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Curriculum

# The *Tigriopus* CURE – A Course-Based Undergraduate Research Experience with Concomitant Supplemental Instruction †

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**Evidence indicates that students who participate in scientific research during their undergraduate experience are more likely to pursue careers in the STEM disciplines and to develop increased scientific reasoning and literacy skills. One avenue to increase student engagement in research is via their enrollment in course-based undergraduate research experiences (CUREs), where they are able to conduct authentic research as part of the laboratory curriculum. The information presented herein provides an example of a CURE which was developed and implemented in an introductory cell and molecular biology course at the University of Northern Colorado. In addition to describing the *Tigriopus* CURE curriculum itself, we also present evidence regarding the effectiveness of the CURE in promoting students' development of confidence in science process skills, quantitative reasoning skills, and written communication skills. The curricular details of the *Tigriopus* CURE are provided in this article to provide instructors who are interested in CUREs the opportunity to implement this specific CURE in their own course.**

## INTRODUCTION

Recently, there has been a call for increased undergraduate research opportunities for all science students, as there is evidence that participation in research strengthens student preparation for continued work in the domain, provides students with exposure to how science is practiced, and increases retention in the science, technology, engineering, and mathematics (STEM) disciplines (1–4). Traditionally, such research opportunities occur in the laboratory of a faculty research mentor; however, due to the small number of positions available, few students conduct this type of authentic research during their undergraduate career (5, 6). In response, some faculty members have developed course-based undergraduate research experiences (CUREs), which are research experiences that occur during the normal laboratory time of an undergraduate course (6, 7). Many of these CUREs have been designed by individual faculty for their upper-level courses and are focused on faculty research expertise (5). Those CUREs that are applicable to the lower-level curricula are usually part of a national CURE network such as the HHMI SEA PHAGES program (8), and many are limited to a smaller subset of the student population in the course, typically those students who select this option from the outset (9, 10). Although faculty often express an interest in providing students with an authentic research opportunity, many are hesitant to implement a CURE due to an increase in faculty workload, a lack of experience with CUREs, and a fear that students will be less successful in understanding biology concepts (11). To address some of the primary concerns associated with CUREs, a new CURE, called the *Tigriopus* CURE, has been developed and is presented herein. This CURE has been specifically designed for an introductory-level biology course, has been implemented as a required portion of the course for all students, and has been designed around an organism that can be obtained and cultured easily, thus reducing the cost and effort associated with the CURE. In addition, the authors have successfully implemented this CURE in large courses (> 650 students) as well as small summer courses of only 15 students, thus demonstrating the scalability of the CURE and it applicability at institutions of various sizes. By presenting the detailed curriculum of the *Tigriopus* CURE, we hope to reduce faculty concerns related to workload and alleviate the apprehension of those faculty who are considering implementing CUREs in their own courses.

Likewise, the *Tigriopus* CURE was specifically designed to ease an additional faculty concern related to CURE implementation—that the bridge between lecture and laboratory material would be absent following course reform. In the traditional lab setting, prescribed experiments

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are typically conducted on topics that are directly related to the lecture material. This provides students with an opportunity to interact with the material in a different setting and to review lecture topics that may have been confusing to them. However, most CUREs focus on a research topic that is separate from the lecture material; therefore, this link between lecture and lab is absent. To address this issue, we incorporated supplemental instruction as an integral component of the CURE curriculum. This supplemental instruction consisted of active-learning exercises based on the topics currently being discussed in lecture, thus providing students with the opportunity to review the information presented in the lecture portion of the course. These exercises were led by undergraduate teaching assistants, with graduate teaching assistants available to assist if necessary, and were implemented during the first 30 to 45 minutes of each laboratory session (e.g., 12).

While this review of material has been shown to be beneficial to students (13), it does not provide them with the opportunity to carry out authentic biological research, which is the primary objective of this CURE. To enable us to accomplish that objective, students first had to be trained in basic laboratory techniques prior to being given the opportunity to conduct their own scientific investigations. The semester was therefore divided into these two primary components: learning techniques and conducting scientific research. During the first six weeks of the course, students (working in groups of four) carried out technique-driven labs focused on assisting them in better understanding how to use the types of scientific equipment necessary for conducting their own research. To ensure continuity across the semester, all experiments were conducted on the model system that would be used for their individual research project (*Tigriopus californicus*). Students also spent these first six weeks developing and designing their research project. The next eight weeks were spent conducting scientific research on the model system, with the final week designated for presentations (Fig. 1).

### Intended audience/Prerequisite student knowledge

Because this CURE is intended for students in an introductory biology course, there is no prerequisite knowledge beyond a high school background in the sciences. The CURE has currently been implemented in an introductory cell and molecular biology course. However, because there is limited research on the model organism used in this CURE, the range of project ideas is quite broad, and each instructor can guide students to ask research questions applicable to a wide range of biology topics. Thus, this CURE would also be applicable to either an ecology-focused course or a cellular-focused course at both the introductory and advanced course levels.

Presently, the *Tigriopus* CURE has been implemented in courses that range in size from 15 students to more than 650 students. Thus, it is easily scalable to fit a wide range of class sizes, including the large classes that are common in many universities. Additionally, the CURE has been implemented in a course with a diverse student population (see 13 for a description of demographic diversity within the course). For instance, students participating in the *Tigriopus* CURE include those majoring in a variety of natural sciences such as biology, nursing, chemistry, sport and exercise science, psychology, nutrition and dietetics, and audiology.

### Learning time

Congruent with the traditional laboratory course, the *Tigriopus* CURE was developed to encompass a full semester (15 weeks) of instruction, with students required to attend one three-hour lab session each week. As mentioned previously, each three-hour laboratory session began with 30 to 45 minutes of supplemental instruction using a variety of active-learning exercises. These sessions were designed to review the information presented during the lecture portion of the course and afforded students the opportunity to engage with the material in a different format (e.g., kinesthetic exercises, graphic organizers). Following the supplemental instruction session, students spent the remainder of the three-hour laboratory period on the more formal laboratory experiences. These included six weeks of technique-driven labs followed by nine weeks of conducting scientific research and presenting their results.

During the first week of the semester, students organized into groups of four and were presented with the roles available to them: Principle Investigator, Protocol Expert, Data Expert, and Analysis Expert (modified from 14) (Table 1). They were also introduced to the model system that they would be investigating and conducted a lab exercise on experimental design.

At the beginning of week two, each group was required to hand in their original research question. This required


FIGURE 1. Timeline for the laboratory schedule for one standard 15-week semester

TABLE 1.
Roles for each student in the laboratory research group and the responsibilities associated with each role.

| Role | Responsibilities |
|---|---|
| Principal Investigator | • Organize and schedule members of the group<br>• Conduct background research<br>• Write the introduction of the lab report<br>• Present the introduction material |
| Protocol Expert | • Write the protocols for the group<br>• Modify the protocols as the methods change<br>• Write the methods section<br>• Present the methods material |
| Data Expert | • Create graphs and tables as data are collected<br>• Enter data into a combined file<br>• Write the results section<br>• Present the results |
| Analysis Expert | • Analyze the data and summarize existing research as it relates to the new data<br>• Develop new hypotheses based on data<br>• Write the discussion section<br>• Present the discussion |

These roles were modified from (14).

them to engage in the experimental design process from the very start of the semester. After peer review and feedback from the graduate teaching assistant (TA), each group's preliminary research proposal was due in week three. While this format requires a great deal of work at the beginning of the semester, it allows the students to get involved in their project from the onset, provides interaction with the TA, and affords them time to modify their experimental design. By the fifth week of the semester, each group had to submit a final research proposal and list of supplies that would be required to begin their individual projects during week six. Once the research projects began, each student was required to maintain his or her own laboratory notebook and provide a weekly update to the rest of the students in the lab section. At the end of the semester, each group submitted a final lab report and gave a final presentation on their research project. This scaffolding of assignments provided students with low-stakes assessments along the way as they learned how to read and understand primary literature and as they developed their initial ideas into feasible experiments that could be conducted within the time constraints of the traditional semester. Also, by assigning each student to a particular role, it made them accountable for their participation in the group project and provided a mechanism for the TAs to assign individual grades. With the format that was used for grading throughout the semester, every student's grade was comprised of approximately 80% individual grades and 20% group grades. We found that this reduced the friction among group members that can occur when one member is not participating fully in the project.

Some students returned to the laboratory multiple times throughout each week to collect data or maintain their animals, but this time outside of the scheduled class was specific to each student's experimental design and was usually limited to less than two hours per week.

### Learning objectives

Upon completion of the *Tigriopus* CURE, students will be able to:

1. Demonstrate increased confidence in science process skills development
2. Articulate the findings of their research in written format
3. Apply quantitative reasoning skills needed to analyze student-collected research data
4. Exhibit more expert-like attitudes and motivation in the domain

## PROCEDURE

### Materials

The model system used for this CURE was the planktonic copepod *Tigriopus californicus*. This species is a common inhabitant of tide pools along the west coast of the United States, where it serves as the foundation for many marine food chains. Although its congener, *T. japonicas*, has been well studied (15–17), surprisingly little is known about the biology of *T. californicus*. This allows students to propose and empirically assess basic questions that still remain unanswered. For example, students in the pilot semester of this CURE investigated abiotic rearing conditions such as salinity, temperature, light cycle, and diet. This information can then be used to inform new questions for upcoming semesters as we continue with this model system. These plankton were also chosen because they possess a number of useful attributes for laboratory research. They are amenable to rearing under laboratory conditions with minimal equipment costs, their life cycle is brief yet complex, they possess unusual mating behaviors, are easy to sex, can tolerate a wide range of abiotic conditions, and can be ordered from Carolina Biological Supply Company at low cost. Because all students will be conducting the same laboratory exercises during the first six weeks, a supplies list is available in the Supplemental Materials (Appendix A). However, because each student group will be conducting their own experiments during weeks 7 to 14, a more general list of supplies is provided in Appendix B.

### Student instructions

An abridged version of the laboratory manual is provided in the Supplemental Materials (Appendix C).

The laboratory instructions are designed for students to work in pairs or groups of four. Students were provided with an electronic copy of the lab manual at the start of the semester, which they were then required to print out and bring to lab in its entirety. In addition to the laboratory manual, students were provided with active-learning supplemental instruction throughout the duration of the CURE, with the exception of individual sessions in which education research data were being collected or exams were being held in the lecture portion of the class. Student procedures for completing each exercise were provided either in the form of a verbal prompt or stated explicitly as part of the activity itself (for instance, as instructions on a graphic organizer handout).

### Faculty instructions

This CURE is designed to be carried out over the course of a 15-week semester during three-hour laboratory periods. For the first six weeks, specific instructions for faculty on how to set up each laboratory experiment are provided in Appendix D. However, because students begin designing their experiment during the first week of classes and then have a series of scaffolded assignments as they progress, we have provided faculty instructions for the authentic research project portion of the course in Appendix E. It is important to note that instructors will need to culture algae and copepods at the outset of the semester, and instructions for doing so are also provided in Appendix E.

### Suggestions for determining student learning

Because this CURE is designed to provide students with the opportunity to increase their content knowledge and science process skills, analyze their data, and present their research findings in both written and oral formats, there are many opportunities to evaluate student learning. Weekly quizzes were used to assess content knowledge, and these quizzes focused on the lab material for the first six weeks and then the supplemental instruction material during the remainder of the semester. In order to assess students' ability to develop a research question and design an experiment, students were required to submit their research question in week two and were provided with feedback from their TA. Based on this feedback, the students then submitted a research proposal in rough draft form and again were provided feedback before completing the final draft of the research proposal. This process allowed for scaffolding of assignments and enabled students to develop and refine their ideas as the semester progressed. To allow the instructors to track student progress during their experiments, each student was required to keep a lab notebook that was graded weekly, as well as give an oral summary of project status to date. At the end of the semester, each group was required to write a formal lab report that mimicked the format of a primary research article and that included references from the primary literature. Each group was also required to present their research to the other members in their laboratory section in the form of an oral PowerPoint presentation. The rubrics for these assignments can be found in Appendix C.

One challenge with this type of laboratory experience is providing individual grades for work performed as a group. To alleviate this issue, each student in the group chose a role (as described above) and was therefore responsible for fulfilling the components associated with that role. Additionally, much of the graded work was individual assignments such as quizzes and lab notebooks, so that by the end of the semester, the lab grade was approximately 80% individual grades and 20% group grades. We found, anecdotally, that this decreased some of the anxiety among students that is commonly observed when students must depend on others for their overall course grade.

### Sample data from student investigations

Examples of student research questions and overall results are shown in Table 2 (more examples are provided in Appendix F to aid instructors in the design process). Because much remains unknown about this research organism, students were able to start with more basic questions of rearing conditions and abiotic tolerance for their projects. Other students were more interested in toxicity effects or diet and designed their experiments accordingly. Appendix G provides an example of a final laboratory report written by students in this CURE.

### Safety issues

There are very limited safety issues associated with this CURE. Students will be working with seawater, algae, and copepods, none of which are toxic. If instructors allow students to design research projects associated with tolerance to pesticides or other toxicants, then those chemicals must be handled in accordance with their safety protocols. Each student was required to read and sign a safety agreement that is maintained at the university. This agreement is shown in the abridged lab manual (Appendix C).

## DISCUSSION

### Field testing

The *Tigriopus* CURE has been implemented in all sections of an introductory cell and molecular biology course since the spring 2015 semester. The overall enrollment in the course varies from approximately 150 students during the spring semester to 650 students during the fall semester. However, the *Tigriopus* CURE was implemented in the laboratory sections, which are limited to 24 students per section. One strength of this CURE is that it is scalable from smaller courses to those with much larger enrollments.

## Evidence of student learning

In accordance with our learning objectives, mixed methods approaches were employed to ascertain the impact of the *Tigriopus* CURE on cognitive and non-cognitive student outcomes ($n$ = 125) (Table 3). Data indicate that participation in the CURE results in a significant increase in students' development of expert-like attitudes and motivation in the domain, as well as enhancement in their self-reported confidence in designing, implementing, and evaluating their own research investigations (i.e., investigations for which they posed the initial question). These data have been previously reported (13).

With specific regard to CURE students' development of science communication (learning objective 2) and quantitative reasoning skills (learning objective 3), a modified version of the Association of American Colleges and Universities' (AAC&U) "Inquiry and Analysis," "Written Communication," and "Quantitative Literacy" VALUE rubrics (Appendix H) were used to assess end-of-semester laboratory reports ($n_{reports}$ = 12) obtained from a randomized sample of student research teams. Each report was first blinded and then evaluated by two researchers with expertise in the areas of biological sciences and bioeducation. High inter-rater reliability was observed ($\kappa = 0.85$, $p < 0.001$), with all disputes resolved through discussion between the two researchers. More broadly, descriptive analyses of students' performance on the end-of-semester reports were further conducted to determine variability in proficiency among student teams. Collectively, these data indicate that CURE students are relatively adept in areas related to topic selection, grammar/syntax, context (i.e., crafting a report targeted for a scientific audience), and interpretation of quantitative outcomes, as evidenced in their writing samples (Fig. 2). In contrast, for most other major areas assessed, students' average scores are within the "Milestone" demarcation (see Appendix H). In other words, while students do not possess low levels of proficiency on those constructs, they are presently in a state of skills development in those areas.

## Possible modifications

After three semesters of running this CURE in the introductory biology course at our institution, we have made some modifications and have some areas for potential further modifications in the future. One area of current modification has focused on the supplemental instruction, where we have included more training for the undergraduate TAs who lead the supplemental instruction and a tighter correlation between the material used in the supplemental

TABLE 2.
Example student research questions and summary of results.

| Example Research Question | Results Summary |
|---|---|
| What are the salinity tolerance limits of adult male *Tigriopus californicus*? | Multiple student projects indicate highest survival at 30–35 ppt, with a strong decline at lower salinities |
| What temperature leads to the highest reproduction? | Number of eggs produced per female was highest at 25°C |
| Do copepods survive better with a diet of fish food or algae? | Multiple student projects indicate highest survival with an algal diet |
| Is algae alone or algae plus fish food a better diet? | Survival of gravid females was highest on the combination diet |

TABLE 3.
*Tigriopus* CURE learning objectives and methods of assessment.

| Student Learning Objective | Method of Assessment |
|---|---|
| 1. Demonstrate increased confidence in science process skills development | Student Assessment of Learning Gains (SALG) questionnaire[a] |
| 2. Articulate the findings of their research in written format | Modified version of the Association of American Colleges and Universities "Written Communication" VALUE rubric (post-intervention) |
| 3. Apply quantitative reasoning skills needed to analyze student-collected research data | Modified version of the Association of American Colleges and Universities' "Inquiry and Analysis" and "Quantitative Literacy" VALUE rubrics (post-intervention) |
| 4. Exhibit more expert-like attitudes and motivation in the domain | Colorado Learning Attitudes in Science Survey—Biology (CLASS-Bio) (18); Biology Motivation Questionnaire (BMQ) (19)[a] |

[a]Data reported in (13).

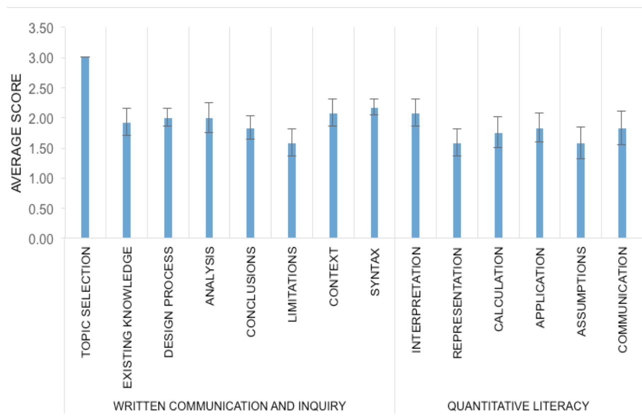


FIGURE 2. Results of the analysis of student science communication and quantitative reasoning skills as evidenced by the American Association of Colleges and Universities' VALUE Rubrics.

instruction and the material presented during the lecture portion of the course. Another modification has been to add detail to the rubrics to ensure that expectations are clear for students and to increase consistency in grading by the teaching assistants.

A possible modification for the future could include an altered timeframe. This CURE has been used for summer courses, where the semester is only six weeks long, and it could also be included in a year-long introductory course where students would be able to design more complex experiments, including those that require a longer data collection period. Additionally, because this CURE allows for a range of different experimental questions, it provides a flexible foundation for use in a variety of courses. For example, *Tigriopus californicus* can be used in toxicity testing and would be a useful organism in an introductory environmental science class. It also has some unique mating behaviors that may make it amenable to use in a class on animal behavior. The ability to modify the *Tigriopus* CURE is one of its strengths and makes it applicable in a wide range of courses.

## CONCLUSIONS

The *Tigriopus* CURE has been implemented successfully in an introductory biology course for multiple semesters and in courses with widely varying enrollment (15 to over 650 students). The addition of supplemental instruction to the CURE was a novel approach that has allowed students to review material from the lecture portion of the course, and the CURE itself has provided an opportunity for students to meet laboratory objectives. The authors hope that providing curricular information will make it easier for instructors who are interested in implementation of CUREs in their own classroom to either use this specific CURE as is or use it as a framework for creating a CURE tailored to their own individual courses. This will likely reduce the time and effort involved in creating a CURE, which is often described by faculty as a major barrier to CURE implementation.

## SUPPLEMENTAL MATERIALS

Appendix A: Materials for weeks 1–6 of the *Tigriopus* CURE
Appendix B: General supplies for research projects for the *Tigriopus* CURE
Appendix C: Abridged laboratory manual for students
Appendix D: Faculty instructions for weeks 1–6
Appendix E: Faculty instructions for the authentic research experience
Appendix F: Examples of student research questions
Appendix G: Sample student laboratory report
Appendix H: Modified version of AAC&U's VALUE rubrics

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