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Semester-long Projects

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This discussion is focused on some experiences of semester-long course projects. At Rochester Institute of Technology (RIT), the first year laboratory courses (150 students per semester) are semester-long projects. We have adapted the Small World Initiative project (antibiotics from soil bacteria) and have devised and adapted other projects as a lens to teach laboratory techniques and engage our beginning scientists in authentic inquiry. Examples include Daphnia ecotoxicology and Fall tree studies. This past year has been challenging with the COVID-19 pandemic and the need to adapt laboratory courses to include students who are learning online, as well as planning for a pivot to online for the entire class. At the University of Kentucky (UK), in a Jr/Sr level Animal Physiology Course with a lab (120 students per semester) and a neurophysiology lab (Sr level) with 16 students we have focused on a theme this year with the effect of bacterial induced sepsis and to focus in on the direct effect of endotoxin (Lipopolysaccharides, LPS) from gram-negative bacteria. This was approached as authentic scientific inquiry. The novel investigation appeared to stimulate student engagement and curiosity. In the neurophysiology class the project turned into a publication with all students as co-authors. In the animal physiology course, the topic was woven through the various bodily systems from the cell level to the whole body. What students found interesting is how little is known on the direct effects of LPS as compared to the downstream actions of cytokines. To bridge this across kingdoms, the effects of LPS on root growth in plants and sensitivity to subsequent exposure as a defense mechanism were compared.

Keywords: semester long project, project-based learning, CURE

Introduction

Semester-long research projects have been previously demonstrated to provide experiences in applying scientific practices while building a scientific community (National Research Council [NRC] 2003; Lopatto 2007; Auchincloss et al. 2014; Shapiro et al. 2015). Furthermore, authentic experiences, such as semester-long projects, have been demonstrated to support critical thinking and scientific practices (collaboration, argumentation, perseverance, problem-solving skills) (i.e., Ditty et al. 2013; Miller et al. 2013; Auchincloss et al. 2014). Despite these benefits, instructors are faced with instructional challenges while designing semester-long projects (Shortlidge et al., 2016).

The 2021 ViABLE Conference provided opportunities for conference participants to discuss the benefits and challenges of integrating authentic scientific research within college classrooms by attending the panel discussion titled Semester-Long Projects. Herein, the panelists summarize conversations within the panel discussion. This short manuscript consists of two sections: 1) a summary of the challenges with semester-long projects, and 2) summaries of projects discussed within the panel.

Summary of Challenges

In this panel discussion the group covered the benefits and challenges of working with classes on semester-long projects. A portion of the panel discussion included topics related to the challenges of balancing content, research, and instruction. The first challenge-related topic within the panel included integrating research ideas that are congruent with course structure (i.e., lecture courses, laboratory-based courses, and courses with a combined lecture and laboratory). For example, a laboratory-based course is likely to be more equipped to support a semester-long project. A combined lecture and laboratory course can provide opportunities to teach relevant content related to the research. A lecture course may present the challenge of research in a traditionally didactic setting and may have to rely on alternative avenues of research, such as *in silico* methods. Another related consideration includes developing a project appropriate for the length of the course (i.e., quarters, semesters, and trimesters). A team-taught course could present a challenge in ensuring that multiple faculty are executing the same research project, or are responsible for mentoring a small group of students within the course to complete a short research project. Lastly, a textbook may not include a theme. A course with a semester-long semester project may need to create a theme to supplement the text.

A topic related to instructional challenges included field courses, compared to indoor laboratories which have an environmental consideration to consider. The time expectations for projects, for example if out-of-class time was required, or if all the needed effort could be managed within the time allotted for a course, were additional instructional challenges to consider.

Another issue presented was the level of the course, such as a lower division course, that has more foundational material than a senior level course. Unlike upper division courses where students should have established foundational knowledge, students in lower division courses are learning foundational information. When designing semester-long research projects in lower division courses, extra consideration is required to support learning while doing research and learning content for the first time. Otherwise, students may experience a cognitive overload. In this case, lecture can support the content needed to engage in the semester-long project. The project itself can provide a “hands on” component to support and solidify content knowledge within the course. The course modality and level need to be considered to keep students engaged.

Discussed within the panel discussion were the instructional challenges with the COVID-19 pandemic, during which many courses were taught in a hybrid or online format. Semester-long projects need to be developed to instruct students within these formats. Many instructors within the panel discussion commented on how hybrid and online formats hindered semester-long research projects and more development is required within this area.

Lastly, the expenses and funding for any associated costs was a consideration raised. This led to the consideration that the number of students in a course determines the hands-on content in a lab and cost of supplies. A suggestion is to design semester-long projects that can be supported with laboratory fees if the project cannot be supported with a grant.

Semester-long Project Examples

One example of a topic was for a course at the University of Kentucky (Bio 350 Animal Physiology). This is a required course for B.S. biology major and is taught on a semester basis. The course consists of approximately 120 students, and most are senior biology majors who have an allied health interest. This course meets for three hours of lecture and three hours of lab each week. There were seven different lab sections with about twenty students each. The lab consisted of twelve experimental workstations. There were two teaching assistants and a lab coordinator in each lab session.

The theme taught throughout was bacterial infection on a comparative basis from invertebrates to humans, where students considered different systems (endocrine, cardiovascular, neuro, renal, GI, muscle). For example, two weeks of instructional laboratory time emphasized how the endotoxin from gram negative bacteria (i.e. lipopolysaccharides (LPS)) affected the cardiac function of frogs and larval *Drosophila.* The budget was not an issue as the students pay a lab fee (~$120 USD per student) and this covered all the associated costs. There are two detailed presentations in this volume on assessment of the students with this module and the laboratory procedures covered.

There are two other examples of themes for semester-long projects for freshman students conducted under COVID restrictions (masks and social distancing) with freshman students in two different lab-only classes at the University of Kentucky. Each class had eight students for one hour per week with a limited budget of $1,000 per section. However, only about $200 was spent for each class. The students were of diverse STEM- major academic backgrounds and were graded on a pass/fail basis. This was an elective class for freshman where the course objective was to expose students to research. To engage the students in research and experimental design, the semester-long project included a relevant theme. Students engaged in open-ended projects, in which they pursued one of several research avenues.

One course focused on the effects of Mn^{2+}on various invertebrate organisms. Given that manganese (Mn^{2+}) is found in many plants and animals that are consumed by humans as food, as well as being an essential element, this topic was used to engage students. Mn^{2+} is also toxic at high levels. Thus, it is of interest to understand the threshold at which subtle effects in physiological processes begin to be compromised significantly. It is difficult to determine what physiological symptoms may manifest when chronically exposed to low levels of manganese but examining acute actions at high levels may provide some insight into potential effects. Mn^{2+} is found in seaweed (130 to 735 mg/kg dry weight), formula milk consumed by developing infants (above recommended daily limits) (Frisbie et al., 2019), marine and freshwater fish (<0.2 to 19 mg/kg dry weight) and can bioaccumulate in blueberries as well is found on plants from application of agricultural sprays in the range of 2000–4000 mg/kg (Howe, et al., 2004). Larval *D. melanogaster* and $MnSO^4$ are inexpensive to obtain. Body wall, crawling, and mouth hook movements are readily assessed behaviors to examine the dietary actions of consuming Mn^{2+} in larvae (Dasari et al., 2007; Badre and Cooper, 2008). Thus, to gain some insight into the effects of dietary Mn^{2+}, these larval behaviors were examined in this study, as well as survival. The students were able to obtain data and were divided into groups of four to present research posters by the end of the semester at an undergraduate research conference. In addition, the results of this research were compiled and submitted for review to a scientific journal (Comparative Biochemistry and Physiology) with all students as co-authors. We do not yet know if the manuscript is accepted for publication.

The other group of freshman students studied social interactions of intraspecies pairs of Australian crayfish (*Cherax quadricarinatus*), interspecies pairs of Louisiana red swamp crayfish (*Procambarus clarkii*), and *Cherax quadricarinatus.* Students examined the potential for the Australian crayfish to become an invasive species in North America since they are being introduced now as an edible food source and are being raised in aquaculture facilities. The students designed many different experiments including examining the effects of temperature and size of animals interacting with each other. The students were able to present their research in four different posters at the end of the semester at a university undergraduate research conference. Two students plan to follow up on the project as research projects for a graded course (Bio395 Undergraduate Research). These two courses required minimal funds while supporting student engagement. Students felt the authentic nature of the topics were relevant, in addition to realizing that it was possible to publish their research.

In an example for a semester-long project covering more difficult content and a higher level of sophistication was in a course where the students were generally junior and senior biology or neuroscience majors. The course consisted of one hour of lecture with a three-hour laboratory section each week (Bio446 Neurophysiology Lab, University of Kentucky). The expenses were covered by the Biology Department based on the $100 USD lab fees charged to the students. In this course, there were several different animal preparations presented to students. Students learned about topics ranging from synaptic transmission, effects of temperature on resting membrane potential, modulation of neuronal function and pharmacological actions. Developing a theme or a project though out the semester may seem arduous, but each topic was related to the others. Using a variable such as how varying levels of extracellular K^+ effects each topic connected the different aspects of the course. Examples of themes covered within the past four years include the effects of increased K^+ or Ca^{2+}, the effects of clinical used pharmacological agents (i.e., TEA and 4-AP) which block subsets of K^+ channels, as well as the effects of lipopolysaccharides (LPS) on neuronal function. Each of these topics and others have resulted in peer reviewed publications for the class with all the students as co-authors.

Students were aware that each project was an authentic research project. This ACURE (authentic course-based undergraduate research experience) approach builds on the CURE (course-based undergraduate research experiences) philosophy (Linnet al., 2015; Bakshi et al., 2016;); however, it aids students experiencing a more complete research experience. Authentic scientific investigations with students in a classroom setting are a trend which is being promoted to expose students to research. This approach with authentic research has been very rewarding for students, producing tangible outcomes and genuine interest in the research projects by the students. Detailed examples of this class productivity are listed in these following citations: Dayaram et al., (2017a,b), Malloy et al., (2017), Grau et al. (2018), Wycoff et al. (2018), Stanback et al. (2019), Stanley et al. (2020), McCubbin et al. (2021), and Nethery et al. (2021).

Some more “accessible” semester-long projects include well-publicized projects such as the

Small World Initiative and Tiny Earth. Both projects focus on crowd-sourcing student efforts to identify antibiotic-producing bacteria from soil samples. These projects provide training and support to faculty members, as well as a like-minded community for both faculty and students. Rochester Institute of Technology (RIT) runs semester-long projects in their Introduction to Biology (100 level) courses. In recent years, the courses have focused on soil microbiology, and used the project as a lens to teach skills appropriate to a first-year class. Such skills include basic microbiology and molecular biology, along with math and writing skills. The Small World Initiative training gives a great overview of BioSafety, as well as discussing the basic scheme, and possible extensions. Supplies such as bacterial strains and discounts on DNA sequencing are available to participants, in addition to mentorship from more experienced participants. Faculty at RIT tested the Small World Initiative protocols for the first time in Fall 2019 and Spring 2020. In Fall 2019, students were taught basic microbiology and talked about the antibiotic resistance crisis. They took part in the CDC “Do Something about Antibiotic Resistance” challenge in November 2019 and produced a wide array of educational materials: videos, games, flyers, surveys and posters. Some groups submitted their efforts to the Small World Facebook page. In Spring, students got as far as identifying the antibiotic producing bacteria using 16S rRNA PCR and DNA sequencing. Faculty had great plans for letting student groups choose their own adventure (attempting to isolate the antimicrobial compound, exploring growth conditions for maximal antibiotic production and pigment production were a few popular directions). This was cut short by COVID-19, so student groups worked on literature searches and produced 2-page papers for a general audience about the bacteria they isolated. In Spring 2021, students were able to do some short group projects, and to repeat the “Do Something” Challenge. In conclusion, projects such as Small World Initiative, Tiny Earth (a similar project from University of Wisconsin), SEA PHAGEs (hunting for bacteria phage in soil) and PARE (Prevalence of Antibiotic Resistance in the Environment) are great projects to try out as semester-long project.

Another example from RIT is Plant Molecular Biology, an upper-level elective course. This course has become known as the CRISPR course, because students construct plasmids to knock out plant gene function (produce mutants). We’ve worked in *Arabidopsis* and explored the well-annotated *Arabidopsis* genome through TAIR (The Arabidopsis Information Resource), and found some interesting-sounding mutants to work with. Students devised their own workflows from papers, designed guide RNAs using Benchling and cloned them into plant binary vectors that express Cas9 (Kim et al., 2016). In 2020, we got as far as introducing the CRISPR plasmids into *Agrobacterium tumefaciens* ready for plant transformation by floral dip (Clough and Bent 1998). The latest iteration of this course will change crops to tomato and introduce students to plant tissue culture and the class will work on producing CRISPR knockouts in genes in plant hormone signalling pathways. Recent collaborations, begun at ABLE meetings, have resulted in an NSF-RCN entitled “Bringing CRISPR-Cas9 Technologies to the Undergraduate Classroom: an Undergraduate Instructor’s Network.”

Conclusions

This manuscript presents a summary of discussion related to semester-long research projects during the 2021 ViABLE Conference. Discussion often related to challenges while designing semester-long projects embedded within courses including course structure, modality, course level and engagement, funding, and the COVID-19 pandemic. Examples of semester-long projects from the University of Kentucky and Rochester Institute of Technology were presented, providing examples on overcoming such challenges.

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