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

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Abstract

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

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

Introduction

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

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

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

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

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

Current biology laboratory curriculum

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

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

Purpose

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

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

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

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

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

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

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

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

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

Conclusions

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

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

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Community Engaged CURE Modules

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