CASE STUDY

A student-partnered approach to design a course-based undergraduate research experience (CURE) in biological sciences

Olivia Hawco†, Erynne Sutanto†, Haider Alsafar, Eshal Dave, Aditi Bansal, Ayuni Ratnayake, *Emily Bell *and* ***Aarthi Ashok,*** *Department of Biological Sciences, University of Toronto Scarborough, Canada.*

† Authors contributed equally

Contact: aarthi.ashok@utoronto.ca and es.bell@utoronto.ca

ABSTRACT

Immersive research opportunities allow students to take ownership of their learning, explore based on curiosity, and engage in the scientific process while developing confidence and skills. However, research positions for biology undergraduates are limited, and conventional teaching labs are often restricted to pre-designed experiments without opportunities for curiosity-driven research. Course-based undergraduate research experiences (CUREs) are discovery-based research experiences that provide students with accessible avenues to explore research. Here we describe a unique student-partnered approach to the design of a foundation-level CURE in biological sciences (BIO-CURE). As student partners, we were mentored by faculty as we designed CURE projects that considered the interests and abilities of our peers to create a course structured around student-driven scientific exploration. We anticipate that this case study of our approach and experiences as the student partners of the CURE design team will serve as a helpful resource for other departments and institutions.

KEYWORDS

undergraduate research opportunities, course design, experiential learning, STEM education, students as partners, course-based undergraduate research experiences

Course-based undergraduate research experiences (CUREs) are defined as immersive pedagogical learning experiences in which students work to formulate and address a novel research question, thereby fuelling scientific discovery and permitting early exposure to research (Dolan, 2016; Walker et al., 2023). These contrast traditional undergraduate laboratory courses that often limit student-driven inquiry, as detailed procedures are often proposed with a previously established result in mind, thereby limiting student exploration and individual interests (Brownell et al., 2012; Shuster et al., 2019). The innovative approach presented by CUREs establishes a theme of research interest that prompts students to formulate appropriate research questions and experiments, which could produce novel findings. This subsequently guides students toward meaningful discussions and peer critiques of their original work (Heim & Holt, 2019).

CUREs have been shown to be highly beneficial in promoting research and technical skill development, enhancing self-regulated learning (SRL), and cultivating disciplinary interest (Harrison et al., 2011; Kortz & Van der Hoeven Kraft, 2016; Russell & Weaver, 2011; Shaffer et al., 2010). SRL is the process of actively participating in the learning process through understanding personal motivations and learning behaviours, setting and monitoring goals, and consciously implementing strategies to achieve those goals (Zimmerman, 2001). This process enhances student understanding of course content and improves academic performance (Zimmerman, 2001; Morisano et al., 2010). CUREs can facilitate SRL by challenging students to set research goals, strategize and plan experimental procedures, and become motivated through inquiry-based learning (Berton et al., 2022; Shortlidge et al., 2016; Sun et al., 2020). Students completing CUREs in science, technology, engineering, and mathematics (STEM) courses report increased confidence in laboratory settings, enhanced critical thinking and problem-solving skills, and greater learning efficacy (Heim and Holt, 2019; Shaffer et al., 2010).

Importantly, CUREs provide students with opportunities to develop a strong disciplinary identity as they engage in authentic scientific discovery (Auchincloss et al., 2014; Bangera & Brownell, 2014; Corwin et al., 2015; Mraz-Craig et al., 2018; Wong, 2015). Hence, CUREs can support student persistence in STEM degree programs, as they feel part of the scientific community (Estrada et al., 2016; Rodenbusch et al., 2016). Consequently, expanding access to research opportunities could promote diversity in STEM; currently, only 34% of the American workforce in STEM fields identify as female, of which only 11.6% identify as people of colour (Burke et al., 2022). Indeed, students from underrepresented groups involved in research reported higher scientific identity and scholarly productivity and greater intentions to pursue a STEM Ph.D. than those not exposed to research (Aikens et al., 2017). Additionally, students with no interest in pursuing STEM careers still benefit from participation in CUREs as they effectively complement academic courses, thereby increasing knowledge retention (Bangera & Brownell, 2014), enhancing student engagement in class, and promoting critical thinking (Howell, 2021).

Participating in research allows students to form close relationships with faculty and gain access to inclusive and social learning spaces (Puljak & Vari, 2014; Walkington & Ommering, 2022). This connects undergraduate students to additional career opportunities and pathways, such as recruitment into faculty research groups (Dolan, 2016; Brownell et al., 2012). Unsurprisingly, CURE experiences also aid in graduate school admissions (Arena et al., 2015) and future employment (Rodenbusch et al., 2016). CUREs provide unique mentoring opportunities for instructors and teaching assistants, especially given that CUREs can often lead to novel and unexpected research findings (Elgin et al., 2016). Additionally, faculty report that teaching CUREs is more intellectually stimulating, intriguing, and enjoyable than teaching traditional lab courses (Dolan, 2016).

Currently, student access to research opportunities within the Department of Biological Sciences at our institution is limited, offered primarily through one-on-one mentored thesis projects in the fourth year. This is similar to most biology degree program offerings in research-intensive universities across Canada (see the U15 Group of Canadian Research Universities for more information). As biology degree program students, we are enthusiastic about providing broader and more equitable access to research opportunities for our student peers. Inspired by the CUREs literature that documents the benefits to student learning, skill development, and disciplinary belonging, we worked alongside faculty members to develop a BIO-CURE course for second-year biology students at our institution. We hope that our unique student-partnered approach to the BIO-CURE course design will be of significant interest to other educators who value research experiences that promote student learning and a sense of belonging in the scientific community, foregrounded by the values of equity and access.

LOCAL CONTEXT: THE NEED FOR CUREs AT OUR INSTITUTION

While CUREs have been successfully integrated into post-secondary institutions throughout the United States, they are largely absent in Canadian institutions (Auchincloss et al., 2014). The Student Experience in the Research University (SERU) 2021 survey, conducted at the University of Toronto, Scarborough, reveals that although 60% of students have done research projects as part of their coursework, only 18% of them have enrolled in independent study courses (Office of the Vice-Provost, Students, 2021). Hence, the scope for immersive, discovery-based research experiences is small. Another student-led data collection initiative within our department suggests that only 3% of students from 2016 to 2021 were enrolled in mentored research courses (Undergraduate Research Course Report, 2022). Notably, 48% of students (n=21) regarded research at our institution as a deciding factor when applying to the campus (Undergraduate Research Course Report, unpublished data). Yet, only 18% of survey respondents could obtain research opportunities in the context of their biology degree program at our institution (Undergraduate Research Course Report, 2022). While the sample size for this survey collection was small, it makes clear the dearth of research opportunities even among students who have identified research as an important activity in the context of their undergraduate degree.

As previously mentioned, students primarily engage in research at our institution through one-on-one thesis courses; however, this approach is not ideal, as it often limits opportunities and can exclude certain students with barriers such as financial issues that prevent students from accommodating unpaid mentored research opportunities (Bangera & Brownell, 2014). In addition, grade point averages (GPAs) are often used as selection criteria, despite being inaccurate predictors of research capabilities (Cooper et al., 2019).

Hence, an examination of our local context suggests that a CURE course would improve equity and access to immersive research experiences. Importantly, this could provide a solid foundation for students with significant interest in pursuing mentored one-on-one research experiences in the future. Our team thus launched the “BIO-CURE” design initiative to create authentic research opportunities for biology program students with lower barriers to participation.

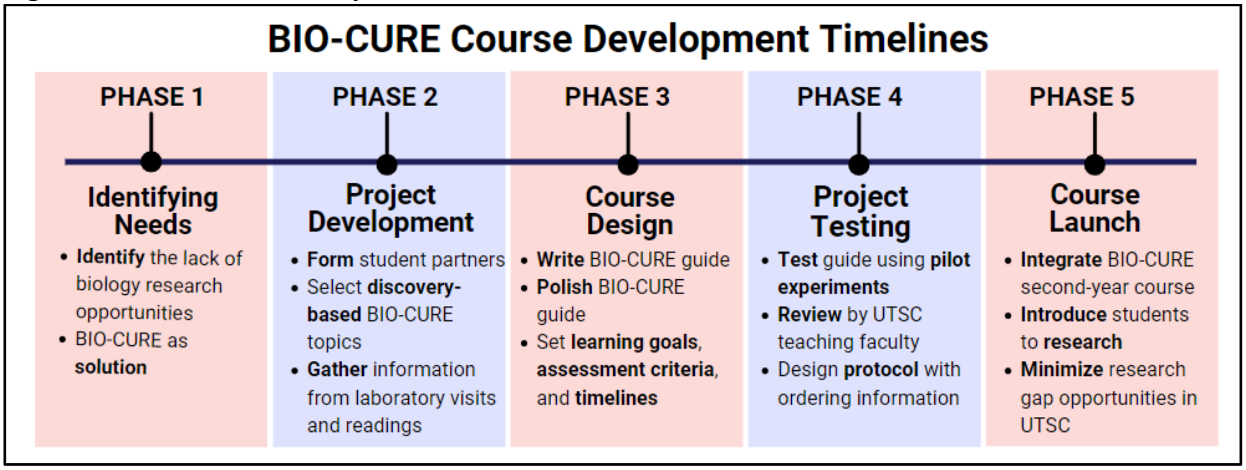
Student involvement in BIO-CURE course design

The BIO-CURE employs a unique student-partnered approach in which undergraduate students are actively involved in designing the course structure and assessments, piloting key procedures to develop CURE project themes, and providing feedback to faculty mentors on tools to support student learning and assessing the impact of the course. This partnership empowers undergraduate students to make meaningful contributions to the project (Walkington &

Ommering, 2022). Student engagement in curriculum design has been shown to elucidate new perspectives previously not considered by faculty members, such as highlighting practical considerations of course material and workloads in relation to other courses (Brooman et al., 2015). This student perspective helps refresh and transform teaching practices while allowing student partners to explore the role of educators as they develop a scholarly identity and professional competency (The Center for Teaching, Learning, and Technology [CTLT], 2021). The students-as-partners initiative in higher education documents increased student engagement and the development of subject-specific skills and provides a compelling alternative to the current consumerist model of curriculum design. This transformative concept is supported by numerous high-impact journal publications and pivotal discussions at educational conferences (Healey et al., 2016).

As student collaborators, we were involved in the conceptualization, planning, budgeting, and testing phases of this BIO-CURE project (Figure 1). Our team was composed of five undergraduate students, one research assistant (a recent alumna of our biology program), and two faculty mentors. The structure of the BIO-CURE was established using the backward design approach (Cooper et al., 2017). As student partners, we first selected a topic based on each of our interests and curiosity. The topics were intended to align with research themes explored by faculty in research labs in the Department of Biological Sciences. We then developed a stronger background understanding of our topics by conducting literature reviews, visiting campus laboratory spaces, and speaking with faculty specializing in our area of interest (Phase 2 of Figure 1). We combined information and advice from the project development phase with our own undergraduate experiences to inform the development of our BIO-CURE proposals, guides, and budgets (Phase 3 of Figure 1). Finally, we used our BIO-CURE design and guides to run pilot experiments to measure the feasibility of our framework in the context of course timelines, teaching laboratory and technical support capacities, and experimental outcomes (Phase 4 of Figure 1). Our focus as student partners was to develop the discovery themes and individuality of each BIO-CURE project. We wanted future students to feel a sense of ownership with their projects and foster intrinsic motivation by emphasizing aspects such as creativity, problem-solving, and critical thinking. As the BIO-CURE project demonstrated success at all stages of development, our faculty mentors hope to implement this course within the biological sciences department at our institution in the next academic year following a successful university governance review (Phase 5 of Figure 1). By situating the BIO-CURE as a fundamental component of the biology curriculum, we hope to support equitable access to discovery-based learning for future cohorts of students. These projects are meant to be dynamic, as they are expected to continually evolve each year with ongoing student and faculty input.

Figure 1. BIO-CURE development



Development of the BIO-CURE course by student-partners occurred in five phases: (1) identifying a need for the BIO-CURE; (2) selecting research topics, research faculty advisors, and student partners; (3) developing learning goals and assessments into a course format; (4) testing the BIO-CURE sample experiments; and (5) launching BIO-CURE as a course at our institution.

BIO-CURE: A CURE DESIGNED FOR STUDENTS, IN PARTNERSHIP WITH STUDENTS

Course outline

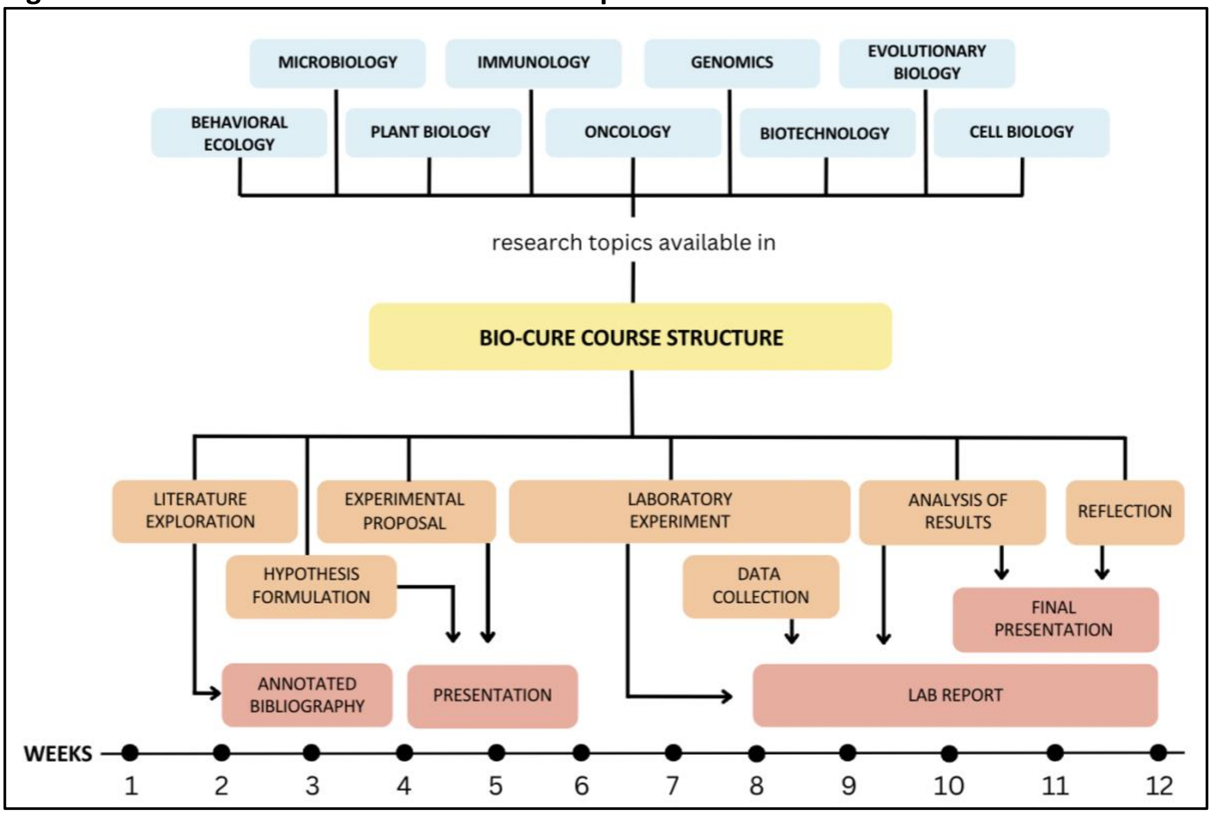
The BIO-CURE course will span a 12-week semester (Figure 2), including a weekly 1-hour lecture and a 3-hour laboratory component. Week 1 introduces students to the course and their peer groups (4–5 students) and encourages project topic selection from a variety of biology subdiscipline themes (e.g., cell biology, microbiology, plant biology, and genomics; Figure 2). The themes are research areas that were explored by us as student partners on this design project. Topic selection grants student groups a sense of autonomy and promotes student ownership of learning through curiosity. Each BIO-CURE topic is coupled with a research guide containing reference material (e.g., papers and validated experimental techniques) to aid research question formulation and experimental design. While failure is a hallmark of research, it is important to strike a balance between student satisfaction and complexity, as overwhelming setbacks can deter scientific exploration (Beatty et al., 2021). For this reason, the research guides offer adequate initial support. Following topic selection, students would begin a comprehensive literature review to build a strong foundational understanding of their chosen topic (Weeks 1–2).

Weeks 2–4 will involve peer groups crafting a research question, hypothesis, and experimental design. Students must think critically about their research area and theorize possible outcomes regarding their proposed experiment. With the guidance offered by teaching assistants (TAs) and instructors, independent and innovative protocols would be created. Week 5 sees peer groups presenting their background information and experimental designs to their classmates to receive constructive peer feedback.

During Weeks 6–7, students conduct their experiments and collect data, supervised by course TAs. Collaborative work in our BIO-CURE model brings fresh perspectives, fosters supportive academic relationships, and boosts self-esteem, all in the context of collaborative and curiosity-driven immersive research (Laal & Ghodsi, 2012).

Weeks 8–10 involve analysis of results and data interpretation, with the completion of a joint lab report (one per peer group). Original findings are presented to the class in Week 11, allowing further opportunity for peer feedback as well as the development of effective scientific presentation skills.

Figure 2. BIO-CURE course structure and components



The proposed BIO-CURE course structure will allow students to conduct discovery-based research on research topics of interest (blue) guided by assignment-based milestones with feedback. Based on a 12-week course timeline, students will begin with an exploration of relevant literature and end the course with a deep reflection on their research and experience. The progress of this discovery-based research and evaluation of the achievement of learning goals are structured as assignments, presentations, and a lab report (red). The scaffolded blocks of the research process (orange) and the course deliverables (red) are superimposed on the 12-week semester length of the BIO-CURE course.

Assessments

This BIO-CURE utilizes various assessments to ensure students grasp the course material and align with weekly goals (see Figure 2). These assessments mirror milestones in scientific investigations. To aid organization and progress tracking, students will be expected to maintain a lab journal.

In Weeks 2–4, students will create an annotated bibliography (Figure 2). Drawing from our own experiences as students and collaborators on this project, we decided that annotated bibliographies effectively capture and summarize research articles, aiding students in building background understanding. As presenting ideas to peers is vital in research, two collaborative presentations are integrated in our BIO-CURE: one in Weeks 4–6 to present background research and another in Weeks 10–12 to present final results (Figure 2). These presentations are designed to be collaborative such that students can support each other as they explain and discuss their ideas and directions (Figure 2). When designing the BIO-CURE (Figure 1, Phase 2 and 3), we presented our own progress and findings to each other. Inspired by our own student partnership experiences, we saw the benefit of embedding this same aspect into BIO-CURE. Through these presentations, students will learn how to receive input and constructive criticism from their peers and how crucial that can be for research.

Lastly, as an important aspect of BIO-CURE, students will craft experimental protocols. These will reference approved procedures in the provided research guides; however, it is the responsibility of the students to tailor these protocols to specific research questions and goals. In Weeks 4–6, students will present their proposals and justify their designs. TA feedback, which we valued in our experiences as students, will aid in guiding future students through this phase of the course. This design aspect of the course encourages student accountability for their experiments and results, mirroring authentic disciplinary research.

Student team reflections

As detailed in this manuscript, this BIO-CURE at our institution follows a unique student-partnered approach in its design, aiming to provide undergraduates with an authentic, foundational research experience. Inspired by our own experiences in traditional lab courses as undergraduate students, we devised a BIO-CURE aimed to foster curiosity, independence, and discovery.

Reflecting on our experiences as student partners, we are satisfied with our contributions to developing BIO-CURE and are excited for future students to engage with it. Unlike traditional lab courses, students will design individual protocols and produce their own results, embracing setbacks for skill improvement and celebrating unexpected data (Brownell et al., 2012). We believe students will thrive through self-directed paths, learning that fluctuations of successes and failures normally exist in scientific research.

Despite our accomplishments in designing a systematic research-based course, we faced several challenges along the way. We encountered difficulties in selecting BIO-CURE topics that were digestible and feasible (Figure 1, Phase 2). We recognized that our initial exploration of the scientific literature could be used to create guidelines to orient students in BIO-CURE with a more structured dissection of primary literature. This could address challenges reported by novice readers, such as the overwhelming impact of unfamiliar terminology, struggles with critically analyzing evidence, understanding experimental rationales, and discerning implications of results beyond passive reading (Round & Campbell, 2013; Gillen, 2006). This can be problematic as several studies report that anxiety and perceived difficulty with course material can lead to poor academic performance and decreased persistence in STEM (England et al., 2019; Pekrun et al., 2002). Thus, we also wanted to ensure that students had a basic level of understanding in relevant disciplines to lessen anxiety and build on a foundation of confidence. Moreover, we addressed this by providing research guides with reference papers, as previously mentioned (see "Course Outline" subsection).

We faced another obstacle in Phase 4 (Figure 1) upon designing our pilot experiments, where we met resource and space constraints. As we are not experienced researchers, deciding where and how to obtain the necessary materials was a large managerial task and solidified the need to develop projects in collaboration with research faculty holding relevant expertise. Scheduling was also challenging as we needed to find time around our courses for the full setup and execution of lab protocols. This reinforced the need to work as a team of student partners in both the project design and testing phases. Next, we found that some of our initial pilot experiments were too technically challenging to be feasible in BIO-CURE. In contrast, others could be scaled down to better fit time and budget constraints. These important takeaways were only possible with the engagement of student partners in test experiments. Overcoming hurdles, our proposals garnered faculty approval, providing us the green light to progress through Phase 4.

We anticipate some challenges in the implementation of BIO-CURE (Phase 5 in Figure 1), particularly in the area of TA training. TAs are an integral part of our course design, as they will guide and supervise students in formulating hypotheses, designing novel protocols, performing experiments, and interpreting results. These tasks may prove difficult without sufficient training on how TAs can help students embrace setbacks and promote independent discovery. This is particularly true given that traditional lab-based TA opportunities do not often allow for student autonomy, focusing instead on a controlled learning environment (Gormally et al., 2016). Studies have shown how student experiences and perceptions of the impact of CUREs is largely dependent on the environment created by graduate student TAs. When TAs do not provide a supportive learning environment or when they demonstrate inherent biases about the abilities of undergraduates in a research-based curriculum, it can lead to student disinterest, anxiety, and negative learning experiences (Goodwin et al., 2022, 2023). Ensuring that TAs understand the central thrust of BIO-CURE, are adequately trained in giving constructive student criticism, and are enthusiastic about their role in our initiative will likely require structured training and student feedback (Shortlidge et al., 2023).

Finally, we also realize that we are limited in how many CURE topics we can implement at one time, and the topics selected may not cater to the interests of all students. And regardless of our best efforts, launching a CURE project will still risk that not all students will have a positive experience with our CURE. While we acknowledge this limitation, we believe that BIO-CURE represents a constructive approach for undergraduate students to begin their research journey. A study investigating student experiences in an introductory research laboratory course in microbiology found that even students not interested in the research topic being investigated still felt that the experience itself was beneficial and provided them with the skills needed for future research and laboratory courses (Gasper & Gardner, 2013). We hope that students enrolled in BIO-CURE will feel similarly, given the careful course design that incorporates skill development and reflection.

Therefore, BIO-CURE will broaden access to research experiences for undergraduates beyond the limited opportunities currently available through one-on-one mentored programs (Adebisi, 2022). Supporting more equitable access to research for our diverse student body is another important goal we hope to achieve through the launch of BIO-CURE. The diverse student design team that will support ongoing CURE project development will provide additional opportunities for students to take on leadership roles, engage in multidisciplinary research projects, and hone problem-solving skills (Olimpo et al., 2016). We are inspired by studies that show students who participate in CUREs are at least 14% more likely to persist in graduate school and future STEM endeavours than students who did not participate (Linn et al., 2015). Keeping this in mind, we aim to work towards diversifying our discipline and promoting equity and inclusion.

Acting as student partners in CURE design was a unique learning experience. Exploring the administrative side of undergraduate curriculum development, we learned how to budget, manage resources, and gauge feasibility effectively. We enhanced our collaborative skills with fellow undergraduate students and built important relationships with our faculty supervisors. Weekly meetings to deliberate ideas helped us keep track of our progress. We enlisted the aid of additional biological sciences faculty (i.e., research faculty mentors) to review our pilot experiments and comment on the feasibility of BIO-CURE. One of the most important lessons that we learned is that failure is not always a bad thing. Failure and experiencing setbacks are often seen negatively, but through our time as student partners, we found that some of our greatest successes came after our most formidable barriers. We hope this lesson transfers to future BIO-CURE students, fostering resilience in scientific exploration.

CONCLUSION

CUREs offer noted benefits for students, including the discovery of new research avenues and the development of independence and confidence in the lab (Heim & Holt, 2019; Shaffer et al., 2010). CUREs also present unique mentoring and intellectually stimulating opportunities for faculty. A small percentage of students from our department participate in the current selection of research courses at our institution. To expand undergraduate research opportunities for a diverse population of students, a student-partnered approach was employed to guide the implementation of a foundational CURE course in biology—the BIO-CURE. The partnership between students and faculty in course development offers distinct advantages. Students provide practical insights into the difficulty of course content in conjunction with concurrent courses, ensuring this future BIO-CURE is engaging and attracts adequate student enrolment. Our objective is to expose first- and second-year students to research, enhancing their STEM interests and transferable research skills. Through an exploration of scientific literature, the formulation of hypotheses, and the creation of an experimental protocol and lab report, BIO-CURE students will gain first-hand experience in research and the scientific method. We hope that our unique approach to CURE development will inspire educators at other institutions to enact curricular innovation through a student-partnered approach.

ACKNOWLEDGEMENTS

This work has been supported by the University of Toronto Learning and Education Advancement Fund (LEAF) and the University of Toronto Scarborough Experiential Learning Fund (ELF) and Departmental Research Fund (DRF).

We would like to acknowledge the contributions of:

Dr. Gonzales-Vigil and the EGV Lab for introducing biochemistry experiments that have helped us in initiating BIO-CURE pilot experiments and course implementation.

Dr. Tod Thiele for introducing us to neuroscience lab spaces and providing advice on the use of CRISPR manipulated model organisms in research.

Dr. Béatrice Lego and the University of Toronto Scarborough Campus Farm for showing us how to obtain research materials and how we could involve the campus farm in our course development.

Dr. Ina Anreiter for providing advice on the feasibility of an RNA fluorescence in-situ hybridization BIO-CURE and supervising a subsequent pilot experiment.

NOTE ON CONTRIBUTORS

Olivia Hawco *recently graduated from the University of Toronto Scarborough with an Honours Bachelor of Science and has since begun a Master of Science at the same institution, specializing in cellular neuroscience, stem cell biology, and recombinant protein biochemistry.*

Erynne Sutanto *is a graduate from the University of Toronto Scarborough with a HBSc specializing in Molecular biology and Biotechnology.*

Haider Alsafar *recently graduated from the University of Toronto with a HBSc and is now pursuing a Master's of Science in the Ecology & Evolutionary Biology Department at the University of Toronto.*

Eshal Dave r*ecently graduated from the University of Toronto Scarborough with a HBSc specializing in Biochemistry and Molecular Biology and is now pursuing medicine at the Chicago College of Osteopathic Medicine program at Midwestern University.*

Aditi Bansal *is a graduate from the University of Toronto Scarborough with a HBSc specializing in Molecular biology and Biotechnology with a Minor in Biomedical Ethics.*

Ayuni Ratnayake *is a Master's student from the University of Toronto, specializing in complement biology, immunology, and cell biology.*

Emily Bell *is an Assistant Professor, Teaching Stream, in the Department of Biological Sciences at the University of Toronto Scarborough and specializes in CURE development and undergraduate education in molecular biology.*

Aarthi Ashok *is a Professor, Teaching Stream in the Department of Biological Sciences at the University of Toronto Scarborough and specializes in Biology Education Research projects, including the development and impact of CUREs.*

REFERENCES

Adebisi, Y. A. (2022). Undergraduate students' involvement in research: Values, benefits, barriers and recommendations. *Annals of Medicine & Surgery, 81*. https://doi.org/10.1016/j.amsu.2022.104384

Aikens, M. L., Robertson, M. M., Sadselia, S., Watkins, K., Evans, M., Runyon, C. R., Eby, L. T., & Dolan, E. L. (2017). Race and gender differences in undergraduate research mentoring structures and research outcomes. *CBE life sciences education, 16*(2), ar34. https://doi.org/10.1187/cbe.16-07-0211

Arena, R., Chambers, S., Rhames, A., & Donahoe, K. (2015). The importance of research—A student perspective. *Behavior Analysis in Practice*, *8*(2), 152–153. https://doi.org/10.1007/s40617-015-0084-x

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

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

Beatty, A. E., Ballen, C. J., Driessen, E. P., Schwartz, T. S., & Graze, R. M. (2021). Addressing the unique qualities of upper-level biology course-based undergraduate research experiences through the integration of skill-building. *Integrative and Comparative Biology*, *61*(3), 981–991. https://doi.org/10.1093/icb/icab006

Berton, P., Barnes, R., Telmadarreie, A., & Bryant, S. (2022). A course-based research experience to introduce engineering students to research aimed at innovation in early years. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.vi.15839

Brooman, S., Darwent, S., & Pimor, A. (2015) The student voice in higher education curriculum design: is there value in listening? *Innovations in Education and Teaching International, 52*(6), 663–674 https://doi.org/10.1080/14703297.2014.910128

Brownell, S., Kloser, M., Fukami, T., & Shavelson, R.J. (2012). Undergraduate biology lab courses: Comparing the impact of traditionally based "cookbook" and authentic research-based courses on student lab experiences. *The Journal of College Science Teaching*, *41*(4), 36–45. https://www.academia.edu/2788575/Undergraduate_Biology_Lab_Courses_Comparing_the_Impact_of_Traditionally_Based_Cookbook_and_Authentic_Research_Based_Courses_on_Student_Lab_Experiences

Burke, A., Okrent, A., & Hale, K. (2022). *The state of U.S. science and engineering 2022: U.S. and global STEM education and labor force*. U.S. National Science Foundation and National Science Board. https://ncses.nsf.gov/pubs/nsb20221/u-s-and-global-stem-education-and-labor-force.

Cooper, K. M., Soneral, P. A. G., & Brownell, S. E. (2017). Define your goals before you design a CURE: A call to use backward design in planning course-based undergraduate research experiences. *Journal of Microbiology & Biology Education*, *18*(2). https://doi.org/10.1128/jmbe.v18i2.1287

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

Corwin, L. A., Graham, M. J., & Dolan, E. L. (2015). Modelling course-based undergraduate research experiences: an agenda for future research and evaluation. *CBE—Life Sciences Education*, *14*(1), es1. https://doi.org/10.1187/cbe.14-10-0167

Dolan, E. L. (2016). *Course-based undergraduate research experiences: Current knowledge and future directions*. Committee on Strengthening Research Experiences for Undergraduate STEM Students, Texas Institute for Discovery Education in Science, The University of Texas at Austin. https://advance.louisiana.edu/sites/advance/files/Course-based%20Undergraduate%20Research%20Experiences%20Current%20knowledge%20and%20future%20directions.pdf

Elgin, S. C., Bangera, G., Decatur, S. M., Dolan, E. L., Guertin, L., Newstetter, W. C., San Juan, E. F., Smith, M. A., Weaver, G. C., Wessler, S. R., Brenner, K. A., & Labov, J. B. (2016). Insights from a convocation: Integrating discovery-based research into the undergraduate curriculum. *CBE—Life Sciences Education*, *15*(2), fe2. https://doi.org/10.1187/cbe.16-03-0118

England, B. J., Brigati, J. R., Schussler, E. E., Chen, M. M. (2019). Student anxiety and perception of difficulty impact performance and persistence in introductory biology courses. *CBE—Life Sciences Education, 18*(2). ar21. https://doi.org/10.1187/cbe.17-12-0284

Estrada, M., Burnett, M., Campbell, A. G., Campbell, P. B., Denetclaw, W. F., Gutiérrez, C. G., Hurtado, S., John, G. H., Matsui, J., McGee, R., Okpodu, C. M., Robinson, T. J., Summers, M. F., Werner-Washburne, M., & Zavala, M. (2016). Improving underrepresented minority student persistence in stem. *CBE—Life Sciences Education*, *15*(3), es5. https://doi.org/10.1187/cbe.16-01-0038

Gasper, B. J., & Gardner, S. M. (2013). Engaging students in authentic microbiology research in an introductory biology laboratory course is correlated with gains in student understanding of the nature of authentic research and critical thinking. *Journal of Microbiology & Biology Education, 14*(1), 25–34.https://doi.org/10.1128/jmbe.v14i1.460

Gillen, C.M. (2006). Criticism and interpretation: Teaching the persuasive aspects of research articles. *CBE—Life Sciences Education, 5*(1). 34–38. https://doi.org/10.1187/cbe.05-08-0101

Goodwin, E. C., Cary, J. R., & Shortlidge, E. E. (2022). Not the same CURE: Student experiences in course-based undergraduate research experiences vary by graduate teaching assistant. *PLoS One. 17*(9), e0275313. https://doi.org/10.1371/journal.pone.0275313

Goodwin, E., Cary, J., Phan, V., Therrien, H., & Shortlidge, E. (2023). Graduate teaching assistants impact student motivation and engagement in course-based undergraduate research experiences. *Journal of Research in Science Teaching, 6*(9), 1–31. https://doi.org/10.1002/tea.21848

Gormally, C., Sullivan, C. S., & Szeinbaum, N. (2016). Uncovering barriers to teaching assistants (TAs) implementing inquiry teaching: Inconsistent facilitation techniques, student resistance, and reluctance to share control over learning with students. *Journal of Microbiology & Biology Education, 17*(2), 215–24. https://doi.org/10.1128/jmbe.v17i2.1038

Harrison, M., Dunbar, D., Ratmansky, L., Boyd, K., & Lopatto, D. (2011). Classroom-based science research at the introductory level: Changes in career choices and attitude. *CBE—Life Sciences Education*, *10*(3), 279–286. https://doi.org/10.1187/cbe.10-12-0151

Healey, M., Flint, A., & Harrington, K. (2016). Students as partners: Reflections on a conceptual model. *Teaching and Learning Inquiry, 4*(2), 8–20. https://doi.org/10.20343/teachlearninqu.4.2.3

Heim, A. B., & Holt, E. A. (2019). Benefits and challenges of instructing introductory biology course-based undergraduate research experiences (CUREs) as perceived by graduate teaching assistants. *CBE—Life Sciences Education, 18*(3), ar43. https://doi.org/10.1187/cbe.18-09-0193

Howell, K. (2021). Enhancing research and scholarly experiences based on students' awareness and perception of the research-teaching nexus: A student-centred approach. *PLOS ONE*, *16*(9), e0257799. https://doi.org/10.1371/journal.pone.0257799

Kortz, K. M., & Van Der Hoeven Kraft, K. J. (2016). Geoscience education research project: Student benefits and effective design of a course-based undergraduate research experience. *Journal of Geoscience Education*, *64*(1), 24–36. https://doi.org/10.5408/15-11.1

Laal, M., & Ghodsi, S. M. (2012). Benefits of collaborative learning. *Procedia - Social and Behavioral Sciences*, *31*, 486–490. https://doi.org/10.1016/j.sbspro.2011.12.091

Linn, M., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Undergraduate research experiences: Impacts and opportunities. *Science*, *347*(6222). https://doi.org/10.1126/science.1261757

Majeed, T. A., Jamal, H., Azizi, A. S., Abraham, J. C. P., Awan, Z., & Ashok, A. (2022). Undergraduate Research Course Report: Recommendations for implementing Course-based Undergraduate Research Experiences into the Biological Sciences curriculum at the University of Toronto Scarborough Campus [Unpublished manuscript]. Department of Biology, University of Toronto Scarborough.

Mraz-Craig, J. A., Daniel, K. L., Bucklin, C. J., Mishra, C., Ali, L., & Clase, K. L. (2018). Student identities in authentic course-based undergraduate research experience. *Journal of College Science Teaching*, *48*(1), 68–75. https://www.jstor.org/stable/26491348

Morisano, D., Hirsh, J. B., Peterson, J. B., Pihl, R. O., & Shore, B. M. (2010). Setting, elaborating, and reflecting on personal goals improves academic performance. *Journal of Applied Psychology*, *95*(2), 255–264. https://doi.org/10.1037/a0018478

Office of the Vice-Provost, Students. (2021). *Student experience in the research university (SERU).* University of Toronto. https://www.viceprovoststudents.utoronto.ca/about-ovps/reports/seru/

Olimpo, J. T., Fisher, G. R., & DeChenne-Peters, S. E. (2016). Development and evaluation of the tigriopus course-based undergraduate research experience: Impacts on students' content knowledge, attitudes, and motivation in a majors introductory biology course. *CBE—Life Sciences Education, 15*(4), ar72. https://doi.org/10.1187/cbe.15-11-0228

Pekrun, R., Goetz, T., Titz, W., & Perry, R. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist, 37*(2), 91–105. https://doi.org/10.1207/S15326985EP3702_4

Puljak, L., & Vari, S. G. (2014). Significance of research networking for enhancing collaboration and research productivity. *Croatian Medical Journal*, *55*(3), 181–183. https://doi.org/10.3325/cmj.2014.55.181

Rodenbusch, S. E., Hernandez, P. R., Simmons, S. L., & Dolan, E. L. (2016). Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees. *CBE—Life Sciences Education*, *15*(2), ar20. https://doi.org/10.1187/cbe.16-03-0117

Round, J. E., & Campbell, A.M. (2013). Figure facts: Encouraging undergraduates to take a data-centered approach to reading primary literature. *CBE—Life Sciences Education*, *12*(1). https://doi.org/10.1187/cbe.11-07-0057

Russell, C. B., & Weaver, G. C. (2011). A comparative study of traditional, inquiry-based, and research-based laboratory curricula: Impacts on understanding of the nature of science. *Chemistry Education Research and Practice, 12*(1), 57–67. https://doi.org/10.1039/C1RP90008K

Shaffer, C. D., Alvarez, C., Bailey, C., Barnard, D., Bhalla, S., Chandrasekaran, C., Chandrasekaran, V., Chung, H.-M., Dorer, D. R., Du, C., Eckdahl, T. T., Poet, J. L., Frohlich, D., Goodman, A. L., Gosser, Y., Hauser, C., Hoopes, L. L. M., Johnson, D., Jones, C. J., Elgin, S. C. R. (2010). The genomics education partnership: Successful integration of research into laboratory classes at a diverse group of undergraduate institutions. *CBE—Life Sciences Education*, *9*(1), 55–69. https://doi.org/10.1187/09-11-0087

Shortlidge, E. E., & Brownell, S. E. (2016). How to assess your CURE: A practical guide for instructors of course-based undergraduate research experiences. *Journal of Microbiology & Biology Education*, *17*(3), 399–408. https://doi.org/10.1128/jmbe.v17i3.1103

Shortlidge, E.E., Kern, A.M., Goodwin, E.C., & Olimpo, J.T. (2023). Preparing teaching assistants to facilitate course-based undergraduate research experiences (CUREs) in the biological sciences: A call to action. *CBE—Life Sciences Education, 22*(4), es4. https://doi.org/10.1187/cbe.22-09-0183

Shuster, M.I., Curtiss, J., Wright, T.F., Champion, C., Sharifi, M., & Bosland, J. (2019). Implementing and evaluating a course-based undergraduate research experience (CURE) at a Hispanic-serving institution. *Interdisciplinary Journal of Problem-Based Learning, 13*(2). https://doi.org/10.7771/1541-5015.1806

Sun, E., Graves, M. L., & Oliver, D. C. (2020). Propelling a course-based undergraduate research experience using an open-access online undergraduate research journal. *Frontiers in Microbiology*, *11*. https://www.frontiersin.org/articles/10.3389/fmicb.2020.589025

The Center for Teaching, Learning, and Technology (CTLT). (2021). *Students as partners in course design*. University of British Columbia. https://ctlt-sap-2021.sites.olt.ubc.ca/files/2021/09/SAP_DiscussionPaper_2021.pdf

Walker, J. P., Allen, W. E., Clevenger, L., Hosbein, K. N., Kennedy, A. M., Vance-Chalcraft, H., & Whiting, B. (2023). Course-based undergraduate research experiences as a community of practice (COP). *Journal of Chemical Education*, *100*(7), 2520–2528. https://doi.org/10.1021/acs.jchemed.2c00844

Walkington, H., & Ommering, B. (2022). How does engaging in authentic research at undergraduate level contribute to student well-being? *Studies in Higher Education*. *47*(12), 2497–2507. https://doi.org/10.1080/03075079.2022.2082400.

Wong, B. (2015). Careers "From" but not "in" science: Why are aspirations to be a scientist challenging for minority ethnic students? *Journal of Research in Science Teaching, 52*(7), 979–1002. https://doi.org/10.1002/tea.21231

Zimmerman, B. J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (2nd ed., pp. 1–37). Lawrence Erlbaum Associates Publishers. https://psycnet.apa.org/record/2001-06817-001