DEVELOPING A COURSE-BASED RESEARCH EXPERIENCE FOR UNDERGRADUATES: THE ASU WEST EXPERIENCE

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ABSTRACT

To improve the quality of undergraduate science education at Arizona State University's West campus, a course-based undergraduate research experience (CURE) class was implemented, in which students develop their own hypotheses, design experiments, and gather their own data to try to answer a research question. Three modules were developed, the first examined capsaicinoid content and of hot peppers, the second used wild bee and plant populations, and a third explored the suitability of using plants to remediate metal pollution in mine soils. The class has been successful in facilitating student participation in research and the presentation of their findings at conferences through talks and posters. Future development and expansion of the class is planned for the coming semesters to improve the class and make it available to significantly more students.

THE DEVELOPMENT OF RESEARCH-BASED UNDERGRADUATE COURSES

Science ultimately is the process of constructing knowledge (National Research Council 2003). Scientists do this through the design and execution of laboratory experiments and field studies that by their very nature are interdisciplinary (Steen 2005). Unfortunately, students of science often are not exposed to the process of designing robust experiments or field studies during their undergraduate education (Weaver et al. 2008). Although learning gains are well documented with undergraduate research experiences (URE) in which a student works in a faculty member's lab (e.g., Lopatto 2004, 2007), there can be serious drawbacks to this mentee-mentor model. Individual UREs can be expensive and time consuming. Furthermore, not many students get this opportunity, and so the impact of undergraduate research is diluted across a student body. Additionally, a URE is often started when the students are juniors or seniors (as faculty members want students who have already taken courses that prepare them for the undergraduate research project) even though the American Association for the Advancement of Science (AAAS 2011) suggests students should start in an authentic research experience early in their careers. Also, training could be spotty, depending on the faculty member. Anecdotal stories from students indicate that UREs can be anything from an intensive learning experience to simple manual labor. As well, depending on the research project, students can be isolated in a lab setting and can miss out on peer-learning and interactions that can enhance learning at all levels. Teaching strategies that use peer learning have been found to greatly improve outcomes for students, especially minorities underrepresented in STEM (science, technology, engineering, and math) fields (Snyder et al. 2016). Thus, although UREs have the potential to be transformative for students, they are not a one-size-fits all solution to STEM teaching and learning.

Inquiry-based labs have been proposed as one way to overcome the tendency of science to be taught and learned as a series of facts. Inquiry learning can include a wide variety of types of activities including experiments done in a traditional lab setting in which part of the experiment is designed by the students themselves such as the Bio-Rad GMO Investigator Kit in which students follow a prescribed set of instructions but are allowed to bring in their own food to test. A more student-oriented approach in which students were asked to bring in a common household solution to test for mutagenicity was developed by one of the coauthors (Marshall 2007). In this laboratory assignment, students were first assigned to read the scientific literature on the use of *Saccharomyces cerevisiae* (yeast) to test for mutagenicity. Students then had to design their own research protocol and execute it in the laboratory. The study noted that student response was overwhelmingly positive, with many responses in post assessment expounding on the importance of how the experiment related to the student's everyday life. The instructor noted that the exercise greatly improved student understanding of data structures such as dose/response curves and the importance of positive and negative controls. In a second study conducted by the same coauthor (Marshall 2013), the entire protocol development was the responsibility of the students. In this study, students were presented with the concept of a tongue taste map, and a list of foods to test the idea. Students had to devel-

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op their own hypotheses, experimental protocols and techniques to generate both qualitative and quantitative data, and present that data to their peers and judges (this was part of the Arizona Science Olympiad Experimental Design Challenge). Student groups gained real-world knowledge of individual variability as well as experimental design and hypothesis testing. Thus, inquiry activities lie on a continuum from more instructor designed to more student designed to students actively conducting research. Studies of student outcomes demonstrate benefits to learning from inquiry-based approaches compared to traditional didactic lectures, and even greater benefits to research-based approaches than lectures or even inquiry-based approaches (Weaver et al. 2008). In a meta-analysis of 225 studies that compared active learning with traditional lecture approaches, Freeman et al. (2014) found that student performance on concept inventories and examinastions improved by 0.47 standard deviations, examination scores in the courses involved were improved on average 6% by the active-learning techniques and that students in traditional lecture settings were 1.5 times more likely to fail the course. In a review of inquiry-based laboratory approaches that looked at 142 studies, Beck et al. (2014) found that while the move to implement inquiry-based laboratory exercises is slower than desirable and the assessment of learning gains from them is not yet standardized, inquiry-based laboratory approaches can provide significant improvements to student learning of science.

On the continuum of inquiry experiences between the mentee-mentor model and the inquiry labs lies the Course-based Undergraduate Research Experience (CURE). A CURE is a course designed around a research question or system in which the students participate as true researchers, often designing hypotheses and experiments, and answering questions for which no one yet knows the answer (reviewed in Auchincloss et al. 2014). Many CUREs also lead to undergraduate authorship on research publications. Our CURE has two examples so far (Lowe and Foltz-Sweat 2016, Sweat et al. 2016). There are many examples of successful CUREs, most of which are biology focused. One example is the Howard Hughes Medical Institute's SEA PHAGES course in which students isolate phages from locally collected soil samples, isolate and sequence the DNA, and then annotate the phage genome (Jordan et al. 2014). Other projects include the National Science Foundation (NSF)-funded Genomics Education Partnership, in which students participate in research to improve the quality of the fruit fly genome (Shaffer et al. 2010), the NSF-supported Genome Consortium for Active Teaching that has incorporated microarray techniques into research based student experiences (Campbell et al. 2007), the Dynamic Genome course that uses transposons in maize to have students detect transposable element insertion site polymorphism in multiple maize strains (Burnette and Wessler 2013), the Small World Initiative that engages students in searching for new antibiotics in soil samples (Yale University 2014), and the NSF-funded CUREnet network, that encompasses multiple institutions and projects that use a research course for undergraduates in science (Franklin College of Arts and Sciences and University of Georgia 2014). Furthermore, there are also successful interdisciplinary research projects. Examples of multidisciplinary research projects include iGem, where student projects involve design and synthesis of genetically engineered biological systems that have standardized, interchangeable parts (Vilanova and Porcar 2014). Genomic analysis also can integrate biology, mathematics, and computing, in projects such as the Genomics Instructional Units Minicollection, which has assembled a collection of inquiry-based laboratory modules for undergraduate courses on a range of subjects from wood frog populations to olfactory receptor gene subfamily in dogs to the evolution of cauliflower and broccoli (Banta et al. 2012) and the Integrated Microbial Genomes Annotation Collaboration Toolkit, which can be used in course assignments to use active-learning techniques to study operon and gene structure or at a larger level using genome annotation exercises (Ditty et al. 2010). The entire first-year biology experience at two institutions has been transformed by a CURE experience utilizing yeast genetics (Brownell et al. 2015) and sticky monkeyflower (Kloser et al. 2011). There are a wide variety of successful CURE examples and projects that students across the globe have been involved in to enhance their STEM preparation for both skills-based learning objectives, such as critical thinking, as well as workforce development.

CUREs are proven ways to stimulate student interest in science (Auchincloss et al. 2014, Shaffer et al. 2014) and potentially prepare a STEM workforce for the future. CUREs allow students to participate in authentic research experiences, generate and analyze real data, and publish their results, in a more organized and larger format than an URE. CUREs give more diverse students opportunities for authentic research experiences (Bangera and Brownell 2014) and can standardize the process of assessment of the experience (Beck et al. 2014). There has been much recent analysis of CUREs indicating that in addition to learning gains produced by the research component of the CURE (Auchincloss et al. 2014) the standardized format and integration of a lecture component can indeed enhance the learning experience for students (Shaffer et al. 2014). There are also many ways to assess a CURE, depending on the stated learning objectives, and these can include assessment of higher-order thinking, career goals, and experimental design (Shortlidge and Brownell 2016).

To engage as large a population as possible in the process of doing science and improve the undergraduate science education at Arizona State University's West campus we created a CURE. Our CURE is a multidisciplinary course, designed to attract students from the natural sciences, applied computing, statistics, and mathematics majors. Three distinct modules have been deployed over the past seven semesters, one analyzing what factors influence the capsaicinoid content of hot peppers, another that examines local bee populations and plant interactions, and a third module that determined the suitability of using plants to remediate environmental impacts from mining.

A CURE at ASU's West Campus

The CURE class as currently implemented at the Arizona State University's West campus is today a 3-credit upper division class (LSC 388). The class meets once a week for a combined lecture and laboratory period. Students must have taken and passed with a C or better General Biology 1 & 2 (BIO 181 & 182), Database Systems (ACO 320) or Calculus with Analytic Geometry III (MAT 272) to be able to register for the class. The class is held entirely in a science teaching laboratory.

To standardize the course and foster rapid development of future modules, a common course outline was developed. The common course outline is described in Table 1.

To ensure consistency across the topics and semesters, a common set of learning objectives was developed. The learning objectives are described in Table 2.

Table 1. Common course outline.

Lesson number	Lesson content:
1	Introduction to study organism and overarching question. Assign reading of core literature.
2	Literature search and citation software. Discuss in detail core literature.
3	Hypothesis development and Methods I. Bibliography with unique citations due. Assign methods section part 1.
4	Review of methods 1 section as class. Assign student proposals - methods 2.
5	Study design - discuss student proposals as a class.
6	Execute study - collect data.
7	Analyze data. Graphical presentations of data. Assign results section.
8	Review results section as class. Assign discussion.
9	Review discussion section as class. Assign introduction.
10	Review introduction as class. Assign abstract.
11	Review abstract as class. Assign poster and or manuscript.
12	Design and produce poster and/or paper manuscript.

Core Literature

To facilitate student understanding of the specific research question used in each particular course module, a set of ca. five papers was selected by the instructor in advance – the core literature. These papers were chosen to represent the primary research tools used in the particular area of research and to suggest avenues for students to design their own research question. The core literature papers were discussed in length in the classroom, using a Socratic approach that allowed the instructor to focus student attention on specific issues presented in the papers. The questions over the papers were given to students in advance, allowing students to first attempt to answer them on their own before coming together to discuss them. Questions regarding laboratory techniques (e.g., gas chromatography), statistical techniques (e.g., network analysis), and figures and graphs allowed the instructor to build student knowledge of crucial research tools, techniques, and appropriate methods to communicate scientific ideas as they directly related to the research topic.

Individual and Group Writing Assignments

To ensure student participation, writing assignments were done first at the individual level, then as a research group. As an example, for lesson 3 in the

Table 2. Student learning objectives

Objective number	Learning objective
1	Conduct a primary literature search on the research topic.
2	Formulate a hypothesis to test with research experimentation.
3	Design an experiment that will evaluate the formulated hypothesis.
4	Execute the experimental design.
5	Appropriately analyze the experiment to obtain sound conclusions regarding the outcome of the experiment.
6	Effectively communicate the results of scientific research through an oral PowerPoint, Prezi or similar presentation.
7	Demonstrate awareness and adherence to the principles of general lab safety.

common course outline, a methods section was assigned to be completed by each student on their own. The assignment was due in three days, allowing the instructor time to review and comment on the individual methods before they were returned to students at the next class meeting one week later. For lesson 4, students in each research group would then review their own and their group members' methods assignment, and from all of them synthesize a group methods section that could build upon the ideas each student had brought forth.

Three different modules have been developed and taught, some numerous times, using the common course outline described above. A description of each module and examples of student generated questions and the core literature used are given in Table 3.

INITIAL IMPRESSIONS OF THE CURE AT ASU'S WEST CAMPUS

The student and faculty response and reviews from the first seven semesters demonstrated the feasibility of offering CURE courses at ASU's West campus, as well as highlighting the tasks that are needed to scale-up the size and the number of these classes to reach a large student population. The successes of the project are:

- Enthusiastic student response. Student teaching evaluations near unanimously gave the instructor the highest rating possible (five out of five) in overall performance in all seven completed semesters.
- Eight posters have been generated from student research and presented at the campus research expo in 2017 and 2016, as well as the 2016 Arizona-Nevada Academy of Sciences Conference. Both posters presented at the 2017 campus research expo received awards (2nd and 3rd place) for best-presented research poster.
- Five students continued research in the CURE topic and now have generated two manuscripts that have been accepted for publication.
- One student gave an oral presentation of their research at the 2016 Arizona-Nevada Academy of Sciences Conference and won the best presentation award.
- Nine students have been accepted in faculty research laboratories as a result of their CURE experience.

GOALS FOR FUTURE WORK

Although successful, the preliminary CURE modules revealed limitations that faculty are beginning to address so that the classes can be expanded to deliver the desired outcome to a larger population of students. Those areas are:

- The original credit allocation to the class (two credit hours) was inadequate for the class. This was changed in the Spring of 2017, when the class will be offered for three credit hours and have a hybrid designation to more accurately reflect the amount of out-of-class online work students are responsible for.
- Inclusion of statistics and applied computing majors in the course. To facilitate quantitative majors, the prerequisites of Database Systems (ACO 320) or Calculus with Analytic Geometry III (MAT 272) were added to the course as alternatives to the existing General Biology 1 & 2 (BIO 181 & 182) prerequisites.
- To encourage students to build collaborations across disciplines, the course has been made available to statistics and applied computing majors within the school. This interdisciplinary approach greatly enhances the experience for the students, and more accurately reflects the modern academic and business environment where quantitative assessment of large datasets ("big data") is becoming a valuable skill.
- Development of new modules. In the summer of 2017 a new module titled Environmental Microbiome Research was developed.

Table 3. CURE modules developed and taught at Arizona State University's West campus.

Module title (semesters taught)	Module description	Student research questions	Core literature
Capsaicin Content in Chili Peppers (Spring 2014, Fall 2015)	Student research questions examined how capsaicinoid production could be manipulated by research interventions.	Do nitrate fertilizer rates affect capsaicinoid content? Does herbivory affect capsaicinoid content? Does cooking alter capsaicinoid content?	Arrowsmith et al. 2012 Kirschbaum-Titze et al. 2002 Mueller-Seitz et al. 2008 Scoville 1912 Todd et al. 1977 Yaldiz et al. 2010 Zewdie and Bosland 2000
Bee Ecology in Urban and Wild Habitats (Fall 2014, Spring 2015, Spring 2016, Fall 2016)	Student research questions examined the differences between urban and natural park populations as well as species and color preferences of bees.	Do bee communities vary between urban and native floral communities? Does flower color affect pollinator visits? Does nectar content and quality affect pollinator visitation?	Baldock et al. 2015 McIntyre and Hostetler 2001 Minckley et al. 1999 Potts et al. 2003 Vanbergen 2013 Williams et al. 2001
Vegetative Remediation of Mine Sites (Spring 2017)	Student research questions centered on the ability of plant seeds or vegetative propagules to establish themselves in soils contaminated with metals typically found in mine sites in Arizona.	Can creosote seeds germinate in solutions containing copper and/or lead? Can prickly pear pads root in soils contaminated with arsenic, lead, and/or copper? Can mesquite seeds germinate in solutions of copper and/or lead?	Baderna et al. 2015 Bae et al. 2016 Li et al. 2005 Munzuroglu and Geckil 2002 Padmavathiamma and Li 2007

- Develop in consultation with content faculty appropriate prerequisites for applied computing and statistics students. While development of the class in the context of the biology major has been robust, inclusion of quantitative majors has been less than desired. Recruitment strategies will be developed in consultation with relevant faculty to encourage greater participation by this group of students.

Authentic research experiences have been demonstrated to have a positive impact on student learning and retention in the sciences, especially for student groups underrepresented in these areas (Eagan et al. 2013). Since the academic unit at ASU's West campus (New College of Interdisciplinary Arts and Sciences) where the CUREs are offered is a majority first generation college, strategies that help these students are highly desirable. Future development of the class is envisioned to integrate it more fully into the science degree programs offered at the West campus. The authors are actively working to facilitate the transition from our current preliminary CURE classes to a larger program that can impact more students. We are developing an authentic assessment of the program to identify limitations as well as places for improvement. Finally, we look forward to disseminating our results and, as applicable, serving as a model for other institutions to implement and assess CUREs.

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