientific literacy and science attitudes.

Results

Scientific Literacy

Logistic regression was used to identify the effect of course design (inquiry-based and CURE) and test timing (pre- and post-test) on scientific literacy scores and its nine subscores as determined by the Test of Scientific Literacy Skills. For the full TOSLS score, we found no significant difference between treatment nor timing of instruction (Table 13). Our model predicts that students in the inquiry-based section have a 60% chance of achieving a score of 50% or higher correct answers on the TOSLS compared to the 46% chance of CURE students. Prior to instruction, 48% (N=283) inquiry-based students scored positively whereas 54% (N=15) scored positively at the end of the semester. For the CURE semester, 52% (N=220) scored positively initially and dropped to 49% (N=152) after instruction.

Table 13. Logistic regression weights, odds ratios, and 95% confidence intervals (CI) for the Test of Scientific Literacy Skills with semester (inquiry-based as reference), timing (post as reference), and the interaction between semester and timing (S*T) as predictors.

Predictor	B	SE	z value	Sig.	OR	95% CI OR
Identify a valid scientific argument						
Semester	1.3863	0.6455	-1.725	0.085	4	1.13 –14.18
Timing	-1.1483	0.6659	-1.279	0.201	0.317	0.09 – 1.17
S*T	1.163	0.6579	1.680	0.093	3.200	0.88 – 11.62
Intercept	1.3863	0.6922	25.2	0.032	4	
Evaluate the validity of sources						
Semester	-0.7201	0.6065	1.516	0.235	0.487	0.15 – 1.60
Timing	-0.5147	0.5974	-0.862	0.389	0.598	0.19 – 1.93
S*T	0.9645	0.6360	-1.187	0.129	2.624	0.75 – 9.13
Intercept	1.0116	0.5839	1.733	0.083	2.750	
Evaluate the use and misuse of scientific information						
Semester	-1.0408	0.6662	-1.562	0.118	0.353	0.10 – 1.30
Timing	-0.6762	0.6585	-1.027	0.304	0.509	0.14 – 1.85
S*T	0.9101	0.6932	1.313	0.189	2.485	0.64 – 9.67
Intercept	1.3863	0.6455	2.148	0.032	4	
Understand elements of research design and how they impact scientific findings/conclusions						
Semester	-0.4726	0.6076	-0.778	0.437	0.623	0.19 – 2.05
Timing	-0.5465	0.5973	-0.915	0.360	0.579	0.18 – 1.87
S*T	0.6265	0.6364	0.984	0.325	1.871	0.54 – 6.51
Intercept	1.0116	0.5839	1.733	0.083	2.750	0.88 – 8.64

Table 13. Logistic regression weights, odds ratios, and 95% confidence intervals (CI) for the Test of Scientific Literacy Skills with semester (inquiry-based as reference), timing (post as reference), and the interaction between semester and timing (S*T) as predictors (continued).

Predictor	B	SE	z value	Sig.	OR	95% CI OR
Create graphical representations of data						
Semester	0.09716	0.57334	0.169	0.865	1.102	0.36 – 3.39
Timing	0.05015	0.56266	0.089	0.929	1.051	0.35 – 3.17
S*T	-0.55278	0.60791	-0.909	0.363	0.575	0.17 – 1.89
Intercept	-0.69315	0.54772	-1.266	0.206	0.5	
Read and interpret graphical representations of data						
Semester	-0.1823	0.5728	-0.318	0.750	0.833	0.27 – 2.56
Timing	0.3032	0.5648	0.537	0.591	1.354	0.45 – 4.10
S*T	0.0991	0.6077	0.163	0.870	1.104	0.34 – 3.63
Intercept	0.6932	0.5477	1.266	0.206	2	
Solve problems using quantitative skills, including probability and statistics						
Semester	-0.2389	0.5175	0.258	0.796	0.788	0.29 – 2.17
Timing	-0.3516	0.5320	-0.661	0.509	0.704	0.25 – 2.00
S*T	0.5844	0.5724	1.021	0.307	1.794	0.58 – 5.51
Intercept	0.1335	0.5175	0.258	0.796	1.143	
Understand and interpret basic statistics						
Semester	-0.1580	0.5429	-0.291	0.771	0.854	0.29 – 2.47
Timing	-0.6978	0.5344	-1.306	0.192	0.498	0.17 – 1.42
S*T	0.4688	0.5761	0.814	0.416	1.598	0.52 – 4.94
Intercept	-0.1335	0.5175	-0.258	0.796	0.875	
Justify inferences, predictions, and conclusions based on quantitative data						
Semester	-0.01564	0.61181	-0.026	0.980	0.985	0.30 – 3.27
Timing	0.04256	0.60038	0.071	0.944	1.044	0.32 – 3.38
S*T	0.26463	0.64877	0.408	0.683	1.303	0.37 – 4.65
Intercept	0.4055	0.5270	0.769	0.442	1.500	
Overall						
Semester	-0.5637	0.5516	-1.022	0.307	0.569	0.19 – 1.68
Timing	-0.4429	0.5410	-0.819	0.413	0.642	0.22 – 1.85
S*T	0.8018	0.5810	1.380	0.168	2.230	0.71 – 6.96
Intercept	0.4055	0.5270	0.769	0.442	1.500	

Like the total TOSLS score, our logistic regressions found no significant difference between semester nor timing of instruction (Table 13). Based on our data, we found that in general, students in the inquiry-based course scored higher on post-tests for all TOSLS subscores and total TOSLS score except for subscale 6, read and interpret graphical representations of data (Figure 2). The CURE semester, on the other hand, only saw improvements after instruction in two subscales, subscales 5 and 8, create graphical representations of data and understand and interpret basic statistics respectively.

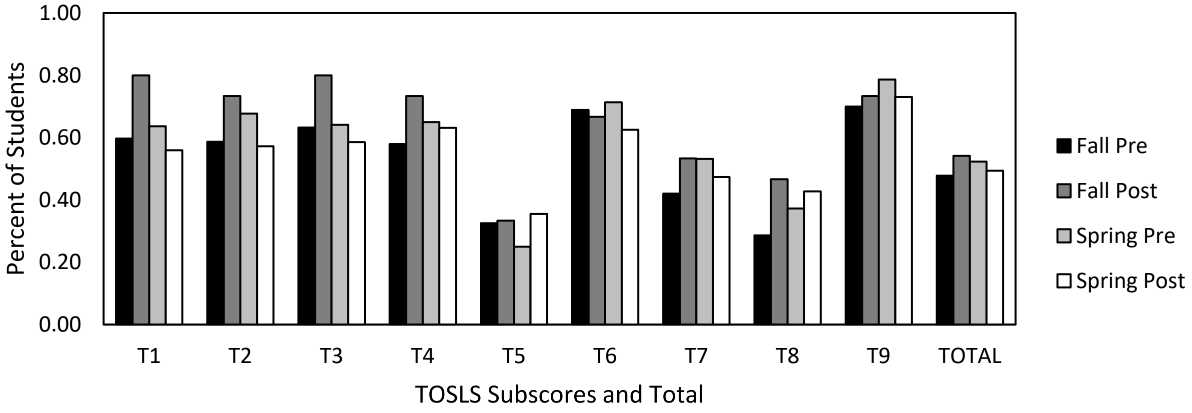


Figure 2. Comparing TOSLS subscores and total from Fall/Spring pre/post.

Science Attitude

Logistic regression was used to identify the effect of course design (inquiry-based and CURE) and test timing (pre- and post-test) on science attitude scores and its nine subscores as determined by the CLASS-Bio survey. For the full CLASS-Bio score, we found no significant difference between treatment nor timing of instruction (Table 14). Our model predicts that students in the inquiry-based section have a 75% chance of achieving a score of 50% or higher positive attitudes towards science on the CLASS-Bio compared to the 78% chance of CURE students. Prior to instruction, 63% (N=206) inquiry-based students scored positively whereas

75% (N=12) scored positively at the end of the semester. For the CURE semester, 68% (N=163) scored positively initially and rose to 78% (N=102) after instruction.

Table 14. Logistic regression weights, odds ratios, and 95% confidence intervals (CI) for the CLASS-Bio survey with semester (inquiry-based as reference), timing (post as reference), and the interaction between semester and timing (S*T) as predictors.

Predictor	B	SE	Wald	Sig.	OR	95% CI OR
Real World Connection						
Semester	0.25131	0.71022	0.354	0.723	1.286	0.32 – 5.17
Timing	-0.32424	0.68332	-0.475	0.635	0.723	0.19 – 2.76
S*T	-0.09215	0.74644	-0.123	0.902	0.912	0.21 – 3.94
Intercept	1.09861	0.66667	1.648	0.099	3	
Enjoyment (Personal Interest)						
Semester	0.1018	0.6197	0.164	0.870	1.107	0.33 – 3.73
Timing	-0.8525	0.6030	-1.414	0.157	0.426	0.13 – 1.39
S*T	0.4265	0.6552	0.651	0.515	1.532	0.42 – 5.53
Intercept	0.3365	0.5855	0.575	0.566	1.4	
Problem-Solving: Reasoning						
Semester	-0.2973	0.6181	-0.481	0.631	0.743	0.22 – 2.49
Timing	-1.2974	0.6059	-2.141	0.032	0.273	0.08 – 0.90
S*T	0.3246	0.6608	0.491	0.623	1.384	0.38 – 5.05
Intercept	0.3365	0.5855	0.575	0.566	1.4	
Problem-Solving: Synthesis & Application						
Semester	0.63539	0.62617	1.015	0.310	1.888	0.55 – 6.44
Timing	0.07709	0.60259	0.128	0.898	1.080	0.33 – 3.52
S*T	-0.76485	0.66135	-1.156	0.247	0.465	0.13 – 1.70
Intercept	0.33647	0.52554	0.575	0.566	1.4	
Problem-Solving: Strategies						
Semester	-0.9235	1.746	-0.859	0.390	0.397	0.01 – 12.17
Timing	-1.5552	1.0550	-1.474	0.140	0.211	0.03 – 1.67
S*T	1.2375	1.1007	1.124	0.261	3.447	0.40 – 29.81
Intercept	2.3979	1.0440	2.297	0.022	11	
Problem-Solving: Effort						
Semester	-0.1823	0.5728	-0.318	0.750	0.833	0.27 – 2.56
Timing	0.3032	0.5648	0.537	0.591	1.354	0.45 – 4.10
S*T	0.0991	0.6077	0.163	0.870	1.104	0.34 – 3.64
Intercept	0.6932	0.5477	1.266	0.206	2	

Table 14. Logistic regression weights, odds ratios, and 95% confidence intervals (CI) for the CLASS-Bio survey with semester (inquiry-based as reference), timing (post as reference), and the interaction between semester and timing (S*T) as predictors (continued).

Predictor	B	SE	Wald	Sig.	OR	95% CI OR
Conceptual Connections/Memorization						
Semester	0.7397	0.7261	1.019	0.308	2.095	0.50 – 8.70
Timing	0.4204	0.6909	0.608	0.543	1.522	0.39 – 5.90
S*T	-0.8098	0.7746	-1.045	0.296	0.445	0.10 – 2.03
Intercept	1.0986	0.6667	1.648	0.099	3	
Overall						
Semester	0.19237	0.70880	1.648	0.099	1.212	0.30 – 4.86
Timing	-0.56181	0.68212	-0.824	0.410	0.570	0.15 – 2.17
S*T	0.02911	0.74262	0.039	0.969	1.030	0.24 – 4.41
Intercept	1.09861	0.6667	1.648	0.099	3	

While most subscales returned nonsignificant results, we found that students on average had a higher probability of returning favorable attitudes regarding problem-solving/reasoning after completing our science courses (Table 14). Our model predicted a 31% and 22% increase in probability for this subscale after instruction for the inquiry-based and CURE respectively. Based on our data, we found students in both treatments returned more favorable attitudes after instruction (Figure 3). For the inquiry-based course, all but subscale 4 (problem solving: synthesis & application) and subscale 7 (conceptual connections/memorization) experienced this increase whereas all subscales and total attitude improved in the CURE.

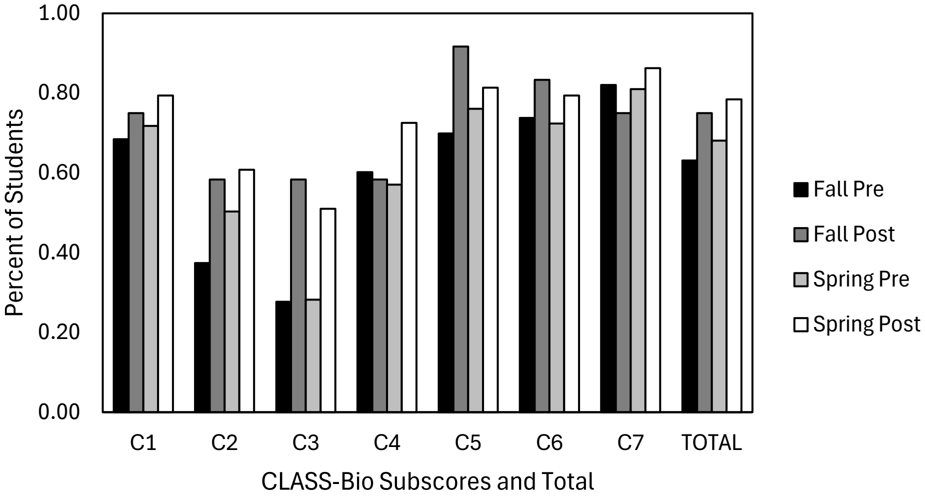
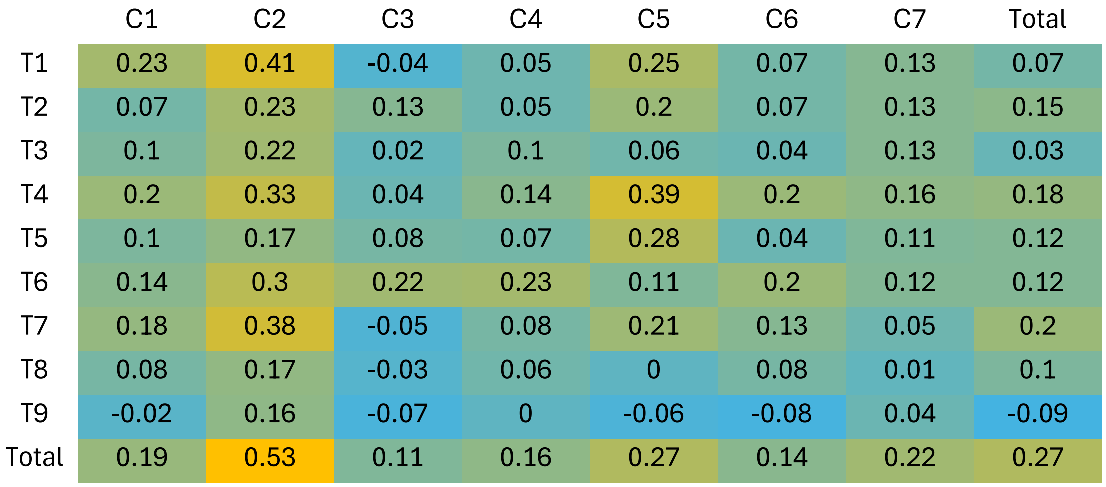


Figure 3. Comparing CLASS-Bio subscores and total from Fall/Spring pre/post.

Correlation of Literacy and Attitude

Post-TOSLS and CLASS-Bio scores for the CURE were analyzed using phi coefficients and populated into a heatmap (Figure 4). Phi coefficients (φ) are similar to, and interpreted like Pearson correlation coefficients and measure the association of binary variables. Post-test scores for the inquiry-based course were not analyzed due to a low number of responses (N=12) as opposed to the CURE dataset (N=102). Overall, we found a weak, positive correlation between CLASS-Bio and TOSLS scores (φ=0.27).

The main finding from our correlation matrix are three moderate positive relationships and two strong positive relationships stemming from subscale 2 (enjoyment/personal interest) of CLASS-Bio. Of the moderate correlations (φ of 0.30-0.39), personal interest in science positively correlates with TOSLS subscores 4 (understand elements of research design and how they impact scientific findings/conclusions, φ=0.33), 6 (read and interpret graphical representations of data, φ=0.30), and 7 (Solve problems using quantitative skills, including probability and statistics, φ=0.38). Strong positive correlations with enjoyment were subscales 1 (identify a valid scientific argument, φ=0.41) and the total scientific literacy score (φ=0.53), our largest association of the matrix.



	C1	C2	C3	C4	C5	C6	C7	Total
T1	0.23	0.41	-0.04	0.05	0.25	0.07	0.13	0.07
T2	0.07	0.23	0.13	0.05	0.2	0.07	0.13	0.15
T3	0.1	0.22	0.02	0.1	0.06	0.04	0.13	0.03
T4	0.2	0.33	0.04	0.14	0.39	0.2	0.16	0.18
T5	0.1	0.17	0.08	0.07	0.28	0.04	0.11	0.12
T6	0.14	0.3	0.22	0.23	0.11	0.2	0.12	0.12
T7	0.18	0.38	-0.05	0.08	0.21	0.13	0.05	0.2
T8	0.08	0.17	-0.03	0.06	0	0.08	0.01	0.1
T9	-0.02	0.16	-0.07	0	-0.06	-0.08	0.04	-0.09
Total	0.19	0.53	0.11	0.16	0.27	0.14	0.22	0.27

Figure 4. Heatmap of phi coefficients for Spring 2022 post-test results for TOSLS (rows) and CLASS-Bio (columns) subscores and totals.

We also found a moderate positive correlation (φ=0.39) between CLASS-Bio subscale 5 (problem-solving: strategies) and TOSLS subscale 4 (research design). Combined with four other weak positive correlations (φ of 0.20-0.29), problem-solving: strategies only resulted with a weak positive correlation with the overall TOSLS score (φ=0.27).

Interestingly, CLASS-Bio subscales 1, 3, 4, 6, and 7 resulted in a negligible correlation (φ of -0.2 to 0.2) for nearly all TOSLS subscales, showing a lack of correlation between much of the subscales of the two surveys. Additionally, only one TOSLS subscale (7, solve problems using quantitative skills, including probability and statistics) correlated weakly with the CLASS-Bio total (φ=0.20).

Discussion

Effects on Scientific Literacy

In this study, we found no significant difference of a CURE versus an inquiry-based approach for introductory nonmajor biology students regarding students' scientific literacy nor science attitudes. On average, the probability of answering more questions correctly on the Test of Scientific Literacy Skills did not significantly differ after taking either course treatment. This lack of gains in scientific literacy after general science education is consistent with many such studies (Impey *et al.*, 2011, Nuhfer *et al.*, 2016, Segarra *et al.*, 2018, and Propsom, Tobin, and Roberts, 2023).

One possible explanation for these results is the time constraint imposed on a one-credit CURE. Many CURE courses are offered as three- or four-credit courses whereas BIOL 100L, like many non-major science lab courses, is only offered as a one-credit course. Therefore, the reduced credit hours place a constraint on what would be expected in a typical majors' CURE course such as less contact time between students and their peers or instructor, less time spent practicing material, and lower out-of-class commitment expectations for students. More instructional time may be necessary to see gains in scientific literacy.

Another confounding variable in our study is the difference in graduate teaching assistants (GTAs). Fidelity of implementation for active learning strategies are tied to their effectiveness. Undertrained GTAs may be ill suited to help facilitate knowledge and skill acquisition. Due to the low sample size of the inquiry-based post-tests, instructor was not included as a predictor for this study. Therefore, a larger study that includes GTA as a covariate may reveal some differences we see in student learning outcomes.

Lastly, these results do not necessarily reflect our students' holistic learning outcomes regarding scientific literacy. Based on the numerous studies that also find no significant difference in TOSLS scores after instruction, there is likely a mismatch between the skills TOSLS tests and those implemented in the course or subscale items are not comprised of enough test items to adequately assess the subscale in question. For example, TOSLS subscale 5 purports to demonstrate a student's ability to 'create graphical representations of data.' However, this subscale consists of a single item in the 28-question inventory asking students to pick the correct graph for given variables. Unsurprisingly, this was our lowest performing subscale, but it is just as reasonable to assume that if it was our highest performing subscale, one question alone is not enough to adequately assess a student's ability to visualize data.

Given the problem-solving and decision-making nature of scientific literacy, a multiple-choice-based approach may be inappropriate. While TOSLS may be easy to implement, it appears to reveal very little regarding scientific literacy on a deeper level. Additionally, the scope of TOSLS provides only a quantitative lens of science. This is important particularly for CUREs that may utilize qualitative methods, such as discipline-based education research, a topic that has been implemented in the Spring 2023 iteration of the course. Therefore, it may be more beneficial to utilize open-ended responses to questions pertaining to big ideas in scientific literacy, such as source validity and scientific argumentation, and analyze the ways in which students navigate these decision-based skills.

Effects on Science Attitude

While much of scientific attitude did not demonstrate a significant change, we did see a significant difference in the likelihood of students responding positively to items relating to reasoning skills in problem-solving. While nonsignificant, we did find that students generally had a higher likelihood of positive science attitudes after completion of our science courses. This contrasts with previous studies that found nonmajor science attitudes decreased after instruction (Slaughter, Bates, and Galloway, 2011) and particularly promising following COVID-19-driven remote learning where science attitudes fell (Wester *et al.*, 2021).

One such explanation for this may be the student-centered design of our studied laboratory courses. A study by Connell, Donovan, and Chambers (2017) found that increasing the number of student-centered pedagogies leads to even higher student learning and attitude gains. These results also concur with Olimpo, Fisher, and DeChenne-Peters' (2017) findings that engaging with CUREs improve nonmajor students' science attitudes.

Like scientific literacy, science attitudes may also be differentially influenced by each section's GTA. Typically, one often cited perk of GTAs in undergraduate education are GTAs ability to connect better with students. This may explain how an undertrained GTA may be ineffective at promoting scientific literacy but may be more effective at promoting science attitudes. How GTAs interact with students in the classroom is one avenue to understanding the differences in GTA teaching strategies and moves GTAs make in the classroom to enhance student attitudes towards science.

Correlation of Scientific Literacy and Science Attitudes

The correlation matrix between scientific literacy and science attitude provides a unique insight into the relationship between these constructs. We identified that a student's personal interest and feelings towards problem-solving strategies as moderately correlated to scientific literacy. We cannot conclude on the causality of these relationships, however if our classes do improve science attitudes, then there may be some scientific literacy changes occurring as well. Alternatively, it may suggest that student attitudes towards science may act as a moderating factor on one's ability to assimilate scientific literacy skills.

Limitations

A variety of students take the introductory, nonmajor biology laboratory course at NDSU. Since these students come from diverse fields that may or may not focus on scientific literacy concepts, controlling for this aspect in the future may explain some of the variation seen from our students' literacy and attitude scores. Based on the results from Chapter 3 that graduate students differ in education training and teaching philosophies that may help or hinder course effectiveness, introducing graduate teaching assistant into the model may also explain differences we see in post-test literacy and attitudes. As stated above, the surveys in question may be inappropriate to fully understand the nature of scientific literacy and science attitudes of our students. One potential option to study scientific literacy regarding evidence-based decision-making may be to utilize think-aloud exercises with students evaluating alleged scientific claims before and after engagement with the course. Science attitudes may benefit more from weekly journaling from students to investigate preexisting and shifting attitudes towards science.

Conclusion

The goals of including science as a general education requirement include developing scientific literacy skills and developing pro-science attitudes. This CURE class was developed to provide support that students that engage in collaborative and iterative research experience significant gains to scientific literacy, develop more pro-science attitudes through engaging in scientific research, and that literacy and attitude gains are correlative. Should these findings be corroborated in this study, this may suggest that a CURE-like semester-long research project is a probable and sufficient way to meet these objectives for our students. Future directions would be to compare the shifts in literacy compared to other nonmajor STEM labs as well as STEM major labs to compare how close nonmajor students approach literacy rates of STEM majors.

CHAPTER 5: CONCLUSIONS

Scientific literacy and positive attitudes towards science are common goals among compulsory K-12 science education, undergraduate general education, and continuing adult education. Such arguments for scientific literacy range from utilitarian purposes, such as healthier decision-making or evidence-based political action, to personal interest, such as understanding of the natural world (Committee on Science Literacy and Public Perception of Science, 2016). Positive science attitudes are thought to contribute to scientific literacy by increasing the motivation to engage with these evidence-based decisions, seek out new and developing science and technology, and adopt a continuing understanding of science (de Jong, Ketting, and van Drooge, 2019). In the wake of the COVID-19 pandemic world, these goals are more needed than ever to combat future pandemics, vaccine hesitancy, and a mistrust of science. The purpose of this dissertation was to show the process of developing and assessing a course-based undergraduate research experience (CURE) for nonmajor Biology students to directly improve both the scientific literacy and attitudes of students, but also an indirect attempt to improve graduate teaching assistants' pedagogical content knowledge.

Chapter 1 outlines the benefits and design elements for CUREs as well as a survey of CUREs researched in the literature. Confirming a previous literature review by Corwin, Graham, and Dolan (2015), CUREs generally result in gains in both science disciplinary skills and affective constructs. Typically, these student outcomes are suggested to occur due to five structural elements of CURE environments: discovery, iteration, collaboration, broad relevance, and the use of scientific practices. I found that broad relevance or relevance to an outside stakeholder was one of the least supported structures suggesting either a need to research this design element further or that it may not be necessary, as suggested by Ballen *et al.* (2018).

Instead, my review found three new constructs for further review: project ownership, autonomy, and formative frustration. Finally, this survey of CUREs in Biology classrooms identified the plethora of CURE implementations from which to model my nonmajor CURE upon. In summary, while CUREs have a breadth of student outcomes stemming from a handful of key structural course features, the implementation of CUREs are still varied in terms of audience, content, and duration suggesting a flexible model that may improve scientific literacy and attitudes for our nonmajor students.

Chapter 2 outlines the design process for developing a nonmajor CURE to highlight the effort, learning theories, and content-based pedagogy that compose evidence-based course design. Chiefly, this nonmajor CURE was designed with the goals to improve scientific literacy and pro-science attitudes and was based heavily on a combination of course objectives from the Next Generation Science Standards and Vision and Change. These initiatives both outline and emphasize the importance of science disciplinary skills in addition to science content, dispelling decades of science being taught as a survey of scientific ‘facts.’ Instead, a science process-focused approach, like CUREs, affords numerous benefits that align with both long-established and developing learning theories and philosophies.

This CURE follows a near century-old belief that learning science should be done through doing science. This process of uncovering novel information regarding the natural world through scientific investigation also mirrors constructivism: students start with an initial hypothesis based on theory, collect evidence that may support or refute their initial understanding, and must make conclusive arguments to explain the natural world with pre-existing schema. As cited in Chapter 1, CUREs also focus heavily on student autonomy in the classroom as students must personally design and enact scientific research. Autonomy and project ownership are further supported by intrinsic motivation and education research with a positive feedback loop existing between motivation and learning. Lastly, assessments during the majority of the course were formative in nature, with only the final project infographic serving as a summative assessment of student work. Instead, weekly lab reports were checked in real time by graduate teaching assistants to provide students with instantaneous feedback. During the project phase, teaching assistants also acted as mentors to students offering suggestions or probing questions to assist students make their own decisions as they navigated their way through their own research project.

However well-designed, course effectiveness is influenced by both those taking the course and those instructing the course. For a large majority of undergraduate nonmajor laboratory experiences, these courses are instructed by graduate teaching assistants (GTAs). These GTAs may demonstrate a large array of teaching and mentoring experience inside and out of the classroom with a varying amount of training. In Chapter 3, I interviewed GTAs of this CURE to understand their challenges, benefits, and perceptions of their students in the course. My results showed that GTAs have favorable opinions towards teaching CUREs to nonmajors, citing numerous personal and professional gains. Personal gains manifested as positive self-efficacy and self-identity as a teacher, mentor, and researcher as well as feelings that teaching a CURE was important for nonmajor students. GTA professional gains mirrored these results suggesting that CUREs offer opportunities to improve teaching, mentoring, and researching skills important for their future careers.

As for the course itself, GTAs reiterated and valued the student-centered design of the course. Specifically, GTAs believed that a core component of the course was helping students struggle to devise, enact, and report a scientific study of their own design. At the same time, most GTAs believed there was too little training in general. While GTAs reported difficulties that are unique to CUREs, their common complaints were ones not dissimilar to any undergraduate teaching experience. These included difficulty rephrasing questions or concepts, keeping students on task or engaged, and general low teaching efficacy.

As for our students, Chapters 3 and 4 investigate student outcomes indirectly through GTA interviews and directly through two surveys, the Test of Scientific Literacy Skills and Colorado Learning Attitudes about Science Survey for Biology. These chapters present conflicting results. From Chapter 3, GTAs felt that students generally became more engaged with the course during the independent project phase of the CURE, felt that their skills improved over the duration of the course, and finally felt that the course design itself was responsible for improving both science attitudes and science disciplinary skills.

However, Chapter 4's findings found almost no difference between scientific literacy nor attitudes save for a single attitude subscale: problem-solving/reasoning. This disconnect between the negative quantitative survey findings and the positive qualitative GTA interviews has a few potential explanations. First, given the inexperienced and undertrained feelings of GTAs, we may expect that their observations alone are not sufficient in diagnosing student learning or shifts in science attitude. Given the low failure rate of the course, however, students completed the course and successfully demonstrated the learning objectives expected of them. Therefore, an alternative explanation may suggest that the scientific literacy survey was inadequate to fully assess student learning of scientific literacy skills. As for attitude, this course does constitute nonmajor science students. While nonmajor students should not be expected to be poorer at science or have low interest in science, shifting attitudes may be particularly difficult, especially when science attitudes were generally favorable to begin.

Future research is necessary in not only assessing the effectiveness of nonmajors CUREs, but also into best methods for assessing CUREs. Whereas surveys and inventories may be easy to implement and interpret, the information gleaned from resulting data is relatively limited. Instead, I propose more directed assessments of skills and content taught in these classes be assessed qualitatively through student reflections during and at conclusion of the course. More attention should be given to students' ability to transfer evidence-based decision-making into their daily lives. Ultimately, if we were successful in improving student scientific literacy, without the internalization of the benefits of utilizing scientific findings for problem-solving or decision-making, these gains are of low relative civil importance. Further, based on GTA interviews, nonmajor science identity and self-efficacy should be investigated as well. Given the level of autonomy students may experience in these classes, investigating a student's perceived competency is important in keeping students engaged, motivated, and striving to learn.

In conclusion, this dissertation has numerous implications for improving nonmajor science education from course design to implementation as well as promotes further research into the graduate teaching assistants that often staff these teaching positions. I have demonstrated that course-based undergraduate research experiences are an authentic solution to engaging students in the process of science. While still in their infancy of iterative course design, these CUREs show promise in promoting science attitude as surveyed by students and scientific literacy as observed by their graduate teaching assistants. I have also shown that outcomes-based assessment of a pedagogical treatment is not sufficient on its own to understand the complexities of designing, implementing, and assessing educational treatments. Finally, I have demonstrated the necessity of improved educational training for graduate students so that they may obtain more benefits from the courses they teach as well as pass these benefits on to our students.

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APPENDIX: STUDENT PROJECT PROPOSAL FORM

A. Study Information

Informative title **[1 pt]**

Author(s) **[1 pt]**

Study Description **[3 pts]**

Please include 1) your overarching research question(s), 2) the purpose of the study, and 3) sufficient background to understand 1-2 (this could mean explaining Foster's Rule or any other biological concept involved in your study. Email a TA for assistance here!).

Hypotheses & Predictions **[3 pts]**

Write your hypothesis here based on your research question. Hypotheses should be concise and testable. Recall that predictions are the specific experimental results you would expect if the hypothesis were supported.

B. Experimental Design

Independent Variables **[1 pt]**

Precisely define all variables you plan to include in your study [this may be one or more].

Dependent Variables **[1 pt]**

Precisely define each variable that you will measure [typically only one for our purposes].

Data Collection Procedures **[2 pts]**

Please describe the process by which you will collect your data. For example, if you are looking at the effects of time of day on elephants in the Gorongosa National Park, you may choose to only include data from Day and Night and exclude Dawn and Dusk OR if you are looking at sex-based weight differences in wolves, you may choose to only include data from North America. Include information about where you will source your information [WildCam and/or Arctos].

Sample Size **[1 pt]**

For the WildCam data, we required at least 500 specimens. For GBIF, you should have more than 1,000 georeferenced records (top of map) for analysis. The Arctos data included at least 100 specimen per treatment (island vs mainland). Why is it necessary to have minimum number of specimen for research purposes?

C. Analysis Plan

Plan of Analysis **[2 pts]**

What statistical test and data visualization (i.e. graphs or figures) will you use to test each hypothesis? Provide enough detail so that another person could run the same analysis with the information provided. A handout has been provided on your desk to help you decide which statistical test is right for your question, but this is a difficult question! Email a TA for help if you are struggling or wish to check your statistical approach.

Data Exclusion **[2 pts]**

Why might someone need to exclude some data for their analysis? Why is it important to state this? Some examples: if investigating WildCam data, you may choose to exclude any Dry-Wet or Wet-Dry data so you can focus on the extremes of the Wet and the Dry seasons. If investigating sex-based weight differences between animals, you would want to exclude all data points where sex is not listed.

D. References [3 pts]

Find 3 articles that relate to your topic and list the title of the articles below and how they will help you gain a better understanding of your study. Hint: You may want to begin by searching your hypothesis/hypotheses. After this, you may wish to search general information regarding the specie(s) you are investigating. Finally, you may wish to find more information about the biological principal you are investigating (i.e. Foster's Rule, Bergmann's Rule, Allen's Rule, Sexual Dimorphism). Ask a TA for help with some keywords!

1.

2.

3.

REMINDER: Do not continue on to Lab 10 before receiving a grade and feedback on this Lab Report!