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66th ANNUAL MEETING

The 66th Annual ACUBE meeting is being planned for Portland, OR. ACUBE members will be receiving a poll to determine if the meeting will take place via Zoom or be held in person. Please check the ACUBE website periodically for up-to-date meeting information.

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Members of ACUBE share ideas and address the unique challenges of balancing teaching, research, advising, administration, and service.

We are a supporting and mentoring community that provides professional development opportunities to:

- develop and recognize excellence in teaching;
- incubate new and innovative teaching ideas;
- involve student research in the biology curriculum;
- advise and mentor students in and out of the classroom;
- enhance scholarship through our international, peer-reviewed journal, *Bioscene*.

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Articles

Factors for First-Year College Biology Students

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Abstract: "January Undergraduate Move Ahead Program" (JUMP) uses winter break as an opportunity to prepare small groups of scholarship students with high financial need for the second semester of their first-year biology curriculum and a career in life science. A winter intersession program has challenges, but more importantly, benefits that distinguish it from summer bridge programs. We designed JUMP to help students build their skills to succeed in lecture and laboratory courses and strengthen their bond to the major and science careers. Thus far, 26 students have participated in JUMP: 73% were female, 54% were students of color (SOC), 62% were Pell grant recipients, and 42% were first-generation college students. Our analyses indicate that the program contributes to advancement to graduation. Scholars graduated at a statistically significantly higher rate in the life sciences than other students in the same cohorts ($p=0.007$). Pell grant recipients graduated in the life sciences at a significantly higher rate than other Pell grant recipients ($p=0.009$). The majority of the participants reported that JUMP made them more comfortable in the biology department and confident in themselves as scientists. JUMP is adaptable to other institutions seeking opportunities to mitigate conditions that put student success at risk.

Keywords: undergraduate; winter break; students of color; first-generation; Pell grant

Introduction

Most college students need a new skill set for college courses, especially in life science curricula. Some pre-college situations put students at high risk of attrition from life science majors particularly in the first year of college. Students who are particularly in need are students whose high schools lacked the resources to prepare them for a rigorous science curriculum. Low-income students are disproportionately represented in this group (Kuh et al. 2006; Engle & Tinto, 2008; Executive Office of the President, 2014) yet, enrollment of low-income students is increasing nationwide (Calahan et al., 2021). We developed a five-day intersession program called January Undergraduate Move Ahead Program (JUMP) to give high financial need scholarship students a "jump ahead" for their second semester first-year biology course and a career in the life sciences.

The high-need JUMP scholars included students who were members of other groups that may experience conditions that put them at risk of attrition from life science majors. First-generation college students are one group with additional barriers to success. The first year can be particularly difficult as they lack their parents' first-year college experiences as a model of what to expect (Padgett et al., 2012). Some first-generation college students struggle with how to advocate for themselves in both academic and extracurricular situations, and how to make use of tutoring and other university services (Collier & Morgan, 2008; Cataldi et al., 2018).

Students of color (SOC) are often first-generation and low-income college students (Adams & McBrayer, 2020). Once they reach campus, SOC often face stereotyping and prejudice. Many SOC feel isolated and are subjected to microaggressions in the classroom from both other students and faculty (Banks & Dohy, 2019; Adams & McBrayer, 2020).

Variations on a theme: the diversity of winter break programs

Some colleges and universities throughout the US have seized the opportunity to develop winter intersession programs

(Marcus, 2019). Winter break programs for students starting college in the spring semester or transferring to a four-year institution (Galvez et al., 2014; Enriquez et al., 2017) are similar to summer bridge programs in that they prepare students for college life. Winter break programs for already-enrolled students are designed to increase student academic success (time management), build skills in a particular discipline (e.g., math skills), inform students about career preparation, or offer experiential learning. Langhoff & Enriquez, (2017) or research experience (Blake, et al., 2013).

Enriquez et al (2013) and Galvez et al., (2014) offer two examples of winter break programs whose outcomes have been evaluated but assessment of winter break program effectiveness is not nearly as thorough as the assessment of summer bridge programs (reviewed in Sablan, 2014; Ashley et al., 2017; Grace-Odeleye & Santiago, 2019; Bradford et al., 2021). Knowledge of winter break program specific benefits and pitfalls is clearly useful to other institutions interested in establishing such programs.

Summer bridge programs tend to focus on course content, orientation to campus, increasing social capital, and getting to know the faculty (Bradford et al., 2021). Winter break programs can be designed to focus on other knowledge and skill development that high school and Summer Bridge did not provide. JUMP focuses on building students' experimental design skills and other skills to prepare them for STEM careers. JUMP is adaptable to other institutions seeking opportunities to mitigate conditions that put student success at risk.

MATERIALS AND METHODS

JUMP: Preparing First-year Students for Second semester

Ursinus College is a liberal arts college in southeastern Pennsylvania, USA that enrolls approximately 1500 students. The JUMP scholars were all first-year students who intended to major in Biology, Biochemistry and Molecular Biology (BCMB), or Neuroscience. Each received a four-year scholarship plus the opportunity to participate in JUMP as part of a National Science Foundation (NSF) S-STEM grant. Thus far,

26 scholars participated: 73% were female, 54% were students of color (SOC), 62% were Pell grant recipients, and 42% were first-generation college students. Scholars were selected based on NSF criteria

(<https://www.nsf.gov/pubs/2020/nsf20526/nsf20526.htm>).

In addition, students were selected who: (1) used high school academic resources such as teacher office hours, (2) reported in their interview that they were likely to attend JUMP and the other programs, and (3) did not have opportunities such as research experiences in university laboratories. Most scholars worked at a job during high school and signified the intention to work during college. The grades of the scholars their first biology course (BIO101 as described below) did not differ significantly from their peers at the $p = 0.5$ level (data not shown).

The Ursinus first-year life science course sequence starts with BIO101 *Ecology and Evolution* in the fall followed by BIO102 *Cell Biology* in the spring. Both courses meet for three hours a week of lecture for 15 weeks plus 1.5 hours of laboratory each week. JUMP prepares scholars for BIO102 laboratory in which students must incorporate laboratory equipment use into an experiment of their own design. Both courses require students to read and discuss primary and secondary literature-- a new and demanding experience for nearly all students.

Program Structure

The five-day program ran Tuesday through Friday in 2017-2019 in the week prior to the start of the spring semester (Table 1).

Recruitment of Scholars

All scholars were strongly encouraged to attend JUMP, but attendance was not mandatory. A \$250 stipend was offered to every scholar to offset possible lost wages. We provided \$24 a day for meals per scholar. There were nine participants in 2017, ten in 2018, and seven in 2019.

Recruitment of Faculty

Each autumn, four faculty were recruited to participate in the program. They were compensated at \$25/hour to prepare for and participate in the program.

Recruitment of Teaching Assistant/Residence Life Assistant

A college-trained resident assistant was paid \$400 total to act as laboratory teaching assistant and resident assistant (TA/RA) during the program. Interviewees were asked about the type of evening programs they would provide, and their personal approach to academic success. Duties included laboratory preparation, organizing group meals and regular RA duties of monitoring student well-being.

Table 1. JUMP Schedule.

| | Monday | Tuesday | Wednesday | Thursday | Friday |
|-----------------|---|---|---|---|-------------------------------------|
| 8:30-9:00 AM | Prior to Arrival: Read Yeast Experiment protocol, Answer Questions | Breakfast Together | Breakfast Together | Breakfast Together | Breakfast Together |
| 9:00-10:00 AM | | Team Building | Continue Experiment | Field Trip to Museum | Tricks for Reading Textbooks |
| 10:00-11:00 AM | | Reading Primary Literature | Preparing for Internships, Jobs, Recommendations | | Lunch Downtown |
| 11:00 AM-Noon | | | Continue Experiment | | |
| noon-1:00 PM | | Lunch with Faculty | Lunch with Dean | Visit with Alums at Research Laboratory at University | Lunch with Faculty |
| 1:00-2:00 PM | | Lab Skills for Bio102 & Beyond | Reflection on Your Bio101 Study Skills | | Reading the Primary Literature |
| 2:00-3:00 PM | | Start Yeast Experiment | Microsoft Excel [®] Use in Bio102 with RA/TA | | Scholars Presentations |
| 3:00-4:00 PM | | | Panel Discussion with Older Students | | |
| 4:00 PM-5:00 PM | | | Finish experiments | | |
| 5:00-7:00 PM | | Dinner Together | Dinner Together | Dinner with Faculty and Other Scholars | Dinner Together |
| Evening | Read 1 st Primary Lit. assignment | Movie with All in Dorm & Read 2 nd Primary Lit. Assignment | Start 3 rd Primary Lit. Assignment; Go to Movies | Finish 3 rd Primary Lit. Assignment | Relax until Classes Start Wednesday |

Program Elements

Scientific Skill Development and Science Identity

JUMP activities designed to help scholars develop laboratory skills and confidence in themselves as scientists included an open-ended experiment on optimal conditions for *Saccharomyces cerevisiae* (brewer's yeast) growth. We pointed out to the scholars that we would offer JUMP to all students if possible, and that they would be able to help their fellow students in lab in BIO102. Staff pre-tested the experiment to minimize student frustration with failed experiments. The experiments occupied a significant portion of the five days. After consulting the literature, the scholars formulated a hypothesis in groups of two-three to assess growth of *S. cerevisiae* under different conditions of pH, light, temperature, and other factors. They were provided with yeast cultures and instructed in measuring growth using a spectrophotometer (Spec 20). They were provided with materials and equipment (e.g., ultraviolet light source, incubators of various temperatures) to test their hypotheses. They did their own calculations for preparing solutions. They continued to develop their Microsoft Excel® skills by analyzing their data. The scholars were instructed on how to give a PowerPoint presentation (e.g., graphic design, slide content). They gave a presentation on their experiment to the Biology Department faculty and other JUMP participants on the last day of JUMP (Table 1).

Learning Skills

Primary literature articles were read and reading skills were discussed. The scholars also met with older scholars and the RA who talked to them about well-informed course scheduling and other hints for STEM success.

Increasing Connection to the Department and Institution and Cohort Building

Some program elements were designed to foster cohort building and a sense of belonging to the department and institution. These elements are all identified as important in STEM success (e.g., Chickering & Gamsen, 1987; Kuh et al., 2006; Engel & Tinto, 2008; Tinto, 2017; Owolabi, 2018; Strayhorn, 2018, p.37). Activities to increase a sense of belonging in the department and the college included interacting with faculty at meals, bowling, and going to the

cinema to see films that provided opportunities for discussion: *Hidden Figures* and *On the Basis of Sex*. They had lunch with a dean who encouraged them to apply for additional scholarships and grants. The scholars read sample recommendation letters written for students applying for professional school, graduate school, or jobs. They were asked to consider what they could do to build their own resumes and relationships with faculty to receive similar recommendations. The scholars visited a local university laboratory where Ursinus alumni scientists described their own journeys to research jobs. Activities that focused on cohort building included breakfast together, cooking dinner together, and evening games.

Results

Comparisons were made between the scholars who attended JUMP and other students enrolled in BIO102 regarding grades and retention. The comparison groups were students in the same courses who entered the college in the same years (2016-18) with the same expected graduation year (2020-22) including all first-year students in the course and certain subsets: first-generation college students, SOC students, and Pell grant students. The sample sizes of scholars who were simultaneously SOC, first-generation and/or Pell grant were too low (fewer than ten) to compare to the same group in the general student population.

Course Grade and Retention in BIO102

To determine if the scholars derived benefit from JUMP, average course grade of the JUMP scholars was compared to that of their peers through a Mann Whitney U test using SPSS. There was a trend toward JUMP scholars performing better than their peers, but there was no statistically significant difference between the JUMP scholars and the comparison groups listed immediately above at the p = 0.05 level (Table 2).

To measure retention through BIO102 the proportion of students successfully completing the course with a passing grade (A+ through D- grade vs. withdrew or F grade) among the scholars vs. their peers was also assessed. The scholars' rate of completion of BIO102 was 100% (no failures). Although this result indicated a trend toward the scholars performing better than their peers, this result was not statistically significantly different from the results of their peer groups (Table 2).

Table 2. Performance and Retention of JUMP Scholars and comparison groups in BIO102

| Student Group | BIO102 Grade | Withdrawals and Failing Grades | Retention through BIO102 |
|---------------------------|-------------------|--------------------------------|--------------------------|
| JUMP | N=26 2.73±0.84 | N= 26 0 W, 0 F | 100% 26/26 |
| All Others | N=407 2.60±0.95 | N = 407 9 W, 9 F | 95.6% 398/416 |
| JUMP 1 st Gen | N=11 2.58±1.00 | N = 11 0 W, 0 F | 100% 11/11 |
| Other 1 st Gen | N= 120 2.42± 0.97 | N= 122 2 W, 5 F | 94.3% 115/122 |
| JUMP SOC | N=14 2.67±1.0 | N= 14 0 W, 0 F | 100% 14/14 |
| Other SOC | N= 87 2.38±0.97 | N= 88 1 W, 5 F | 93.2% 82/88 |
| JUMP Pell Grant | N=16 2.67±0.87 | N= 16 0 W, 0 F | 100% 16/16 |
| Other Pell Grant | N= 71 2.47± 1.0 | N = 71 2 W, 3 F | 93% 66/71 |

Grade means ± standard deviation on 4.0-point scale, number of withdrawals (W) and failing (F) grades, and percent retention. There were no statistically significant differences between JUMP scholars and other groups.

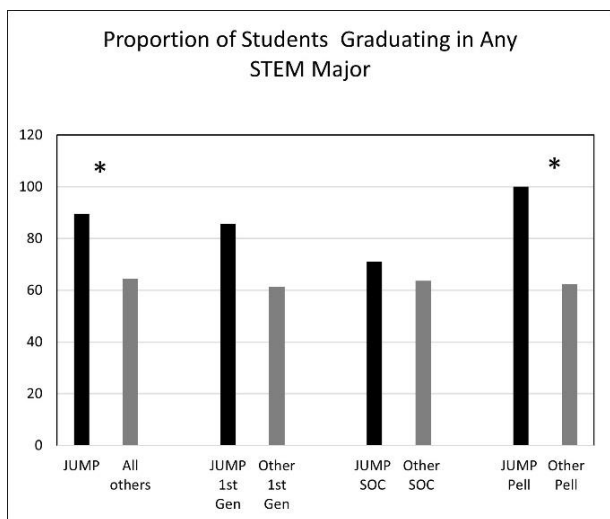
Retention to Graduation in Four Years

Retention to graduation was analyzed for the first two cohorts; the third cohort are seniors in the 2021-22 academic year. Students do not declare their major upon matriculation, therefore a method was devised to determine if first-year students who intended to major in the life sciences were retained to graduation in the life sciences. To that end, enrollment in BIO101 as a first-year undeclared science major was used to indicate that a student intended to major in a life science (Biology, BCMB, Environmental Studies, Health and Exercise Physiology, and Neuroscience) because enrollment in BIO101 is recommended to first-year students intending to pursue these majors and only these majors. Students who left the college or left the life sciences and graduated in a different major were counted as not retained in the life sciences. Some students who enrolled in BIO101 ultimately graduated in another major in the STEM division (chemistry, physics, or math and computer science) therefore a second comparison was made using all STEM graduates for a more conservative estimate of retention. Students who left the college or left the life sciences and graduated in a different major were counted as not retained in STEM.

The four-year graduation rate in the life sciences observed among the JUMP scholars (17/19) was statistically significantly higher ($p = 0.007$) than that of other first year undeclared science students ($N= 152/259$) using a Fisher exact test (Figure 1). JUMP Pell grant scholars also graduated ($N=10/10$) at a significantly higher rate ($p = 0.009$) than other Pell grant students enrolled in BIO101 ($N=22/40$). The difference in graduation rates in the life sciences between the SOC students and between scholars who were first-generation college students ($N=7$) and other first-generation college students was not tested due to sample size in these groups.

Figure 1. Fisher Exact tests of the difference in retention to graduation between scholars and the general student population and the Pell eligible student subgroup.

*Indicates data were statistically significant at the 0.05 level.

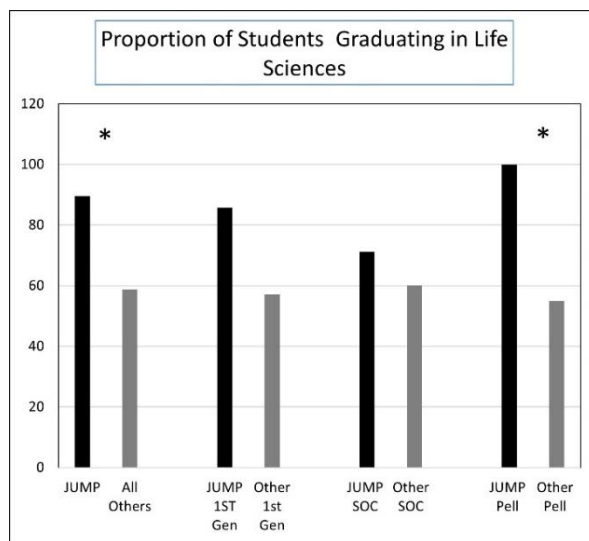


The first-generation and students of color data were not tested by a Fisher Exact test as the JUMP scholars' samples were fewer than ten scholars.

The four-year graduation rate in STEM observed among the JUMP scholars (17/19) was statistically significantly higher

($p = 0.025$) than that of the general population of students who took BIO101 ($N= 167/259$) using a Fisher exact test (Figure 2). JUMP Pell grant scholars also graduated ($N=10/10$) at a significantly higher rate ($p = 0.022$) than other Pell grant students enrolled in BIO101 ($N=25/40$). The difference between the SOC scholars who graduated ($N=7$) in STEM and other first-generation college students was not tested due to sample size in these groups.

Figure 2. Fisher Exact tests of the difference in retention to graduation between scholars and the general student population and the Pell eligible student subgroup



*Indicates data were statistically significant at the 0.05 level. The first-generation and students of color data were not tested by a Fisher Exact test as the JUMP samples were fewer than ten scholars.

Scholar Perceptions of JUMP

Scholars completed anonymous surveys about the JUMP program immediately after the program, and after they completed BIO102 (Table 3 & 4). A Fisher exact test was used to test for change in responses between the first and second survey. The scholars reported that they had a positive experience in JUMP in the first survey. All respondents agreed or strongly agreed that formulating a hypothesis, practicing laboratory skills, and practicing calculations helped to prepare them for BIO102 and that they became better acquainted with other scholars (Table 3). Most agreed or strongly agreed that practice reading the primary literature and learning how to give a PowerPoint presentation were useful and that JUMP made them feel more at home in the Biology Department (where most life science faculty reside). We asked the scholars which academic and social activities to retain in the program for the following year. Over 75% of the scholars felt that the laboratory visit with alumni scientists, the science museum visit, lunch with faculty, and meals together should be retained in the program

Student survey responses about the JUMP program were again positive after they completed BIO102 (Table 4). There was a significant decrease in the proportion of scholars (4 of 22 scholars) who felt that JUMP gave them greater confidence in themselves in the major, which was statistically significant

using a Fisher exact test ($p = 0.04$). There were no other statistically significant differences using a Fisher exact test between the answers given immediately after JUMP and the answers given after BIO102. We asked the scholars which academic and social activities we should retain in the program in subsequent years in both the post-JUMP and the post-BIO102 survey. None of the differences in answers were statistically significant at the $p \leq 0.05$ level.

We considered other programs designed to increase student success in which students might enroll and the salutary effect of these programs on grades and retention. The other programs are tutoring, co-curricular program (skills building), intensive advising, and recitation (content reinforcement). No data is available on tutor use prior to Spring 2019. No scholars used tutors in Spring 2019. Of the

Table 3. Survey given at the end of the last day of JUMP to three cohorts of scholars who participated in the program.

| Truncated Survey Questions | Strongly Agree | Agree | Disagree | Strongly Disagree | Total Responses |
|--|----------------|-------|----------|-------------------|-----------------|
| Formulating a hypothesis, a useful experience for BIO102 | 57.6% | 42.3% | 0.0% | 0.0% | 26 |
| Lab skills good practice for BIO102 | 61.5% | 38.4% | 0.0% | 0.0% | 26 |
| Practicing Lab calculations helped prepare me for BIO102 | 41.0% | 58.8% | 0.0% | 0.0% | 17 |
| Practicing PowerPoint presentations useful | 52.9% | 41.1% | 5.8% | 0.0% | 17 |
| Lessons on primary literature reading useful for BIO102 | 42.3% | 46.5% | 11.5% | 0.0% | 26 |
| JUMP made me feel more at home in Biology Dept. | 61.5% | 30.8% | 7.9% | 0.0% | 26 |
| JUMP made me more confident about my major | 65.4% | 34.6% | 0.0% | 0.0% | 26 |
| Stipend major motivation for participation | 11.1% | 66.7% | 22.2% | 0.0% | 9 |
| JUMP allowed me to get to know other scholars better | 91.3% | 8.6% | 0.0% | 0.0% | 23 |

Nine scholars in 2017, ten scholars in 2018, and seven scholars in 2019 for a total of 26 participants. One scholar in 2018 did not complete the survey at all, and not all participants responded to all questions. The question about the stipend was asked only in 2018.

Table 4. Survey given in the fall following BIO102 to three cohorts of scholars

| Truncated Survey Questions | Strongly Agree | Somewhat Agree | Neither Agree nor Disagree | Somewhat Disagree | Strongly Disagree | Total Responses |
|--|----------------|----------------|----------------------------|-------------------|-------------------|-----------------|
| Formulating a hypothesis a useful experience for BIO102 | 63.6% | 31.8% | 4.5% | 0.0% | 0.0% | 22 |
| Lab skills good practice for BIO102 | 81.8% | 9.1% | 9.1% | 0.0% | 0.0% | 22 |
| Practicing Lab calculations helped prepare me for BIO102 | 68.2% | 27.3% | 4.5% | 0.0% | 0.0% | 22 |
| Practicing PowerPoint presentations | 84.6% | 7.7% | 7.7% | 0.0% | 0.0% | 13 |
| Lessons on primary literature reading useful for BIO102 | 54.5% | 36.3% | 9.1% | 0.0% | 0.0% | 22 |
| JUMP made me feel more at home in Biology Dept. | 63.6% | 22.7% | 13.6% | 0.0% | 0.0% | 22 |
| JUMP made me more confident about my major | 59.0% | 22.7% | 18.1% | 0.0% | 0.0% | 22 |
| Stipend major motivation for participation | 31.8% | 31.8% | 36.4% | 0.0% | 0.0% | 22 |
| Valuable to create a sense of community through JUMP | 77.3% | 18.2% | 4.5% | 0.0% | 0.0% | 22 |

Nine scholars responded in 2017, nine scholars in 2018, and four scholars responded in 2019 for a total of 22 responses. The Likert scale and the wording of one question were changed in the post-BIO102 survey for greater resolution of responses. The same two surveys were used in all three years.

scholars who attended JUMP, seven scholars out of the three cohorts fully attended (attended at least seven of the eight sessions) the co-curricular program. A total of 24 non-scholars fully attended the co-curricular program over the three-year period. Due to these low sample sizes, these data were not analyzed further. Records were not kept of student visits to office hours.

DISCUSSION

Course Grade and Retention in BIO102

The JUMP scholars succeeded in BIO102. Although there was a trend toward JUMP scholars earning higher grades and persisting through BIO102 at a higher rate than their peers, the differences between the JUMP scholars and their peers were not statistically significantly different, perhaps due to sample size in the scholar groups.

The JUMP scholars graduated at a statistically significantly higher rate than other life science majors and other STEM majors. While we cannot attribute this outcome solely to JUMP, it is apparent that JUMP is helping scholars to attain their academic goals. The aptitude and hard work of the scholars, even though many of them still worked at a job for 3-30 hours a week during college, was probably the strongest contributor to their success. We did not analyze the rate of advancement into science careers due to incomplete and constantly chasing information on graduates. Anecdotally, we note that of the scholars who have graduated, four were inducted in Phi Beta Kappa. Of the 18 graduates, two are seeking employment in STEM, one is accepted to veterinary school, one is applying to medical school, and the others are in graduate school, working for biotech firms, or government or university research labs.

Scholar Perceptions of JUMP

The scholars' own perceptions of the JUMP program were important evidence of the success and benefit of JUMP. The scholars' responses to the surveys indicated that they had a positive experience. Making students feel at home at their institution is important to their success (Kuh et al., 2006; Walton & Cohen, 2011; Owolabi, 2018) as well as their confidence in themselves as scientists (Carlone & Johnson, 2007; Cole, & Espinoza, 2008; Martin-Hensen, 2018). Four of the 22 scholars who reported feeling more confident of themselves as life science majors immediately after the JUMP program reported feeling less confident a few months later after completing BIO102. We take this result seriously; we have instituted a program through a second NSF grant to provide scholars with more academic support in their sophomore year.

Challenges of winter break programs

Some aspects of college winter breaks may require innovative solutions to carry out a JUMP-type program. A plan for meals must be made if the dining services are closed. Students may not have transportation to buy food, utensils to cook, or access to a dormitory kitchen, and it is difficult to make economic purchases of staples for five days. Issuing funds to students requires time-consuming bookkeeping for reimbursements. Eventually we supplied all meals every day to the students. It was efficient and effective at cohort-building.

Faculty buy-in is essential for any new program, including winter break programs. For institutions on a two

semester (Fall-Spring) schedule, faculty may not be available for a winter break program (Galvez et al., 2014); January is a time for rejuvenation, family life, and preparation for the spring semester. Faculty compensation is helpful, but an interest in helping students to reach their full potential is a strong motivator.

Student safety on campus over winter break is a consideration. None of the JUMP scholars was alone on a dormitory floor during JUMP because athletes were on campus and a resident advisor was present. So that the scholars did not need to arrange and pay for transportation home and back to campus again, we allowed scholars to stay on campus through the weekend after the program until the semester began. Student health is also a consideration- we informed the scholars far in advance that the college wellness facility was closed in winter so that scholars could make other arrangements for health care or opt out of JUMP.

Benefits of winter break programs

Winter break provides an opportunity to focus on scientific skills and science identity rather than orientation to campus and other topics common to summer bridge programs. An advantage of winter break programs, no matter what the pedagogical content might be, is that they keep students intellectually engaged during a long period of academic inactivity. Loss of discipline-specific skills has been shown to occur over long breaks from academic pursuits (Van de Sande & Reiser, 2018). We were concerned that it would be difficult to convince students to return to campus in the last few days of winter break. On the contrary, by the third week of the winter vacation, students were ready to return to campus. Further, winter break programs can take advantage of local scientific resources, especially those that are inaccessible during the semester due to students' course schedule constraints.

The JUMP program at Ursinus College has a positive impact on scholars: they feel comfortable in the Biology Department and confident about themselves as science majors. Other institutions could use winter break to develop JUMP-type programs that provide opportunities for small groups of students to work closely with faculty and other staff to address the specific needs of the students. Ursinus College will continue this program in the coming years. We are looking forward to inviting a wider variety of students to participate.

Acknowledgements

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REFERENCES

- Adams, T.L., & McBrayer, J.S. (2020). The lived experiences of first-generation college students of color integrating into the institutional culture of a predominantly white institution. *The Qualitative Report*, 25(3): 733-756.
- Ashley, M., Cooper, K.M., Cala, J.M., & Brownell, S.E. (2017). Building better bridges into STEM: A synthesis of 25 years of literature on STEM summer bridge programs. *CBE—Life Sciences Education*, 16(4): es3.
- Banks, T., & Dohy, J. (2019). Mitigating barriers to persistence: A review of efforts to improve retention and graduation rates for students of color in higher education. *Higher Education Studies*, 9(1): 118-131.
- Blake, R.A., Liou-Mark, J. & Chukuigwe, C. (2013). An effective model for enhancing underrepresented minority participation and success in geoscience undergraduate research. *Journal of Geoscience Education*, 61(4): 405-414.
- Bradford, B.C., Beier, M.E. & Oswald, F.L. (2021). A meta-analysis of university STEM summer bridge program effectiveness. *CBE—Life Sciences Education*, 20(2) p.ar 21-14.
- Cahalan, M.W., Addison, M., Brunt, N., Patel, P. R., & Perna, L.W. (2021). *Indicators of higher education equity in the United States: 2021 historical trend report*. <http://pellinstitute.org/indicators>.
- Carlone, H.B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, 44(8): 1187-1218.
- Cataldi, E.F., Bennnett, C.T., & Chen, X. (2018). *First-generation students: College access, persistence, and postbachelor's outcomes*. *Stats in brief*. NCES 2018-421. National Center for Education Statistics. <https://files.eric.ed.gov/fulltext/ED580935.pdf>.
- Chickering, A.W., & Gamson, Z. F. (1987). Seven principles for good practice in undergraduate education. *AAHE bulletin*, 3:7.
- Cole, D., & Espinosa, A. (2008). Examining the academic success of Latino students in science technology engineering and mathematics (STEM) majors. *Journal of College Student Development*, 49(4): 285-300.
- Collier, P.J., & Morgan, D.I. (2008). "Is that paper really due today?" Differences in first-generation and traditional college students' understandings of faculty expectations. *Higher Education*, 55(4): 425-446.
- Engle, J., & Tinto, V. (2008). *Moving beyond access: College success for low-income, first-generation students*. http://www.pellinstitute.org/publications/Moving_Beyond_Access_2008.shtml.
- Enriquez, A., Hum, D., Woo C., Price, B., Redding-Lapuz, D., & Camacho, A. (2013). Creating accelerated educational pathways for underprepared STEM students through an intensive math placement test review program. *Proceedings: 2013 American Society of Engineering Education PSW Conference*, 18-20.
- Executive Office of the President. (2014). *Increasing College Opportunity for Low Income Students* <http://www.obamawhitehouse.gov/archives>.
- Galvez, G., Martinez, E., & Monge, A. (2014). HSI STEM: Research opportunities to improve retention an increase the pipeline to graduate school. *Proceedings: 2014 American Society of Engineering Education Zone IV Conference*, Long Beach, CA.
- Grace-Odeleye, B., & Santiago, J. (2019). A review of some diverse models of summer bridge programs for first-generation and at-risk college students. *Administrative Issues Journal: Connecting Education, Practice, and Research* 9(1): 35-47.
- Kuh, G.D., Kinzie, J.L., Buckley, J.A., Bridges, B.K., & Hayek, J.C. (2006). *What matters to student success: A review of the literature* (Vol. 8). Washington, DC: National Postsecondary Education Cooperative. https://nces.ed.gov/npec/pdf/Kuh_Team_Report.pdf.
- Langhoff, N.P., & Enriquez, A.Z. (2017). *Development and Implementation of an Introduction to Research Winter Internship Program for Underrepresented Community College Students*. In 2017 ASEE Annual Conference & Exposition.
- Marcus, J. (2019). *Some colleges start using their long winter breaks to help students plan for jobs*. <http://www.hechingerreport.org/>
- Martin-Hansent, L. (2018). Examining ways to meaningfully support students in STEM. *International Journal of STEM Education*, 5(1): 1-6.
- Owolabi, E. (2018). Improving student retention, engagement and belonging. *Lutheran Education Journal*, 148 58-72.
- Padgett, R.D., Johnson, M.P., & Pascarell, E.T. (2012). First-generation undergraduate students and the impacts of the first year of college: Additional evidence. *Journal of College Student Development*, 53(2) 243-266.
- Sablan, J.R. (2014). The challenge of summer bridge programs. *American Behavioral Scientist*, 58(8) 1035-1050.
- Strayhorn, T.L. (2018). *College students' sense of belonging: A key to educational success for all students*. Routledge, New York
- Tinto, V. (2017). Through the eyes of students. *Journal of College Student Retention: Research, Theory & Practice*, 19(3) 254-269.
- Van De Sande, C. and Reiser, M. (2018). The Effect of Summer Break on Engineering Student Success in Calculus. *International Journal of Research in Education and Science*, 4(2): 349-357.
- Walton, G.M., & Cohen, G.L. (2011). A brief social-belonging intervention improves academic and health outcomes of minority students. *Science*, 331(6023): 1447-1451.

Cyber Peer Led Team Learning (cPLTL) Supports Marginalized Groups, Including Women, in Science, Technology, Engineering, and Mathematics (STEM)

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Abstract: Peer Led Team Learning (PLTL) is an active learning model that is particularly effective for improving the academic achievement and retention of students who have been marginalized in Science, Technology, Engineering, and Mathematics (STEM), such as women, and members of underrepresented minority groups. Cyber Peer Led Team Learning (cPLTL) is a recently developed variation of PLTL that has been transitioned from a face-to-face environment to a synchronous online setting. Studies have found that PLTL and cPLTL students earned comparable educational outcomes in terms of standardized final exam scores and final course grades. Given the benefits of PLTL for marginalized students and the similarities of cPLTL to PLTL, we were interested in understanding the impact that cPLTL had on marginalized groups, including women, in an introductory biology course at a large, research-intensive institution. We found evidence that participating in cPLTL improves the retention of marginalized groups in STEM, and that student perceptions of cPLTL are generally high, especially for women. Participating in cPLTL may have several additional benefits, such as increased motivation, feelings of belonging, comfort in asking questions, and understanding of course content.

Keywords: Peer led Team Learning, cyber Peer Led Team Learning, achievement, retention, perceptions, women, first-generation college student, BHA student, STEM, introductory biology, online learning.

Introduction

For over a decade, major professional organizations have called to reform traditional Science, Technology, Engineering, and Mathematics (STEM) education by using more active learning pedagogies (AAAS, 2011; NCR, 2012). These calls were based on a large and growing body of evidence that has repeatedly confirmed that active learning is a more effective and equitable teaching method than the traditional lecture, regardless of discipline, class size, or course level (Freeman et al., 2014; Theobald et al., 2020).

Among various active learning strategies, Peer Led Team Learning (PLTL; Gosser et al., 1996) is a well-studied instructional model that is often implemented within the context of a large-enrollment gateway course. During a PLTL workshop, groups of six to eight students work collaboratively towards solving a prescribed problem set related to the conceptual content of a course they are taking together. These groups are guided by a peer leader who succeeded in the course during a previous semester by earning a final grade of A or B, and thus was recruited to be a peer leader. Their role is to facilitate teamwork, discussion, and problem solving within the group; not to lecture or tutor the group. The students meet with the same group and peer leader every week to build a sense of community and to develop as a team.

The positive effects PLTL has on undergraduate students has been well documented in a variety of contexts (Snyder et al., 2016; Wilson & Varma-Nelson, 2016). Several studies reported that PLTL students experienced higher academic achievement and improved retention in STEM courses than non-PLTL students (Wilson & Varma-Nelson, 2016). In fact, PLTL is particularly effective for improving the academic achievement and retention of groups of students who have historically been marginalized in STEM (Sloane et al., 2021; Snyder et al., 2016). For example, several studies have shown that women who participate in PLTL achieve higher course grades; lower attrition rates; and lower frequencies of “D”, “F”, or withdrawal (DFW) grades than women who do not participate in the program (Drane et al., 2014; Horwitz & Rodger, 2009; Preszler, 2009; Quitadamo et al., 2009).

Student perceptions of the benefits of PLTL tend to be positive as well. Students have reported that they perceived the PLTL workshop to improve their content understanding, problem solving skills, critical thinking skills, self-efficacy, and

sense of belonging within a course (Wilson & Varma-Nelson, 2016; Wilton et al., 2019). Additionally, students have reported that participating in the PLTL workshops reduced their course-related anxiety (Wilson & Varma-Nelson, 2016).

Cyber Peer Led Team Learning (cPLTL) is a newer and comparatively under-researched variation of PLTL in which student workshops are conducted in a synchronous online setting rather than an in-person context (Mauser et al., 2011). cPLTL was initially developed to provide active learning opportunities to a wider, more diverse student body by creating more flexible scheduling and attendance options. Studies have found that PLTL and cPLTL students earned comparable educational outcomes in terms of standardized final exam scores and final course grades (Mauser et al., 2011; Smith et al., 2014). One study found that students who participated in the PLTL workshop tended to report more positive perceptions of their workshop experiences than cPLTL students, however perceptions of both programs were very positive (Smith et al., 2014).

Further studies demonstrating that cPLTL is effective at improving students’ academic achievement and retention across different campuses, disciplines, and student populations are needed to support wider adoption of the program. Special attention should be given to determining the impact of cPLTL for students from marginalized groups because these groups are subjected to programmatic barriers. Programmatic barriers, such as competitive rather than collaborative gateway courses, can make it difficult for marginalized students to succeed in STEM because students must reach a certain level of achievement to pass through the barrier and move on to the next level.

Here, we investigate the effects of cPLTL on marginalized groups at a large, private, research-intensive (Carnegie R1 designation) university in the Northeastern United States, with a special focus on the program’s impacts for women. This study aims to address the following questions:

- (1) Is participation in cPLTL associated with higher achievement/retention among particular groups of students, including women, in the context of a large-enrollment introductory biology course?
- (2) What perceptions do women hold with regards to their cPLTL experience?

Given the previously shown benefits for marginalized students in traditional PLTL programs and given the many similarities of cPLTL to traditional PLTL, we expected that participation in cPLTL would be associated with higher achievement/retention among women, and that students would generally have positive perceptions of cPLTL.

Methods

Setting and Participants

Our study institution has a well-established PLTL program associated with its introductory biology course, which serves mostly freshman and is open to STEM and non-STEM majors (Sloane et al., 2021; Snyder et al., 2015; Snyder et al., 2016; Winterton et al., 2020). During the Fall 2020 semester, the introductory biology course and its associated PLTL program were transitioned to an online format due to constraints imposed by the COVID-19 pandemic. Unlike other cPLTL studies, we were not able to have a PLTL comparison group because of the circumstances. Therefore, we do not attempt to evaluate whether cPLTL results in comparable student outcomes as PLTL, rather we explore the impact of the cPLTL program individually.

Student demographic information is summarized in Table 1. This information came from institutional data, so we are not able to determine if any students identified beyond the binary with regard to gender. Six hundred and fifteen students (33.1% identifying as men: 66.9% identifying as women) enrolled in introductory biology, of whom 145 (20.7% identifying as men: 79.3% identifying as women) enrolled in the cPLTL program. There were four students for whom gender data was not available. A larger proportion of women opted in to cPLTL than what was represented in the whole class, showing that women preferentially chose to participate in cPLTL, $\chi^2(1, N=611) = 13.1472, p = 0.0003$.

Table 1. Percent of students of each demographic group enrolled in introductory biology and in cPLTL.

| Demographic Group | Course (n=615) | cPLTL (n=145) |
|--------------------------------------|----------------|---------------|
| Gender Identity | | |
| Woman* | 66.9 | 79.3 |
| Man* | 33.1 | 20.7 |
| Race/Ethnicity | | |
| BHA | 26.8 | 24.5 |
| Non-BHA | 73.2 | 75.5 |
| Generation | | |
| First-generation college student | 23.9 | 22.4 |
| Non-first-generation college student | 76.1 | 77.6 |

* Indicates significant differences between proportion of students enrolled in cPLTL vs. the whole course.

Within the course, 26.8% of students identified as Black or African American, Hispanic or Latino, or American Indians or Alaska Natives (BHA). First generation college students made up 23.9% of students in the course. There does not appear to have been a selection bias for BHA students ($\chi^2(1, N=601) = 0.4998, p = 0.4796$) or first-generation college

students ($\chi^2(1, N=586) = 0.2382, p = 0.6255$), as similar proportions enrolled into cPLTL as was represented in the entire course. Race/ethnicity data was missing for 14 students, and parental education information was missing for 29 students.

Implementation

Recruitment for participation in cPLTL took place during class time. Students were shown the results of prior studies (Snyder et al., 2015; Snyder et al., 2016) to highlight the benefits of the PLTL pedagogy. All students had equal opportunity to opt in to the cPLTL program at the beginning of the semester, and no student groups were encouraged to participate more than others.

There were 36 cPLTL groups, each consisting of 5-8 students. Eleven sessions were offered throughout the semester that lasted 50 minutes each. cPLTL sessions occurred outside of regular class time and attendance was encouraged but not mandatory. At the end of the semester, students received a small amount of extra credit for each PLTL session they attended. Unlike other cPLTL studies, we did not provide students with microphones/headsets, webcams, or document cameras (Mauser et al., 2011; Smith et al., 2014; Wilson & Varma-Nelson, 2021). Peer leaders participated in weekly training sessions where they reviewed course content and pedagogical practices. They received course credit as compensation for being a peer leader.

Data Collection and Analysis

Student course grades, withdrawal status, and demographic data were provided by the course instructors and the Office of Institutional Research. While studies reporting on DFW rates often construe this as a measure of achievement, the W in DFW, which stands for “withdrawal”, is also related to retention in the course. Thus, achievement is difficult in some cases to disassociate from retention.

The introductory biology course at our study institution may act as a programmatic barrier because students must earn a C+ or better in the course to declare biology as their major, and/or to meet prerequisite requirements for upper-division courses. Therefore, we decided to focus on the proportion of students earning less than C+ or withdrawing from the course (%CDFW) as a critical measure of achievement and/or retention. Students who achieved a C+ or better in the course were considered to have successfully navigated programmatic barriers, while students who earned a C or less were considered to still have “barriers remaining”. A Chi-squared test was conducted to determine if there were significant differences between cPLTL and non-cPLTL groups in this regard.

Our institution provides optional individual and group tutoring sessions for students in the study course through its Center for Learning and Student Success (CLASS). Data regarding the number of tutoring sessions attended by each student in the course was collected from CLASS so that we could consider the data in light of this potentially confounding variable. Only students who participated in three or fewer of the weekly CLASS tutoring sessions were included in statistical analyses. Of these 595 students, 394 (66.2%) were women, 158 (26.6%) were BHA students, 136 (22.9%) were first-generation college students, and 137 (23.0%) participated in cPLTL.

To explore perceptions of our cPLTL program, students were invited to participate in an online post-course survey. Students were recruited through the course Blackboard site and were awarded a small amount of extra credit for participating. The survey consisted of 15 statements that students responded to using a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree), a question asking students if they would recommend cPLTL to a friend, and an open-ended question for respondents to share any additional details about their cPLTL experience. The percentage of students who somewhat agreed, agreed, or strongly agreed with each statement was summed to determine the percent of students who agreed with each statement. Conversely, the percent of students who somewhat disagreed, disagreed, or strongly disagreed with each statement was summed to determine the percent of students who disagreed with each statement. A Chi-squared test was conducted to determine if there were statistically significant differences in the rate of agreement between men and women, BHA and non-BHA students, and first-generation and non-first-generation college students.

Results

Comparison to Previous Semesters

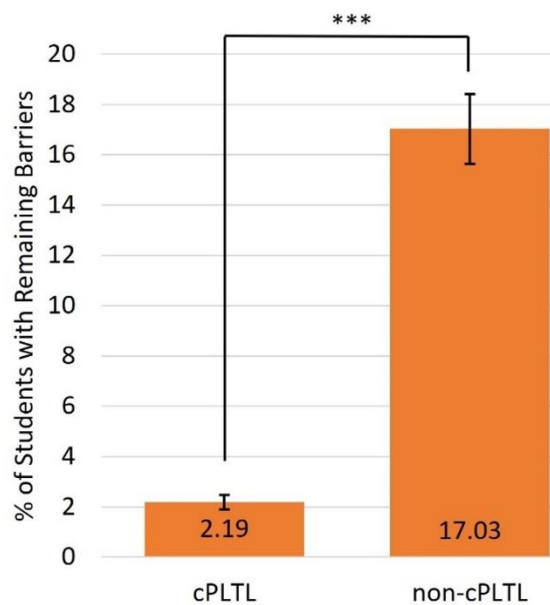
A chi-square test indicated that there was no significant difference in the proportion of students earning CDFW in the introductory biology course between the 2020 and 2019 iterations ($\chi^2 (1, N=1065) = 0.8481, p = 0.3571$). For students who participated in PLTL in 2019 or cPLTL in 2020, there was no significant difference in the proportion of students who earned CDFW ($\chi^2 (1, N = 368) = 0.0234, p = 0.8785$).

Academic Achievement/Retention

Participating in cPLTL was associated with a smaller proportion of students being left with remaining barriers, $\chi^2 (1, N= 595) = 19.7501, p < 0.0001$ (Figure 1). For non-cPLTL students, 17.03% (78/458) were left with remaining barriers, as compared to only 2.19% (3/137) of cPLTL students.

This trend held true when looking specifically at women ($\chi^2 (1, N= 349) = 12.7748, p = 0.0004$), BHA students ($\chi^2 (1, N= 158) = 6.8680, p = 0.0088$), and first-generation college students ($\chi^2 (1, N= 136) = 6.5083, p = 0.0107$; Table 2). For women, 14.39% (41/285) of non-cPLTL students were left with remaining programmatic barriers, as compared to only 1.83% (2/109) of cPLTL students. For BHA students, 22.58% (28/124) of non-cPLTL students were left with programmatic barriers remaining, as compared to only 2.94% (1/34) of cPLTL students. Similarly, 28.57% (30/105) of first-generation college students who did not participate in cPLTL were left with remaining programmatic barriers, as compared to only 6.45% (2/31) of cPLTL students.

Figure 1: Percentage of students with remaining barriers in introductory biology. Bars represent standard error of percent.



*** Indicates significance of chi-square test at $p < 0.0001$.

Perceptions

Three-quarters (104/137, or 75.91%) of cPLTL students completed the post-course survey and overall, responses were positive. For the most part, agreement rates for each statement were around 75% while disagreement rates for most statements were around 10% or less (Table 3). About 83% of respondents agreed they were satisfied with their overall cPLTL experience (Table 3; Figure 2), and about 76% of respondents reported that they would recommend online PLTL to a friend (Figure 3).

The statements with the lowest rate of agreement (“Participating in online Peer Led Team Learning helped me form relationships with other students in the course” and “Participating in online Peer Led Team Learning helped me improve my self-confidence”) were still rather positive, with 64% agreement (Table 3; Figure 4; Figure 5). Statements with the highest level of agreement were “Participating in online Peer Led Team Learning helped me learn the course material” with almost 88% agreement, “I am comfortable asking questions during online Peer Led Team Learning workshops” with 86.83% agreement, and “My Peer Leader was able to provide supportive feedback during the online Peer Led Team Learning workshops” with 85.27% agreement (Table 3; Figure 4; Figure 6).

Table 2. Percent of cPLTL and non-cPLTL students with remaining barriers in introductory biology.

| Student group | Non-cPLTL (n=458) | | cPLTL (n=137) | | p |
|-------------------|-------------------|---------------------------|---------------|---------------------------|--------|
| | n | % with remaining barriers | n | % with remaining barriers | |
| Women (n=394) | 41 | 14.39 | 2 | 1.83 | 0.0004 |
| BHA (n=158) | 28 | 22.58 | 1 | 2.94 | 0.0088 |
| First-gen (n=136) | 30 | 28.57 | 2 | 6.45 | 0.0107 |

Table 3. Percentage of respondents (N=104) who agree, neither agree nor disagree, or disagree with each statement.

| Statement | % Disagree | % Neither | % Agree |
|---|------------|-----------|---------|
| <i>I am satisfied with my overall online Peer Led Team Learning Experience.</i> | 8.53 | 8.53 | 82.95 |
| <i>I am comfortable asking questions during online Peer Led Team Learning workshops.</i> | 7.75 | 5.43 | 86.83 |
| <i>My Peer Leader was able to provide supportive feedback during the online Peer Led Team Learning workshops.</i> | 5.43 | 9.30 | 85.27 |
| <i>Participating in online Peer Led Team Learning helped me learn the course material.</i> | 3.89 | 8.53 | 87.59 |
| <i>Participating in online Peer Led Team Learning improved my ability to work as a part of a team.</i> | 10.09 | 17.83 | 72.09 |
| <i>Participating in online Peer Led Team Learning improved my ability to communicate effectively.</i> | 10.80 | 18.60 | 71.31 |
| <i>Participating in online Peer Led Team Learning improved my ability to solve problems.</i> | 9.30 | 16.28 | 74.42 |
| <i>Participating in online Peer Led Team Learning improved my motivation to learn general biology.</i> | 11.63 | 13.95 | 74.42 |
| <i>Participating In online Peer Led Team Learning improved my performance in general biology.</i> | 6.99 | 15.50 | 77.52 |
| <i>Participating in online Peer Led Team Learning improved my self-confidence.</i> | 17.83 | 18.60 | 63.56 |
| <i>Participating in online Peer Led Team Learning helped me form relationships with other students in the course.</i> | 17.83 | 17.83 | 64.35 |
| <i>Participating in online Peer Led Team Learning made me feel included in the course.</i> | 9.31 | 19.38 | 71.31 |
| <i>Participating in online Peer Led Team learning made the course material more interesting.</i> | 12.40 | 18.60 | 68.99 |

Figure 2. Student responses to the statement “I am satisfied with my overall online Peer Led Tam Learning experience.”

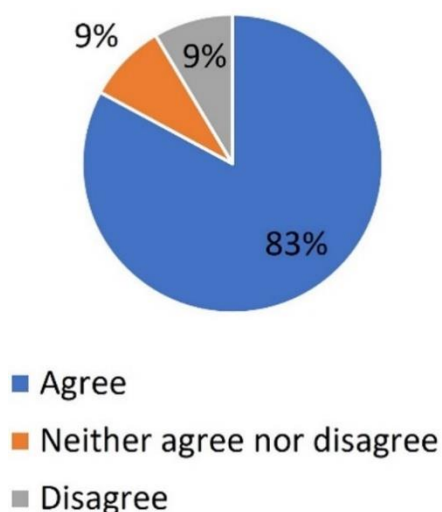


Figure 3. Student responses to the question “Would you recommend online Peer Led Team Learning to a friend?”

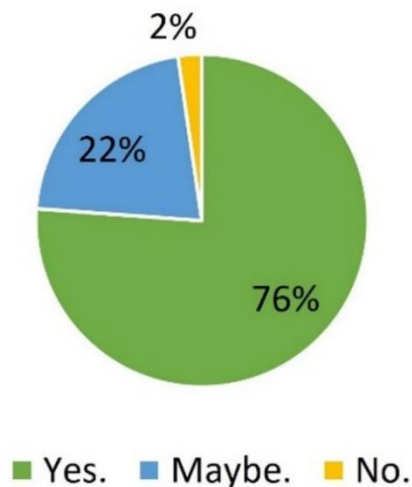


Figure 4. Responses to the statements “Participating in online Peer Led Team Learning improved my self-confidence,” (left) and “I am comfortable asking questions during online Peer Led Team learning workshops,” (right).

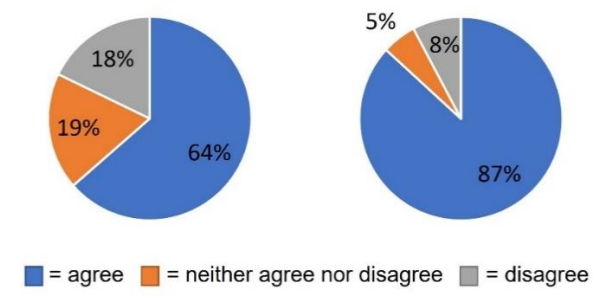


Figure 5. Responses to the statements “Participating in online Peer Led Team Learning helped me form relationships with other students in the course,” (left) and “Participating in online Peer Led Tam Learning made me feel included in the course,” (right)

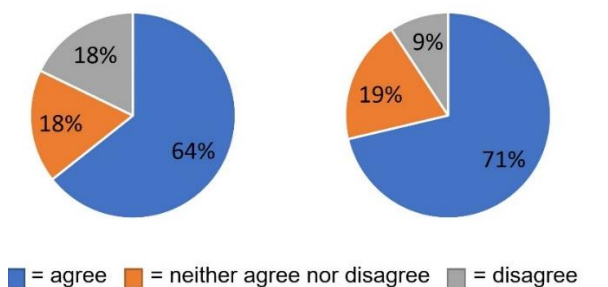
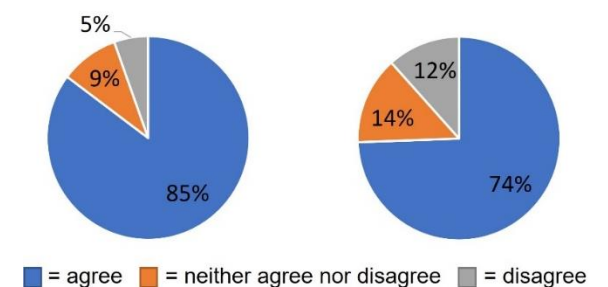
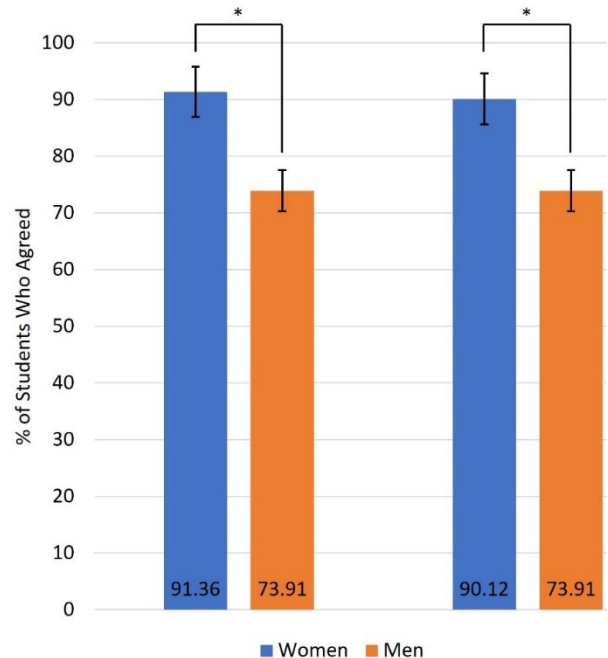


Figure 6. Responses to the statements “My Peer Leader was able to provide supportive feedback during the online Peer Led Team Learning workshops,” (left) and “Participating in online Peer Led Team Learning improved my motivation to learn general biology,” (right).



A chi-squared test indicated that women and men differed significantly in their agreement rate for two of the perception statements (Figure 7). Women agreed more often than men that participating in cPLTL helped them engage with the course material (91.36%; $\chi^2 (1, N = 104) = 4.9843, p = 0.0444$), and improved their understanding of key course concepts (90.12%; $\chi^2 (1, N = 104) = 4.0408, p = 0.0363$). There were no significant differences in the agreement rate of BHA and non-BHA students, or first-generation and non-first generation college students.

Figure 7. Percentage of men (n=23) and women (n=81) who agreed with the statements “Participating in online Peer Led Team Learning helped me engage with the course material.”, (left) and “Participating in online Peer Led Team Learning improved my understanding of key course concepts .”, (right).



* Indicates significance of chi-squared tests at $p < 0.05$

Discussion

Academic Achievement/Retention

Overall, students performed well in the introductory biology course during the Fall 2020 semester. Without cPLTL, 17.03% of students would not have had the option to declare a biology major and would not have met prerequisite requirements for upper-division courses (Figure 1). With cPLTL, this number was reduced to only 2.19%.

We saw similar trends when looking specifically at women, BHA students, and first-generation college students. Out of 109 women who participated in the program, only two were left with remaining barriers, and these women still earned passing grades of C (Table 2). This means that women who participated in cPLTL were 12% more likely to successfully navigate programmatic barriers than those who did not participate, and that 98% (107/109) of women who participated in cPLTL had achievement sufficient to declare a biology major and move on to upper-division courses.

Perceptions

The online format of our introductory biology course and cPLTL program may make it difficult to form relationships with other students in the course. Peer Leaders have observed that students who participate in cPLTL appear to be comfortable working together and spend time talking about topics unrelated to course content, however, the relationships they build may not translate into social connections outside of the cPLTL workshop (Smith et al., 2014). Given the difficulties students may face when forming relationships in an online setting, we are pleased that in the current study, two thirds (64.35%) of the respondents agreed that participating in cPLTL helped them form relationships

with other students in the course and almost three fourths (71.31%) of the respondents agreed that participating in online PLTL made them feel included in the course (Table 3; Figure 5). These findings suggest that participating in cPLTL can have a positive impact on students' feelings of belonging and ability to form relationships within an online gateway course.

Another concern we had was that the online format may reduce students' motivation to show up and participate in class. Motivation is important because it is a critical predictor of many educational outcomes such as academic achievement and retention (Lazowski & Hulleman, 2016; Robbins et al., 2004). Three fourths (76.54%) of our respondents agreed that participating in cPLTL improved their motivation (Table 3; Figure 6). This sentiment is echoed in the responses to the open-ended questions, as one woman wrote:

It took a toll on my motivation not being able to go to a classroom and meet my professors in person [during the pandemic]. I feel like if I had [c]PLTL for other of my classes I would've done better in them and my motivation wouldn't have been so lost.

These findings suggest that increased motivation as a result of participating in cPLTL may be a mechanism by which cPLTL could improve educational outcomes.

Studies on gender-differences in the classroom have shown that men tend to be more comfortable asking questions and to ask more questions than women in academic settings (Daly et al., 1994; Hinsley et al., 2017). This could be because question asking is linked to self-efficacy (Daly et al., 1994). Women may experience lower self-efficacy than men, and thus have lower confidence in their ability to pose an appropriate question (Daly et al., 1994; Good, 1987; McMullin & Cairney, 2004). In the current study, about two thirds (63.56%) of the respondents agreed that participating in cPLTL improved their self-confidence, and nearly nine out of ten (86.83%) agreed that they were comfortable asking questions during cPLTL workshops (Table 3; Figure 4). These findings suggest that participating in cPLTL could facilitate women using their voices and vocally participating in an academic setting. Responses to the open-ended question reflected this idea, as one woman shared, "Overall I found [cPLTL] to be very helpful as it was a much more comfortable environment to ask questions and get help."

In addition to hoping that the cPLTL workshops would be a comfortable place to ask questions, we hoped that the peer leaders would be able to provide supportive feedback to participating students. Receiving supportive feedback can help students form a strong science identity (Park et al., 2018). Identifying with science is important for students in STEM majors, as studies have shown that students with a strong science identity tend to persist in their STEM major longer and experience greater interest in scientific careers than those who do have a weak science identity (Chang et al., 2011; Perez et al., 2014). However, forming a strong science identity can be difficult for women for a variety of reasons. Competitive, rather than collaborative, gateway courses can sometimes lead to women feeling less competent in their scientific knowledge or pose challenges related to stereotype threat (Ahlqvist et al., 2013; Seymour & Hewitt, 1997). In the current study, nearly nine out of ten (85.27%) respondents

agreed that their Peer Leader was able to provide supportive feedback during the cPLTL workshops (Table 3; Figure 6), which suggests that cPLTL may help women identify with science.

The reason we point out that men and women differ in some of their cPLTL perceptions is not necessarily to draw comparisons between them, rather to emphasize the extent to which women perceived cPLTL to have had a positive impact on their experience in an online gateway course. As shown in Figure 7, nine out of ten women who completed the post-course survey agreed that participating in cPLTL helped them engage with the course material (91.36%) and improve their understanding of key course concepts (90.12%). One woman shared, "...the best benefit of [cPLTL] is that you really learn the material since it is reinforced during the one-hour session through engaging activities and questions." Together, these findings highlight the extent to which women feel that participating in cPLTL benefits their learning experience.

Conclusion

We contribute valuable insights and implications into teaching and learning science at the collegiate level by exploring the benefits that cPLTL has to offer for students who have historically been marginalized in STEM. Our study is unique in that we are the first to document cPLTL in an introductory biology course. We found evidence that participating in cPLTL improved achievement/retention among women, BHA students, and first-generation college students. Student perceptions of cPLTL were generally high in our study population, especially for women. Additionally, in our population of students, women preferentially participated in cPLTL. However, we did not see this selection bias for BHA students or first-generation college students. Future work should focus on these groups and understanding how we can encourage them to opt in because cPLTL helps them, too.

In addition to improving educational outcomes of students, participating in cPLTL may have several additional benefits such as increased motivation, feelings of belonging, comfort in asking questions, and support in forming a strong science identity. Future work should use an intersectionality approach to explore the unique lived experiences of students, and to better understand how their personal identities interact with the cPLTL environment to provide these various benefits.

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References

- AHLQVIST, S., LONDON, B., & ROSENTHAL, L. (2013). Unstable identity compatibility: How gender rejection sensitivity undermines the success of women in science, technology, engineering, and mathematics fields. *Psychological Science, 24*(9), 1644–1652.
- AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE (AAAS). (2011). *Science Without Borders*.
- CHANG, M. J., EAGAN, M. K., LYNN, M. H., & HURLADO, S. (2011). Considering the impact of racial stigmas and science identity: Persistence among biomedical and behavioral science aspirants. *Journal of Higher Education, 82*(5), 564–596. <https://doi.org/10.1353/jhe.2011.0030>
- DALY, J. A., KREISER, P. O., & ROGHAAR, L. A. (1994). Question-asking comfort: Explorations of the demography of communication in the eighth grade classroom. *Communication Education, 43*(1), 27–41. <https://doi.org/10.1080/03634529409378959>
- DRANE, D., MICARI, M., & LIGHT, G. (2014). Students as teachers: Effectiveness of a peer-led STEM learning programme over 10 years. *Educational Research and Evaluation, 20*(3), 210–230. <https://doi.org/10.1080/13803611.2014.895388>
- FREEMAN, S., EDDY, S., MCDONOUGH, M., SMITH, M., OKOROAFOR, N., JORDT, H., & WENDEROTH, M. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America, 111*(23), 8410–8415. <https://doi.org/10.1073/pnas.some>
- GOOD, T. L. (1987). Two decades of research on teacher expectations: Findings and future directions. *Journal of Teacher Education, 32*–47.aa
- GOSSER, D., ROTH, VI., GAFNEY, L., KAMPMEIER, J., STROZAK, V., VARMA-NELSON, P., ... WEINER, M. (1996). Workshop chemistry: Overcoming the barriers to student success. *The Chemical Educator, 1*(1).
- HINSLEY, A., SUTHERLAND, W. J., & JOHNSTON, A. (2017). Men ask more questions than women at a scientific conference. *PLOS One*.
- HORWITZ, S., & RODGER, S. H. (2009). Using peer-led team learning to increase participation and success of under-represented groups in introductory computer science. *Proceedings of the 40th ACM Technical Symposium on Computer Science Education, 163*–167. <https://doi.org/10.1145/1508865.1508925>
- LAZOWSKI, R. A., & HULLEMAN, C. S. (2016). Motivation interventions in education: A meta-analytic review. *Review of Educational Research, 86*(2), 602–640. <https://doi.org/10.3102/0034654315617832>
- MAUSER, K., SOURS, J., BANKS, J., NEWBROUGH, R., JANKE, T., SHUCK, L., VARMA-NELSON, P. (2011). Cyber Peer-Led Team Learning (cPLTL): Development and implementation. *EDUCAUSE Review*. http://libaccess.mcmaster.ca/login?url=http://search.proquest.com/docview/968115424?accountid=12347%5Cnhttp://sfx.scholarsport.al.info/mcmaster?url_ver=Z39.88-2004&rft_val_fmt=info:ofi/fmt:kev:mtx:journal&genre=article&sid=ProQ:ProQ:ericshell&atitle=Cyber+
- MCMULLIN, J. A., & CAIRNEY, J. (2004). Self-esteem and the intersection of age, class, and gender. *Journal of Aging Studies, 18*, 75–90.
- NATIONAL RESEARCH COUNCIL. (2012). *Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering* (S. R. Singer, N. R. Nielsen, & H. A. Schweingruber (eds.)). The National Academies Press. <https://doi.org/10.17226/13362>
- PARK, L. E., KONDRAK, C. L., WARD, D. E., & STREAMER, L. (2018). Positive feedback from male authority figures boosts women's math outcomes. *Personality and Social Psychology Bulletin, 44*(3), 359–383. <https://doi.org/10.1177/0146167217741312>
- PEREZ, T., CROMLEY, J. G., & KAPLAN, A. (2014). The role of identity development, values, and costs in college STEM retention. *Journal of Educational Psychology, 106*(3), 307–317. <https://doi.org/10.1037/a0034027>
- PRESZLER, R. W. (2009). Replacing lecture with peer-led workshops improves student learning. *CBE - Life Sciences Education, 8*, 182–192. <https://doi.org/10.1187/cbe.09>
- QUITADAMO, I. J., BRAHLER, C. J., & CROUCH, G. J. (2009). Peer Led Team Learning: A prospective method for increasing critical thinking in undergraduate science courses. *Science Educator, 18*(1), 29–39.
- ROBBINS, S. B., LE, H., DAVIS, D., LAUVER, K., LANGLEY, R., & CARLSTROM, A. (2004). Do psychosocial and study skill factors predict college outcomes? A meta-analysis. *Psychological Bulletin, 130*(2), 261–288. <https://doi.org/10.1037/0033-2909.130.2.261>
- SEYMOUR, E., & HEWITT, N. M. (1997). *Talking about leaving: Why undergraduates leave the sciences*. Westview Press.
- SLOANE, J. D., DUNK, R. D. P., SNYDER, J. J., WINTERTON, C. I., KELLY, M., & WILES, J. R. (2021). Peer-Led Team Learning is Associated with an Increased Retention Rate for STEM Majors from Marginalized Groups. *Proceedings of the National Association of Biology Teachers*.
- SMITH, J., WILSON, S. B., BANKS, J., ZHU, L., & VARMA-NELSON, P. (2014). Replicating Peer-Led Team Learning in cyberspace: Research, opportunities, and challenges. *Journal of Research in Science Teaching, 51*(6), 714–740. <https://doi.org/10.1002/tea.21163>
- SNYDER, J. J., CARTER, B. E., & WILES, J. R. (2015). Implementation of the Peer-Led Team-Learning instructional model as a stopgap measure improves student achievement for students opting out of laboratory. *CBE - Life Sciences Education, 14*, 1–6. <https://doi.org/10.1187/cbe.13-08-0168>
- SNYDER, J. J., SLOANE, J. D., DUNK, R. D. P., & WILES, J. R. (2016). Peer-Led Team Learning helps minority students succeed. *PLoS Biology, 14*(3), 1–8. <https://doi.org/10.1371/journal.pbio.1002398>
- THEOBALD, E. J., HILL, M. J., TRAN, E., AGRAWAL, S., NICOLE ARROYO, E., BEHLING, S., ... FREEMAN, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences of the United States of America, 117*(12), 6476–6483. <https://doi.org/10.1073/pnas.1916903117>
- WILSON, S. B., & VARMA-NELSON, P. (2016). Small groups, significant impact: A review of Peer-Led Team Learning research with implications for STEM education researchers and faculty. *Journal of Chemical Education, 93*(10), 1686–1702. <https://doi.org/10.1021/acs.jchemed.5b00862>
- WILSON, S. B., & VARMA-NELSON, P. (2021). Implementing Peer-Led Team Learning and Cyber Peer-Led Team Learning in an organic chemistry course. *Journal of College Science Teaching, 50*(3), 44–50.
- WILTON, M., GONZALEZ-NIÑO, E., MCPARTLAN, P., TERNER, Z., CHRISTOFFERSEN, R. E., & ROTHMAN, J. H. (2019). Improving academic performance, belonging, and retention through increasing structure of an introductory biology course. *CBE Life Sciences Education, 18*(4). <https://doi.org/10.1187/cbe.18-08-0155>
- WINTERTON, C. I., DUNK, R. D. P., & WILES, J. R. (2020). Peer-led team learning for introductory biology: relationships between peer-leader reliability, perceived role model status, and the potential influences of these variables on student learning gains. *Disciplinary and Interdisciplinary Science Education Research, 2*(1), 3. <https://doi.org/10.1186/s43031-020-00020-9>

Using Evolution as a Narrative Framework for Teaching Introductory Biology

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Abstract: We describe a novel, university-level, introductory biology course that uses evolution as a narrative framework. Our course conveys the content in an introductory biology course by telling the story of the evolution of life on Earth. We begin with early Earth environments in which biological molecules and processes evolved and led to the first RNA-based living entities, then to DNA-based cells, and then to all of the life around us. We use this framework to describe the evolution of the physiological processes important for beginning biology students. This structure contrasts with the widespread “levels of organization” approach in which the order of topics treats the molecular level first, then cells and organisms, and finally evolutionary and ecological processes. This traditional approach is limited in at least two ways: 1) The material taught at each level is not explicitly connected to that at other levels, making the concepts more difficult to assimilate and retain; 2) Evolution is taught as a discrete section of the course, rather than as the integrating principle of life itself. We find that our narrative evolutionary approach enables students to more effectively assimilate, retain, and connect the vast amount of information presented in an introductory biology course.

Keywords: Evolution, pedagogy, introductory biology, narrative, vision and change

Introduction

“This class was my favorite course of my freshman year . . . I am confident in explaining the material that I have learned to others, and I use this material daily when it comes to applying it to daily decisions.”—Linfield Introductory Biology student

Teaching a complex and inherently historical topic like introductory biology requires a thoughtful approach. Narrative is an emerging technique in science education because it uses history to help students understand the complexity of the subject matter. Avraamidou and Osborne’s (2009) review of narrative as a teaching technique reveals advantages over the traditional approach to science education. First, there is higher student interest when content is presented as a narrative as compared to a standard biology text (Prins et. al., 2017). Second, a course whose content is organized as an evolutionary narrative provides students with a framework that both structures the content and provides a scaffold upon which to hang each new concept as the course progresses. Third, comprehension is improved for many students, as a narrative structure is much more effective at conveying scientific content than presenting it simply as a set of facts. In addition, there is a significant increase in mid- to long-term retention. The students who read a narrative text do significantly better on a post-test questionnaire given two weeks after the lesson than those students who use a standard text (Prins et. al., 2017).

In seeking to design a better introductory biology course, we were intrigued by these findings. Most of the students in our introductory biology course are not biology majors but are majors in related scientific fields who enroll in our course to fulfill prerequisites for various careers in the allied health sciences. It can be a challenge to sustain these students' attention throughout a year-long biology course that must also serve the more directed needs of Biology majors. In addition, these students often have taken fewer science

courses in high school than their biology (or biochemistry) major peers. Therefore, the reported benefits of a narrative approach seemed particularly important for the students we routinely teach in our course.

Evolution as an Organizing Narrative

At the same time, we knew from our own experience that teaching evolutionary principles is often challenging in introductory biology courses. Even those students with an advanced secondary school biology experience have a poor understanding of evolution and natural selection and unless the courses integrate biology as a whole with evolution, students frequently leave these courses with misconceptions: “evolution is goal-oriented,” “evolution cannot craft complex structures,” and “evolution led inexorably to humans” are examples (Wescott and Cunningham 2005; Gregory 2009). Recent reports have pointed at this inadequate state of evolutionary knowledge and have called for evolution to become a core competency in undergraduate education. The National Academy of Sciences (1998) published a booklet on the teaching of evolution and the Vision and Change Initiative, put forward by the American Association for the Advancement of Science (Brewer and Smith, 2011), provides a widely accepted framework for content in an undergraduate biology curriculum. It emphasizes that students need to understand five core competencies: evolution, energy transformations, information flow, structure and function, and systems. Likewise, a report from the Association of American Medical Colleges and the Howard Hughes Medical Institute (2009) lists eight core competencies required of students entering medical school, one of which is evolutionary biology. Indeed, a 2010 study by Nesse et al. (2010) underscores the importance of evolutionary thinking in medicine and points out that “most introductory biology courses are insufficient to establish competency in evolutionary biology.” Most relevant to the course we describe here, this report emphasizes that “evolutionary

biology is not just another topic vying for inclusion in the curriculum; it is an essential foundation."

Because these twin issues—the challenges associated with teaching a large, diverse class of students with widely varying preparation, and the specific issues with evolution education—we designed a course that uses the evolution of life on earth as a narrative framework. At least one other author came to the same conclusion. Alles (2001) designed a biology course that uses evolution as a framework, though unlike the course described here, that course was designed for non-science majors and only a portion of it used evolution as an organizing principle. Nevertheless, Alles' course has been successful, even for students challenged by the very idea of evolution, and demonstrates that the evolutionary model can be effective for teaching a diverse class of students. However, the most important way our course differs from other courses is the use of narrative.

Evolution possesses all of the components of a narrative framework. Avraamidou and Osborne (2009) reviewed the use of narrative as a teaching technique and summarized its essential elements as a history with: 1) a specific purpose, 2) a defined chain or sequence of events, 3) a beginning, middle and end, 4) the passage of time, 5) an agent or entity that causes the events, 6) a narrator and 7) a reader. The evolution of life on Earth is the story of a sequence of events that starts with the first cells and continues until today. It is a story that unfolds over time and has a clear agent of change and causality: natural selection. Instructors serve as the narrators of this story for their students (the readers).

"I took an AP Biology class, and we went in order of the book, rather than when it actually occurred, and Linfield's method helped me understand it so much more." -Linfield Introductory Biology Student

Existing Textbooks and Introductory Biology Courses

Our experience and our many conversations with other biology faculty members over many years of teaching indicate that most faculty use their textbook as the guiding structure for their course. It is therefore worth analyzing the structure of textbooks to obtain an understanding of how faculty, in general terms, organize their courses.

Other educators have already published thoughtful critiques of introductory text structure: Hellman (1965) described texts written between the 1880s and 1930s, illustrating the gradual incorporation of evolutionary thought into these books. Hellman's examples indicate that vitalist processes dominated texts from the 19th century and that both evolution and natural selection were controversial until the 1920s. In all these texts, evolutionary processes are not included in chapters that were not themselves "about" evolution.

Considering now the 21st century, both Hillis (2007) and Nehm et al. (2009) described the content of modern biology texts. Hillis analyzed texts used in the high school system in Texas in 2006. The books covered evolution with factual accuracy but generally ignored natural selection; they were "stuck in the 19th century" (meaning their treatment of evolution did not consider either 20th or 21st century

thought); they rarely integrated evolution into the cellular or organismal parts of the texts.

Nehm et al. (2009) state that many introductory biology courses do not use evolution as the "cognitive framework" for organization. They evaluated three texts from 2003 and 2004 and showed that evolutionary terms were used rarely outside the chapters dealing specifically with evolution and diversity. They concluded that this textbook format encourages a lack of integration such that students retain a diverse array of isolated biological facts without grasping that natural selection and evolution are the unifying concepts for these facts. The authors proposed a "desegregation" of evolutionary ideas, suggesting that such ideas be integrated into the entire topical structure of textbooks.

We believe that this integration has not yet occurred on a large scale and is particularly lacking in the available textbooks. These books (and, one presumes, their corresponding course syllabi) are written and organized, with minor variations, in essentially the same way: as a collection of facts loosely held together by "levels of organization." They cover the following topics in this order: atoms, molecules, cells, organisms, populations, communities, etc. This is logical in the sense that these levels progress from simple (most reductive) to complex (most universal and inclusive) in an attempt to show that the foundations of biology rest upon chemistry.

While this is certainly a correct and useful concept, this structure actively masks evolutionary relationships because it does not emphasize the connections between and among organisms, nor does it account for the important elements of time and natural selection. Our most important concern as biologists is that the "levels of organization" approach is a non-evolutionary way to structure content. Our concern as science instructors is that the levels of organization approach suffers because it is a static collection of facts with no unifying theme. There is no concept of time, no sequence of events (although there are plenty of events), and the causal agent (evolution) is relegated to just another chapter, often at the end of the course. For these reasons, a levels-of-organization approach to teaching introductory biology does not promote a deep understanding of evolution specifically nor does it facilitate student learning of introductory biology in general.

In this paper we describe a course that combines these two ideas: 1) a narrative framework and 2) explicit treatment of evolution as a unifying principle. The introductory biology course we describe here discusses the evolution of the first biotic molecules and replicative nucleic acids, then outlines the origin of protocells that used RNA as both a genetic and catalytic molecule. Natural selection then led to the first DNA-based cells (prokaryotes), then Eukaryotes, then multicellular organisms. Within the multicellular Eukaryotes, we describe the physiological, developmental, and ecological principles that illustrate how natural selection has resulted in the organisms we see today. Thus, the narrative of evolution serves both as the framework by which course content is organized and as the context within which introductory biology "makes sense" (Dobzhansky, 1964).

Table 1. Comparison of traditional approach to introductory biology with our approach.

| Traditional Approach | Our Course |
|--|---|
| <p><u>Semester 1</u> Chemistry Macromolecules of life Cell Structure Metabolism Genetics DNA → RNA → Protein Evolution Phylogeny Bacteria Origin of eukaryotic cells</p> | <p><u>Semester 1</u> Environment of the early Earth Chemistry and energy transformation Abiotic synthesis of macromolecules including early RNA RNA World: Ribozymes and replication Natural selection and origin of cells RNA → Protein The origin of DNA from RNA Origin of cells and metabolic pathways Structure, diversity, genetics of Bacteria and Archaea Origin of eukaryotic cells: Endosymbiosis Eukaryotic genetics: meiosis</p> |
| <p><u>Semester 2</u> Plant Biology Fungal Biology Animal biology Ecology</p> | <p><u>Semester 2</u> Phylogenetics: Definition of eukaryotic clades Origin of multicellularity Biology and diversity of plants Biology and diversity of unicellular clades Biology and diversity of fungi and animals</p> |

“The course progression...was much easier to follow. It’s pretty odd for me to not have a complaint or an issue with any aspect of a class, but every morning I found myself excited to get up and go to class to learn about bacteria, cell functions, cell processes, evolution and genetics. I honestly loved this class and how it was taught.”—Linfield Introductory Biology student

Our Introductory Biology Course

When we began work on our restructured course, our goal was not to radically change the content of introductory biology courses, but rather to arrange existing content in a way that would allow students to better understand and retain it. The laboratories for this course have not been completely revised, for example. Some laboratories have been reframed with an overt evolutionary context, and we arrange the laboratories to follow the sequence of topics shown in Table 1. This table shows a side-by-side comparison of the order of topics that we previously used in our course, which closely followed our old textbook, Campbell Biology (Urry et. al., 2016) with largely the same course content re-structured around an evolutionary framework.

Comparison of the two approaches illustrates that all of the concepts and topics we covered in our previous (“Traditional”) approach are present in our current approach. However, telling the story of life on Earth, the story of how each new group of organisms arose through natural selection from previous groups, requires a substantial rearrangement of that content. This new arrangement means that we currently present several topics and concepts in a more evolutionary reasonable order, and that some previously understated content acquires a more prominent role. Below are a few examples:

- Taking into account the recommendations of recent researchers (Hillis 2007, Nehm and Reilly 2007, Nehm et al. 2009) we introduce concepts such as thermodynamics, ecology and natural selection at the very beginning of the course. This provides the content

students need for an in-depth understanding of the origin and evolution of the first cells.

- Our evolutionary framework focuses student attention on how early Earth abiotic conditions, which were very different from today’s conditions, enabled the evolution of the first organic molecules and the first catalytic replicator: RNA. This emphasis on how RNA evolved helps our students better understand that the early Earth environment was not a hindrance to life, as students often initially think, but was in fact a prerequisite.
- RNA-templated protein synthesis, or “translation” as it is usually called, almost certainly predated DNA and DNA-templated RNA synthesis (transcription). Because we cover these topics in the order in which they arose—RNA catalysis, RNA-directed catalysis of proteins, DNA, then transcription—students better understand the ability of RNA to act as an enzyme and that DNA is derived from RNA, not the other way around as the traditional method of teaching these topics—DNA, RNA, proteins—would lead anyone to believe.
- The first cells (similar to today’s Bacteria) appeared somewhat before 3.5 billion years ago and existed for over one billion years in a unicellular and largely asexual state. It was in these cells that basic metabolic processes arose; thus, we cover metabolic processes and pathways in the context of Bacterial biology.
- We do not present evolution and ecology as discrete chapters, but rather as needed for student understanding. For example, natural selection is discussed in the context of self-replicating molecules, the first cells, and the eventual explosion of prokaryotic life forms, whereas other concepts such as genetic drift and migration are presented within the context of Eukaryotic organismal biology. Certain ecological concepts such as abiotic factors, organism-environment interactions, and competition for resources, are discussed in the context of early Earth environments and the origin of RNA. For example, the nitrogen cycle

is discussed as part of the biology of the prokaryotes—rather than as a cycle that is merely in service to plants and animals as it usually is presented to students. In contrast, biome-level ecological concepts such as biogeography are discussed in the context of Eukaryotic organismal biology.

Strengths of the Approach

In our course student learning is improved in many ways. Below, three such strengths are described.

Evolution of the Central Dogma

It is vital to begin an introductory course with the concepts of early-Earth environments, natural selection, and thermodynamics. The evolutionary framework we use links the evolutionary history of organisms to the ecology and environment at that particular moment in Earth's history and describes processes and organisms in the order in which they likely evolved.

Introductory biology texts report the Miller-Urey experiments (Miller, 1953) demonstrating that abiotic mechanisms could have generated a variety of organic molecules on the early Earth. However, the descriptions of these syntheses do not cover two topics: how these simple organic molecules were involved in the processes that ultimately generated life, and what scientists have learned since Miller-Urey regarding abiotic synthesis of complex organic molecules.

Both of these topics can be explained by reference to experimental studies (Keller et al. 2014) showing how the principles of thermodynamics and mechanisms of inorganic catalysis guided biochemical reactions on early Earth even before cells evolved and produced the molecules that later cells appropriated for their own synthetic pathways. This pre-biotic complexity led to biotic complexity in the form of self-replicating and catalytic RNA, thus providing the basis for both early heredity and protein synthesis.

Our framework also provides a basis for the evolution of the Central Dogma. This concept is usually introduced to students in the form shown in the left-hand column of Table 1. Though this scheme is the basis for protein synthesis in extant organisms, the idea behind it was developed at a time (ca. 1958) before RNA was recognized as the actual catalyst for protein synthesis. Our course takes advantage of the wealth of recent research that shows that RNA likely preceded DNA as the genetic material and that RNA is itself a catalytic molecule. Thus, RNA was the first genetic material and the first enzymatic catalyst (Table 1, "RNA World"). Later, proteins replaced RNA as enzymatic catalysts and DNA replaced RNA as the genetic material in cellular organisms. Students presented with an RNA-first model therefore are not confused as to why cells use RNA for translation, as the catalytic role of RNA has already been established. Though the importance of the early RNA World has been understood by researchers for three decades, it has yet to become a central concept in beginning biology courses; our treatment of RNA replication and catalysis introduces students to these important ideas

Evolution of Metabolic Processes

In our course, metabolism is also taught quite differently from the way this topic is presented in textbooks. Standard depictions of metabolic pathways describe metabolism as if

aerobic heterotrophic organisms preceded autotrophic organisms; descriptions thus usually begin with oxidative pathways such as glycolysis, and then move to the tricarboxylic acid cycle and the electron transport system. These processes are usually described as if 1) aerobic mechanisms had always been the basis for metabolism and 2) the pathways evolved for the purpose of glucose oxidation for production of ATP. In addition, textbooks often describe photosynthesis, which uses solar energy to generate complex organic molecules, as if it evolved after the respiratory processes that then break down those same molecules for energy; this is likely a reversal of the actual evolutionary order in which these fundamental metabolic processes evolved.

Synthetic pathways, such as photosynthesis, therefore preceded heterotrophic organisms' oxidative pathways for ATP synthesis (Smith and Morowitz, 2004). Indeed, the pathways generally taught as oxidative, energy-producing reactions may have evolved as reductive pathways in anaerobic Bacteria for the purpose of synthesis of large organic molecules. Only later were these pathways run "backwards" for oxidative purposes (Hügler et al., 2003) in non-photosynthetic organisms – or in photosynthesizers when sunlight was not available. Heterotrophs, whose metabolism is based on oxidative processes, evolved from photosynthetic Bacteria, and allow us to understand the later origin of cellular oxidative electron transport processes (Castresana et al. 1994).

The emphasis of most textbooks on the canonical glycolysis > tricarboxylic acid cycle > electron transport chain appears to result from this order being the metabolic system used by multicellular eukaryotes. Because these aerobic processes generate more ATP than do anaerobic pathways, it is difficult for students to understand why cells would use anything else. Our approach solves this dilemma.

Evolution and Diversity of Eukaryotes

Once we have established the basic biology of eukaryotic cells, we naturally move on to discuss how these cells diversified through time. Most textbooks and courses present this material using the levels of organization approach from little (unicellular) to big (multicellular). Some textbooks even place the unicellular ancestors of the plants and animals in a chapter (often still under the phylogenetically outmoded title "Protists") separate from their multicellular descendants. Thus, not only do most textbooks group all of the "small things" together into one phylogenetically questionable chapter, but this chapter comes before large sections of text on plants and animals. This arrangement prevents students from understanding the evolutionary relationships within the larger plant and animal groups by implying that unicellular eukaryotes are more related to each other than they are to the multicellular species within their own phylogenetic lineages.

Our approach also promotes better student understanding of the evolutionary relationships between Eukaryotic clades. We emphasize that several groups of unicellular Eukaryotes arose after the lineage that would become plants through secondary endosymbiosis. For example, a red algal cell (an early member of the plant lineage) was engulfed by another (presumably heterotrophic) eukaryotic cell (in a manner analogous to the earlier acquisition of mitochondria and chloroplasts). This new organism, a eukaryotic cell harboring another eukaryotic cell,

subsequently evolved and eventually diverged into two groups known today as the Stramenopiles and the Alveolates (Medlin et al, 1997).

The evolutionary arc of our course structure makes this entire topic much easier for students to understand. By presenting these groups in the actual evolutionary order in which they arose, rather than as “little things evolved before big things,” it is much easier for our students to understand the interesting evolutionary relationships within and between Eukaryotic groups.

“Humans spend more time focusing on themselves and how things affect them than on all the other critical aspects of life around them.” –Linfield Introductory Biology Student

Discussion

We present here a theoretical paper that describes a novel framework and arrangement of the course content in an introductory biology course. We have designed this course based on two ideas: that students are not learning evolutionary theory (well) and that a narrative approach to organizing course content is superior to the much more common “levels of organization” approach. For our course, the evolution of life on Earth serves as the narrative framework that allows us to effectively teach introductory biology.

In fact, the resulting course described here covers much of the same material as traditional courses. We discuss fundamental biological principles and processes (e.g., genetics, metabolism, cell biology, physiology, ecology, etc.) and their contribution to the diversity of organisms on Earth (Table 1). Our course organizes this content quite differently, however, and our experience has been that the way the content in a course is conceptualized and presented has a direct impact on student learning (Paolini, 2015). That is, the organization of the course content by itself can improve student learning.

We have done no formal assessment of our approach, that is, we have not quantitatively compared the learning of students in our course with students enrolled in a different, “traditional,” introductory biology course. We do, however, have ample anecdotal evidence that students prefer the narrative framework described here, and that their comprehension and retention of biological content is increased as compared to our previous “levels of organization” approach. These assertions are based on anonymous student essays written in response to a general prompt we have long used in our student evaluation of course instruction:

Discuss one thing you liked, and one thing you didn't like, about your year in introductory biology. Please let us know why you thought specific things worked, or didn't work, and why you liked, or didn't like, something.

Before we switched to the narrative framework described here, students most commonly focused their responses to this prompt on the usual suspects: the laboratories that we use, examination instruments, instructor-student interactions or the inhumanity of 8:00 AM

classes; we never received comments on course organization. In contrast, after instituting our current evolutionary narrative framework, the majority of the feedback (55%) of these essays specifically focused on course organization, and all of these comments (100%) were favorable. We did not ask students to comment on course organization, yet most of them did.

These comments provide an illuminating window into how students view this approach to teaching introductory biology:

“I enjoyed that the focus was on how these processes ... had evolved from simpler processes. For me, the order in which the course was taught worked better than any other course I've taken. It made sense to start from the beginning and follow the train of life as best we know it.”

But the comments we have received go beyond merely course organization, and we have placed student comments as illustrative epigraphs at appropriate places in this paper. For example, the second epigraph appears immediately before our review of existing textbooks, because this student pointed out (unprompted by us) how much better they understood the material when it was presented in an evolutionary sequence, rather than in the levels of organization sequence of the textbook that was used in their previously taken Advanced Placement (AP) course.

Another common theme was a self-reported improvement in critical thinking skills and evolutionary understanding, exemplified by comments such as

“... [the course] let me think more critically about how the things in semester one connect to things in semester two, which is what I like about science, how it all ends up connecting together.”

and from another student

“... we were able to create a hypothesis on how cells evolved from what they were billions of years ago to the cells found on Earth today. Being able to create these kinds of connections encouraged the class to create other connections and think about more than just what our textbook taught us. I feel that this is a useful skill and is something that every college student should be able to do.”

In conclusion, our biology faculty have embraced the narrative approach described here and will not return to the more traditional approach. To support faculty at other institutions who may wish to adopt this course organization, the authors of this paper are well underway on a textbook that supports the narrative framework. Most importantly, we have seen greater student engagement, comprehension, and retention. Our students enjoy this course, and that alone promotes their learning.

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References

- Alles, D. (2001). Using evolution as the framework for teaching biology. *The American Biology Teacher*, 63(1): 20-23.
- Avraamidou L. & Osborne, J. (2009). The role of narrative in communicating science. *International Journal of Science Education*, 31(12): 1683-1707.
- Association of American Medical Colleges-Howard Hughes Medical Institute. (2009). *Scientific Foundation for Future Physicians*. American Association of Medical Colleges and Howard Hughes Medical Institute, Washington, DC.
- Brewer, A. & D. Smith, editors. (2011). *Vision and Change: A Call to Action*. American Association for the Advancement of Science.
- Castresana, J., Lübben, M., Saraste, M., & Higgins, D. (1994). Evolution of cytochrome oxidase, an enzyme older than atmospheric oxygen. *EMBO Journal*, 13: 2516-2525.
- Dobzhansky, T. (1964). Biology, molecular and organismic. *American Zoologist*, 4: 443-452.
- Gregory, T.R. (2009). Understanding Natural Selection: Essential Concepts and Common Misconceptions. *Evo Edu Outreach*, 2:156–175.
- Hellman, R. (1965). Evolution in American school biology books from the late nineteenth century until the 1930s. *The American Biology Teacher*, 27: 778-780.
- Hillis, D. (2007). Making evolution relevant and exciting to biology students. *Evolution*, 61-6: 1261–1264.
- Hügler, M., H. Huber, K. O. Stetter, & Fuchs, G.. (2003). Autotrophic CO₂ fixation pathways in archaea (Crenarchaeota). *Arch Microbiol*, 179: 160–173
- Keller, M., Turchyn, A., & Ralser, M. (2014). Non-enzymatic glycolysis and pentose phosphate pathway-like reactions in a plausible Archean ocean. *Molecular Systems Biology*, 10: 725.
- Medlin, L., Kooistra, W., Potter, D., Saunders, G., & Anderson, R. (1997). "Phylogenetic relationships of the 'golden algae' (haptophytes, heterokont chromophytes) and their plastids." *Plant Systematics and Evolution* 11: 187-219.
- Miller, S. (1953). A production of amino acids under possible primitive Earth conditions. *Science*, 117: 528-529.
- National Academy of Sciences. (1998). *Teaching about Evolution and the Nature of Science*. Washington, DC: National Academy Press.
- Nehm, R. & L. Reilly. (2007). Biology Majors' Knowledge and Misconceptions of Natural Selection. *Bioscience*, 57: 263-272.
- Nehm, R., Poole, T., Lyford, M., Hoskins, S., Carruth, L., Ewers, B., & P. Colberg. (2009). Does the Segregation of Evolution in Biology Textbooks and Introductory Courses Reinforce Students' Faulty Mental Models of Biology and Evolution? *Evolution Education Outreach*, 2: 527–532.
- Nesse, R., Nessea, R., Bergstromb, C., Ellisonc, P., Flierd, J., Gluckmane, P., Govindarajuf, D., Niethammerg, D., Omennh, G., Perlmani, R., Schwartzj, M., Thomask, M., Stearnsl, S., & Valle, D. (2010). Making evolutionary biology a basic science for medicine. *Proceedings of National Academy of Sciences USA*, 107 (suppl. 1): 1800-1807.
- Paolini, A. (2015). Enhancing Teaching Effectiveness and Student Learning Outcomes. *Journal of Effective Teaching*, 15 (1): 20-33
- Prins, R., Avraamidou, L., & Goedhart, M. (2017). Tell me a Story: The use of narrative as a learning tool for natural selection. *Educational Media International*, 54(1): 20-33.
- Smith, E. & Morowitz, H. (2004). Universality in intermediary metabolism. *Proceedings of National Academy of Sciences USA*, 101: 13168-13173.
- Urry, L., Cain, M., Wasserman, S., Minorsky, P., & Reece, J. 2017. *Campbell Biology* 11th ed., Pearson.
- Wescott, D. & Cunningham, D. 2005. Recognizing Student Misconceptions about Science and Evolution. *MountainRise*, 2: 1-8.

Environmental Conditions and Husbandry Approach Affect the Survival and Physiology of the California Blackworm (*Lumbricus variegatus*)

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Abstract: The California Blackworm (*Lumbricus variegatus*) is a freshwater segmented worm species that has been used by biology instructors as a model system for inquiry-based student investigations. The blackworm dorsal blood vessel pulsation rate is easily quantified. Moreover, this species can facilitate the study of neuromuscular functioning via its photosensitive escape behavior which can be quantified as a segmental reflex rate. Both of these variables can be used to examine the physiological response of the *L. variegatus* circulatory and neuromuscular systems to environmental changes. Because knowledge about this species and its optimal environmental conditions is limited, we studied dorsal vessel pulsation and segmental reflexes of *L. variegatus* maintained at differing lighting, temperature and water cleaning frequency conditions. Our data strongly indicate that *L. variegatus* circulatory and motor functions are significantly affected by environmental conditions. We provide evidence-based recommendations for the careful control of environmental conditions that will allow instructors, students and researchers to collect robust data on *L. variegatus* and better utilize this model organism in their investigations.

Key Words: Anatomy and/or Physiology, Animal Behavior (Ethology) and Environmental Biology

Introduction

Lumbricus variegatus, commonly known as California Blackworm, are freshwater segmented worms in the Annelida phylum (Jamieson, 1981). They tend to feed on decaying vegetation and microorganisms (Drewes, 2004). Therefore, they are often found at the shallow edges of ponds and lakes, the temperatures of which often range between 4°C and 15°C.

In the past decade and a half, there has been an increasing interest in this species as a model organism and tool to aid in the understanding of biological systems, such as the circulatory system. *L. variegatus* worms are suited to this task as the body wall is transparent which allows for the macroscopic inspection of the dorsal blood vessel, the larger of two major blood vessels, which runs along the posterior side of the worm (Lesiuk & Drewes, 1999). As *L. variegatus* worms lack true cardiac tissue, they utilize rhythmic contractions of smooth tissue surrounding the dorsal blood vessel to facilitate the flow of blood throughout the body within a closed circulatory system. Therefore, inspecting the dorsal blood vessel can be a convenient and informative approach to examine the *L. variegatus* circulatory system. However, as research studying *L. variegatus* physiology is relatively new, the extent of what we know about this species is limited. Gaining a clearer understanding about this physiology would help researchers, science instructors, and students to better utilize this model organism in their investigations. A detailed understanding of its husbandry is fundamental to such investigation.

L. variegatus are a useful model organism for the study of other physiological systems such as the neuromuscular system (Jamieson, 1981; Drewes & Fortner, 1989). *L. variegatus* are sensitive to a variety of environmental conditions, such as light and slight pressure, that elicit discrete behavioral phenomena such as segmental shortening. Also, we have observed in an oxygen deficiency study (personal observations) that *L. variegatus* movement and dorsal blood vessel pulsation rates change when their environmental water is not frequently replenished. Additionally, vascular performance is highly dependent on temperature. For example, Fillafer and Schneider (2013)

showed that cardiac arrest could occur in *L. variegatus* after heat shock treatment reaches a critical point of 37.2 °C. Although educational settings may most easily use environmental conditions that are similar to room temperature for humans, *L. variegatus* typically inhabit environments with temperatures that deviate from room temperature (Drewes, 2004). Therefore, it is important to establish optimal laboratory husbandry approaches that help maintain these organisms at maximal metabolic function to help the study of their systems, since blood circulation is directly related to metabolic function (Biga et al, n.d.).

To establish these optimal environmental conditions, we studied dorsal vessel pulsation and segmental reflexes of *L. variegatus* maintained at differing lighting, temperature and water cleaning frequency conditions. We hypothesized that dorsal vessel pulsation and segmental reflex rates in *L. variegatus* would be significantly related to these environmental conditions. The range of environmental conditions studied included those typical of the natural habitat of *L. variegatus*. Dorsal vessel pulsation and segmental reflex rates, as well as a qualitative assessment scale of *L. variegatus* cardiovascular health, were utilized to test this hypothesis.

Due to COVID-19 restrictions, the experiments detailed in this manuscript were conducted in the premises of a conventional dormitory room. While a simple light microscope and disposable pipettes were lent by the UW-Madison Biocore department, most of the materials described in this manuscript are common household items. Furthermore, the methodology was designed to be easily executable in a typical dormitory room with little required previous laboratory training. Therefore, while the primary goal of this investigation was to inspect how environmental conditions affect the physiology and survival of *L. variegatus*, the methodology detailed in this manuscript could be utilized as a guideline for biology teachers who instruct students interested in investigating *L. variegatus* physiology and survival in a variety of settings, from traditional science lab classrooms to student dorm rooms, at either the high school or a college level.

Materials and Methods

Timeline

Prior to being used in the study, all worms were refrigerated at 4°C. For all experiments, we housed worms in 10 cm x 10 cm x 8 cm plastic containers, each containing 5 individual *L. variegatus* specimens. Each container was filled with 560 mL of tap water to normalize for the effects of water type and quantity. The effects of air availability were normalized by the use of an air pump in all treatments. An environmental temperature of 10 °C, which was maintained by using a replenishable ice bath, a water cleaning schedule of twice/week and a 24-hour light treatment that utilized commercial 150-watts neon lighting with a distance of 1.8 meters between the container and the light source were considered as control conditions and were used when not otherwise stated.

There were three experimental conditions - elevated temperature, reduced cleaning frequency, and reduced lighting - considered in this study. We conducted studies with these conditions twice: first for quantitative data collection and then for qualitative (body color) data collection. New worms were selected for each study. Individual worms were used only once. All worms were exposed concurrently to their respective environmental conditions for two weeks. At that time, for the quantitative analysis, circulatory and reflexive data (details below) were collected; for the qualitative analysis, color data were collected. Subsequently, all worms were placed in a separate container for disposal. Within each of the two sets of studies - quantitative data and qualitative data - all containers were under study at the same time.

For quantitative data collection, 9 containers were utilized as experimental treatment groups with 3 containers for each treatment group. Due to time restriction and local *L. variegatus* shortage at the time, only 3 containers were utilized as control for all experimental conditions. For qualitative data collection, 9 containers with 3 containers per experimental treatment group were utilized. Because qualitative data collection occurred at a later time when there was less of a local *L. variegatus* shortage, 3 distinct sets of containers were intended to be utilized as control for each environmental condition, for a total of 9 control containers. However, the 3 control containers dedicated to temperature comparison contained old and new worms (which at the time of the study were assumed to be physiologically equivalent). This assumption was called into question when these 3 control containers yielded data that conflicted substantially from the other controls (see appendix A). Hence, these data were discarded, and the other 6 control containers were pooled together to serve as controls for all three experimental treatments. This decision was supported by the fact that the old worms had been kept refrigerated for 3 weeks longer than the new worms. This may have influenced their vascular performance (Fillafer & Schneider, 2013).

Environmental Conditions

For the assessment of environmental temperature, worms in the 3 increased temperature treatment containers were reared at a temperature of 22 °C which was maintained by regulating the room thermostat. For reduced cleaning frequency, 3 containers were maintained using a once/week water cleaning schedule. For the reduced lighting condition, 3 containers were exposed to a 24-hour dark treatment

enforced via an inverted cardboard box. For each of these three experimental treatment situations, the two factors not under direct assessment were kept at control conditions.

The protocol described in the previous paragraph was used for both the quantitative and qualitative data studies. As noted, the same 3 containers were used as the control for each of the environmental conditions for the quantitative data studies. The quantitative data studies utilized 6 containers as control for the three experimental conditions (as explained above).

Quantitative Data Collection

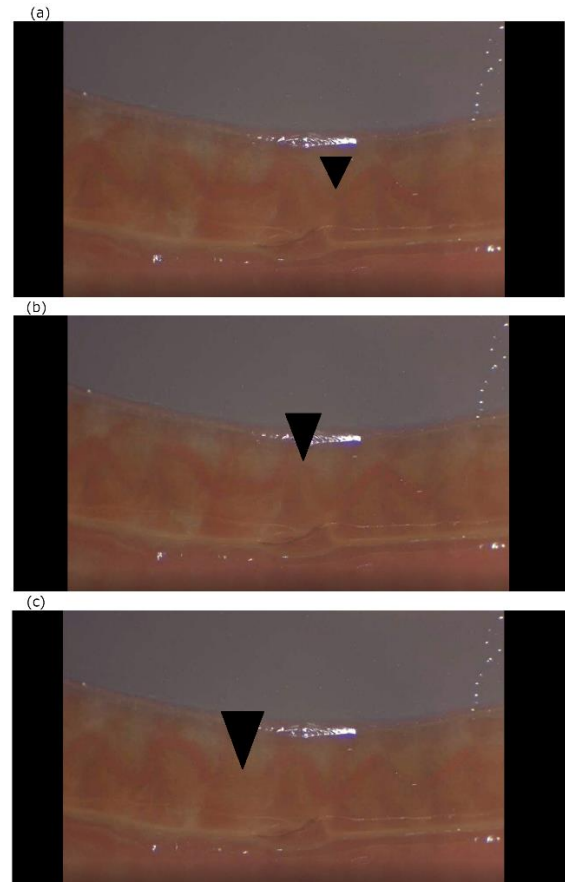
A. Dorsal Vessel Pulsation Rate Calculation

Each *L. variegatus* was placed between two layers of scotch tape. After that, the tape was placed under a light microscope while dorsal vessel pulsations were counted for 30 seconds. Each macroscopic contraction of the dorsal vessel was counted as one pulsation (Figure 1). The number of the pulsations of the dorsal vein in 30 seconds were counted and multiplied by 2 to obtain a dorsal blood vessel pulsation rate with units of pulses/minute (Eq. 1).

$$(Eq.1) \text{ Dorsal Vessel Pulsation Rate } \left(\frac{\text{pulse}}{\text{minute}} \right) = \# \text{ of pulsations per 30 seconds } \cdot 2$$

Figure 1. Microscopic view of dorsal vessel pulsation in *L. variegatus*

The black arrowhead shows how the diameter of one location on the vessel decreased as the smooth muscle surrounding the dorsal blood vessel contracted along the length of the dorsal blood vessel, for one pulse, at different timepoints: (a) 0 seconds. (b) 1 second. (c) 2 seconds. Images taken at a (x35) magnification level.



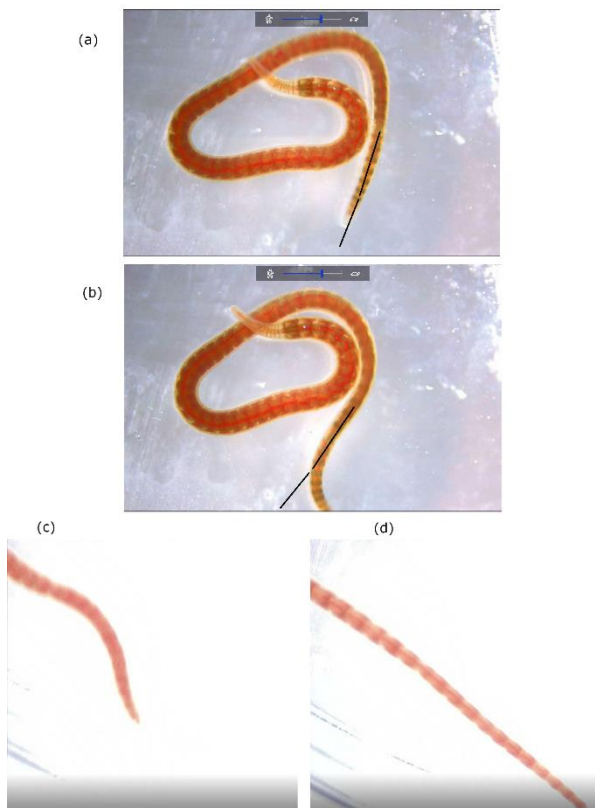
B. Segmental Reflex Rate Calculation

To fully gauge segmental reflex to photic stimulation, one *L. variegatus* worm was placed in a petri dish containing 3 mL of tap water under a light source, such as the lamp of a light microscope. Each head or tail thrashing across the body axis and each attempt to lengthen or shorten segment length were counted as one segmental reflex response (Figure 2). After the first response was recorded, any additional segmental reflex response was recorded for 30 seconds and multiplied by 2 to obtain a segmental reflex rate with units of segmental reflexes/minute (Eq.2).

$$(Eq.2) \text{ Segmental Reflex Rate } \left(\frac{\text{pulse}}{\text{minute}} \right) = \frac{\# \text{ of segmental reflex responses per 30 seconds} \cdot 2}{\text{}}$$

Figure 2. Neuromuscular response of *L. variegatus* to light stimulus

(a) *L. variegatus* at resting position. Note that the segment is aligned along the body axis which is represented with a dashed black line. (b) *L. variegatus* thrashing away from the body axis which is represented with a dashed black line. (c) Segmental shortening of *L. variegatus*. (d) Segmental lengthening of *L. variegatus*. Images taken at a (x28) magnification level.



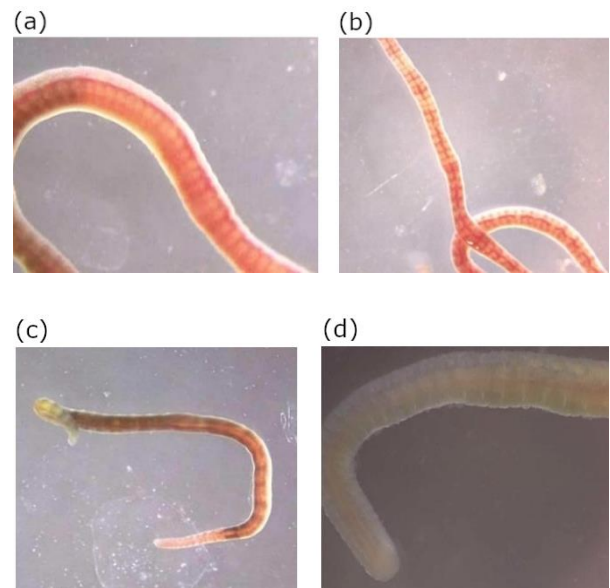
Circulation Assay (for qualitative analysis)

The circulatory performance of *L. variegatus* was assessed using a qualitative color assay where each worm was categorized into one of four ordered groups based on the degree to which the intensity of the red color of the blood vessels as inspected by light microscopy resembled one of 4 discrete patterns (see figure 3). Worms with intensities that were in between two consecutive patterns were classified

into one of three intermediate categories (see figure 3). Thus, each worm was classified to one of 7 ordered categories. To increase consistency, a scale (figure 3) was used as a reference for value allocation. An assay score below 2 indicated poor circulatory health.

Figure 3. Circulation assay reference:

(a) The highest level of circulation score of 3 was indicated by diffused and bright redness along the worm length. (b) An intermediate level of circulation which was indicated by diffused and bright redness intermittent along the worm length was granted an index of 2. (c) A low level of circulation which was indicated by a dim redness and the presence of pale-yellow regions was granted an index of 1. (d) The lowest level of circulation which was indicated by greyness along the worm length was granted an index of 0. Worms that appeared as an intermediate between two of these classifications were assigned an average of the value associated with the two classifications under inspection. Total magnification levels used to obtain images for (a), (b), (c) and (d) were (x28), (x16), (x8) and (x28), respectively.



Statistical Analysis

We used RStudio software for all statistical analyses (RStudio Team, 2019). For quantitative data analyses, we used a nested model with container as the error term for testing environmental condition (and worm as the sub-plot error) to determine if there was a significant difference in the mean blood vessel pulse rates and mean segmental reflex rates of *L. variegatus* worms for the different environmental conditions. A two-sided Fisher's Exact Test was used to determine if there was a significant difference between the qualitatively assigned circulation categories.

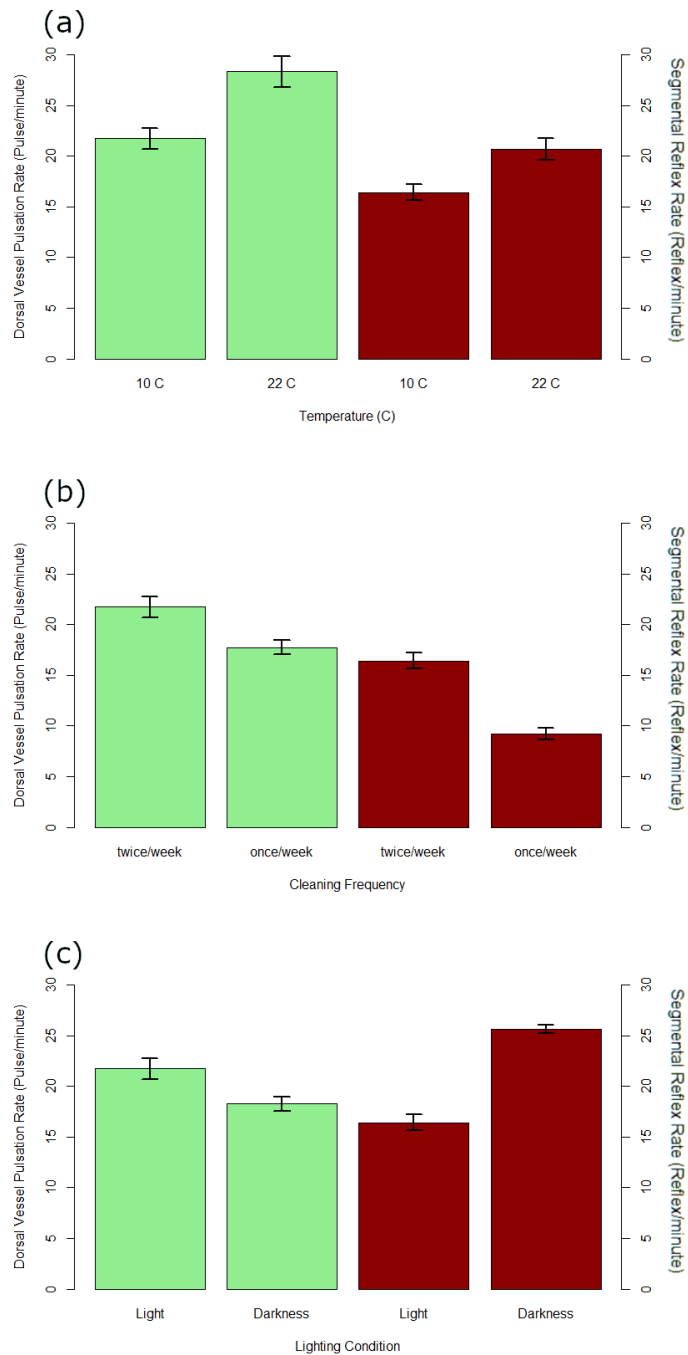
Results

Temperature

As shown in Figure 4a, the mean dorsal vessel pulsation rate of *L. variegatus* worms housed at 10°C was 21.7±4.0 pulsations per minute while *L. variegatus* worms kept at 22°C had an average pulsation rate of 28.3±5.9 pulsations per minute. There was a statistically significant effect at 5% of temperature on dorsal vessel pulsation rate

Figure 4. Effects of Environmental Conditions on Dorsal Vessel Pulsation and Segmental Reflex Rate

(a) Bar plots of mean dorsal vessel pulsation and segmental reflex rate of *L. variegatus* reared in a 10 °C water (control) temperature vs a 22 °C water temperature. Error bars represent +/- 1 SE (n=15). (b) Bar plots of mean dorsal vessel pulsation and segmental reflex rate of *L. variegatus* reared in a water container cleaned twice/week (control) vs *L. variegatus* reared in a water container cleaned once/week. Error bars represent +/- 1 SE (n=15). (c) Bar plots of mean dorsal vessel pulsation and segmental reflex rate of *L. variegatus* reared in a 24-hour light treatment (control) vs *L. variegatus* reared in a 24-hour dark treatment (darkness). Error bars represent +/- 1 SE (n=15). (The variances used in computing the error bars in these plots do not take into account the effect of container. However, these effects are accounted for in the formal statistical analysis.)



(ANOVA $F(1, 4) = 12.8791$, $p = 0.023$). (The analysis also indicated that container-to-container variability was quite small. This was the case for all subsequent statistical analyses of quantitative data and, therefore, will not be formally addressed elsewhere).

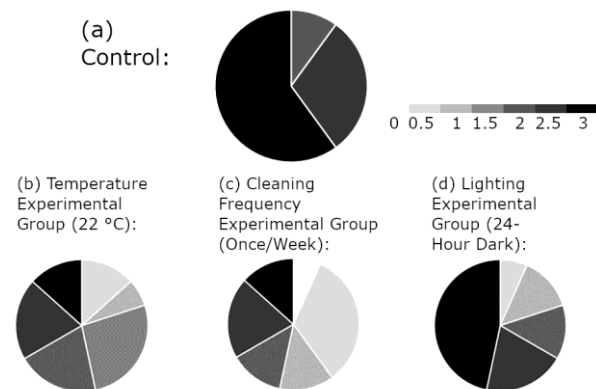
Figure 4a also shows that the mean segmental reflex rate of *L. variegatus* worms housed at the lower 10°C temperature was 16.4 ± 3.0 reflexes per minute as compared to 20.7 ± 4.6 reflexes per minute for worms kept at 22°C. This difference in

segmental reflex rate was statistically significant at 5% (ANOVA $F(1, 4) = 10.3959, p = 0.0321$).

For the circulation assay, the *L. variegatus* worms housed at 10°C yielded a mean index of 2.75 while worms housed at 22 °C had an average index value of 1.83 (Figure 5a,5b). This difference in circulatory index between the two temperatures was statistically significant at 5% (p-value = 0.0003). (Note that in performing the Fisher Exact Test (FET) we ignored the effect of container. A careful examination of the data along with the fact that there was negligible variability due to container in all of the quantitative data analyses using the nested model, indicates that our use of the FET is appropriate).

Figure 5. Circulation Assay of *L. variegatus* Reared under Varying Environmental Conditions

Pie chart shows the results of the circulation assay of (a) control *L. variegatus* reared under a water temperature of 10°C, twice/week cleaning frequency and a 24-hour Light treatment (b) experimental *L. variegatus* reared at 22°C water temperature, (c) experimental *L. variegatus* reared at once/week cleaning frequency, (d) experimental *L. variegatus* reared under a 24-hour dark treatment. Each shade represents a different circulation assay score. The brighter the shade the lower the score. Lower assay scores (1.5 or below) indicate poor circulation as indicated by amount of red coloration. (n=15 for experimental groups, n=30 for the control)



Cleaning Frequency

The mean dorsal vessel pulsation rate of *L. variegatus* housed at a twice/week cleaning frequency was 21.7 ± 4.0 pulsations per minute, but this decreased to 17.7 ± 2.7 pulsations per minute for worms housed at once/week cleaning frequency (Figure 4b). This difference in pulsation rate was statistically significant at 5% (ANOVA $F(1, 4) = 9.7035, p = 0.0357$). The mean segmental reflex rate of *L. variegatus* housed at twice/week cleaning frequency was 16.4 ± 3.0 reflexes per minute while worms housed at once/week cleaning frequency had an average segmental reflex rate of 9.2 ± 2.3 pulsations per minute (Figure 4b). This difference in segmental reflex rate was statistically significant at 5% (ANOVA $F(1, 4) = 53.3647, p = 0.0019$).

For the circulation assay, *L. variegatus* housed at twice/week cleaning frequency had a mean circulation index score of 2.75 as compared to an average index of 1.3 for worms housed at once/week cleaning frequency (Figure

5a,5c). This difference in circulatory index was statistically significant at 5% (p-value = 0.0001).

Lighting Condition

Figure 4c shows that the mean dorsal vessel pulsation rate of *L. variegatus* housed in a 24-hour light treatment was 21.7 ± 4.0 pulsations per minute and decreased to 18.3 ± 2.8 pulsations per minute for worms housed in a 24-hour dark treatment. This difference in pulsation rate under different lighting conditions was not statistically significant at 5% although it was quite close (ANOVA $F(1, 4) = 7.6974, p = 0.0501$). Additionally, Figure 4c shows that the mean segmental reflex rate of *L. variegatus* housed in a 24-hour light treatment was 16.4 ± 3.0 reflexes per minute which increased to 25.7 ± 1.5 pulsations per minute in worms in a 24-hour dark treatment, a difference that was statistically significant at 5% (ANOVA $F(1, 4) = 110.6768, p = 0.0005$).

For the circulation assay, *L. variegatus* worms housed in a 24-hour light treatment had a mean index of 2.75 while worms housed in a 24-hour dark treatment had a circulatory index of 1 (Figure 5a,5d). This difference in circulation index was not statistically significant at 5% (p-value = 0.1485).

A summary of the statistical test results for all of the assays is shown in Table 1.

Discussion

We found a statistically significant increase in mean dorsal vessel pulsation (of about 30%) and segmental reflex rates (of about 26%) in *L. variegatus* groups reared at 22°C, relative to *L. variegatus* groups reared at 10°C (Figure 4a). Moreover, circulation assays showed that a 22°C environmental temperature had a deleterious effect on circulatory performance (figures 3a-3b). Therefore, the hypothesis that dorsal vessel pulsation rate and segmental reflex rate in *L. variegatus* would be significantly related to water temperature was supported. This is further supported by studies that showed that the dorsal vessel pulsation rate of *L. variegatus* tends to increase as environmental water temperature increases (Fillafer & Schneider, 2013). Moreover, circulation assay data showed a statistically significant effect for temperature on circulatory performance (figures 3a, 3b). Hence, our data indicate that it is highly advisable to house *L. variegatus* at temperatures that characterize the typical habitats of this species (4°C - 15°C), particularly, when metabolic activity is the focus of study or educational task.

We found a statistically significant decrease of ~20% in mean dorsal vessel pulsation and a ~44% decrease in segmental reflex rates in *L. variegatus* groups reared in water containers cleaned once/week, relative to *L. variegatus* groups reared in water containers cleaned twice/week (Figure 4b). Furthermore, circulation assays showed that less frequent cleaning of environmental water negatively affects circulatory performance. We believe that these observed effects are biologically meaningful. Therefore, the hypothesis that there would be a significant change in dorsal vessel pulsation and segmental reflex rate in *L. variegatus* reared in water containers cleaned twice/week relative to *L. variegatus* reared in water containers cleaned once/week, which is more representative of the microorganism-rich natural habitats of *L. variegatus* as recorded by Brinkhurst and Gelder (1991), was supported. Our data indicate that water cleaning sanitation is a critical environmental factor to *L. variegatus*

Table 1. Summary of Statistical Testing Results. P-values indicating lack of statistical significance are underlined. DVP = Dorsal Vessel Pulsation. SS = Segmental Shortening. ‡: between treatments. †: within containers.

| | Temperature | Cleaning Frequency | Lighting |
|---|------------------|--------------------|------------------------|
| DVP Rate: p-value (F-value) dF‡ = 1 dF† = 4 | 0.0230 (12.8791) | 0.0357 (9.7035) | <u>0.0501</u> (7.6974) |
| SS Rate: p-value (F-value) dF‡ = 1 dF† = 4 | 0.0321 (10.3959) | 0.0019 (53.3647) | 0.0005 (110.6768) |
| Circulation assay: Fisher-Exact Test: p-value | 0.0003 | 0.0001 | <u>0.1485</u> |

Table 2. Suggested *L. variegatus* husbandry & environmental guidelines for water temperature, lighting and water cleaning frequency, and relative importance for studies of circulation/metabolism and neuromuscular behaviors.

| | Influence on Circulation/Metabolism | Influence on Neuromuscular Reflexes | Suggested Husbandry/Environmental Guidelines |
|--------------------|-------------------------------------|-------------------------------------|--|
| Water Temperature | High Effect | Low-Moderate Effect | Ideally, (4-15) C * Must not exceed 37.2 C |
| Cleaning Frequency | Moderate Effect | Moderate Effect | twice/week |
| Lighting condition | Low-Moderate Effect | High Effect | 24-hour dark treatment for optimal metabolic function. 24-hour light treatment for minimal photosensitive reflex stimulation. |

survival. Interestingly, our own oxygen availability pilot study showed that less frequent cleaning frequencies significantly reduced oxygen concentration inside water containers relative to the oxygen concentration inside more frequently cleaned water containers. This suggested that decreased competition over resources with aerobic microorganisms, which are more likely to be removed with more frequent cleaning schedules, may have contributed to increased vascular and neuromuscular function. In addition, we note the greater effect of cleaning frequency on segmental reflex rate than on dorsal vessel pulsation rate which implies greater sensitivity of neuromuscular function to this factor than that of metabolic function. Therefore, we recommend that researchers consider prioritizing more frequent cleaning schedules regardless of the focus of a study or educational task, particularly, if neuromuscular function is being inspected.

A ~57% statistically significant increase in segmental reflex rate was observed due to the 24-hour dark treatment (Figure 4c). Therefore, the hypothesis that segmental reflex rate in *L. variegatus* would be significantly related to lighting condition was supported. A modest (~16%) decrease in dorsal vessel pulsation rate was observed in the 24-hour dark treatment (p-value = 0.0501). Thus, this can be viewed as providing marginal support for the hypothesis that dorsal vessel pulsation rate in *L. variegatus* would be significantly related to lighting condition. Further work is needed to better elucidate the nature of this relationship. Furthermore, we did not observe a statistically significant effect of lighting on circulatory performance as indicated by circulation assays, indicating that lighting is not a critical factor for *L. variegatus* survival. This finding is supported by the ecological

observation that *L. variegatus* can be found in shallow water surfaces, as well as burrowing in soil layers, two habitats with different light conditions (Jamieson, 1981). Further work could examine whether *L. variegatus* circulatory systems can adapt to a variety of environmental lighting conditions. Our data indicate that circulatory activity is less sensitive to changes in environmental light levels than neuromuscular reflex rate (Figure 4c). It may be that there has been stronger evolutionary selection on morphology and behaviors that allow blackworms to escape predators, as compared to selection on cardiovascular function. Predation evasion has historically been shown to be a significant evolutionary driver (Endler, 1986). It seems reasonable to assume that segmental reflex rate is an indicator of swimming behaviors that allow blackworms to escape predators, (i.e., worms with faster neuromuscular reflexes should be better able to evade predators). The 16% decline in dorsal blood vessel pulsation rate in 24h dark relative to well-lit environments indicates that circulatory responses are much less sensitive to light levels. It is likely that the anaerobic, short-term bursts in neuromuscular activity that occur during predator evasion do not require a substantial change in gas exchange. Our data are thus consistent with the postulation that black worm segmental reflexes have been more sensitive to evolutionary selection pressures than cardiovascular function. Regardless, we conclude that lighting condition is a significant environmental factor to control, at least for maintaining *L. variegatus* for the purpose of monitoring their neuromuscular function, due to the significant effect of lighting on segmental reflex rate.

There are certain limitations to this study that must be acknowledged. This study was conducted in a residence hall

room due to the COVID19 pandemic. Therefore, the data sets collected could have been confounded by fluctuating environmental conditions, such as temperature and humidity. Moreover, the insufficient space of a dorm room limited the ability to use a larger sample size. This fact must be taken into consideration as well. Additionally, due to the fact that the same controls were used for all of the experimental groups within each of the quantitative and qualitative data collections, there is a lack of independence among the three tests of experimental treatments within each type. All these hurdles shed light on the need for flexibility required by research conducted in low-resource settings, such as dorm rooms. Such flexibility, which may incorporate making compromises regarding the use of independent controls for instance, demands the need for the researcher to be extremely diligent and vigilant about study design and implementation in order to produce rigorous, high-quality data. Yet, despite these challenges, it can be observed that studies concerning *L. variegatus* can be undertaken in a range of settings (including dorm rooms) so long as high levels of diligence and vigilance are observed.

In conclusion, our data strongly indicate that *L. variegatus* circulatory and motor functions can be significantly affected by environmental conditions, such as lighting, temperature and water cleaning frequencies. Based on these data and previous research, we have devised suggested guidelines for optimal *L. variegatus* environmental conditions and husbandry approach (Table 2). Our findings emphasize how careful control of environmental conditions will allow instructors, students and researchers to collect robust data on *L. variegatus* which further elucidates how their vascular and neuromuscular reflexive behavior change with varying environmental parameters, such as lighting, water temperature and water cleaning frequencies.

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References

Biga, L. Dawson, S. Harwell, A. Hopkins, R. Kaufmann, J. LeMaster, M. Morrison-Graham, K. Quick, D. & Runyeon J. "Anatomy and Physiology" OpenStax. <https://open.oregonstate.edu/aandp/>

Brinkhurst, R. O. and S. R. Gelder (1991) *Annelida: Oligochaeta and Branchiobdellida*, In Ecology and Classification of North American Freshwater Invertebrates (T. H. Thorp and A. P. Covich, Eds.)

Drewes, C. (2004). *Lumbriculus variegatus: A Biology Profile*. Iowa State University. Retrieved from: <https://www.eeob.iastate.edu/faculty/DrewesC/htdocs/Lvgen4.htm>

Drewes, C. D. and C. R. Fournier (1989) Hindsight and rapid escape in a freshwater oligochaete. *Biological Bulletin (Woods Hole)* 177:363-371.

Endler, J. A. 1986. Natural selection in the wild. - Princeton Univ. Press, Princeton, NJ

Fillafer, C., & Schneider, M. F. (2013). On the Temperature Behavior of Pulse Propagation and Relaxation in Worms, Nerves and Gels. *PLoS one*, 8(6), e66773. <https://doi.org/10.1371/journal.pone.0066773>

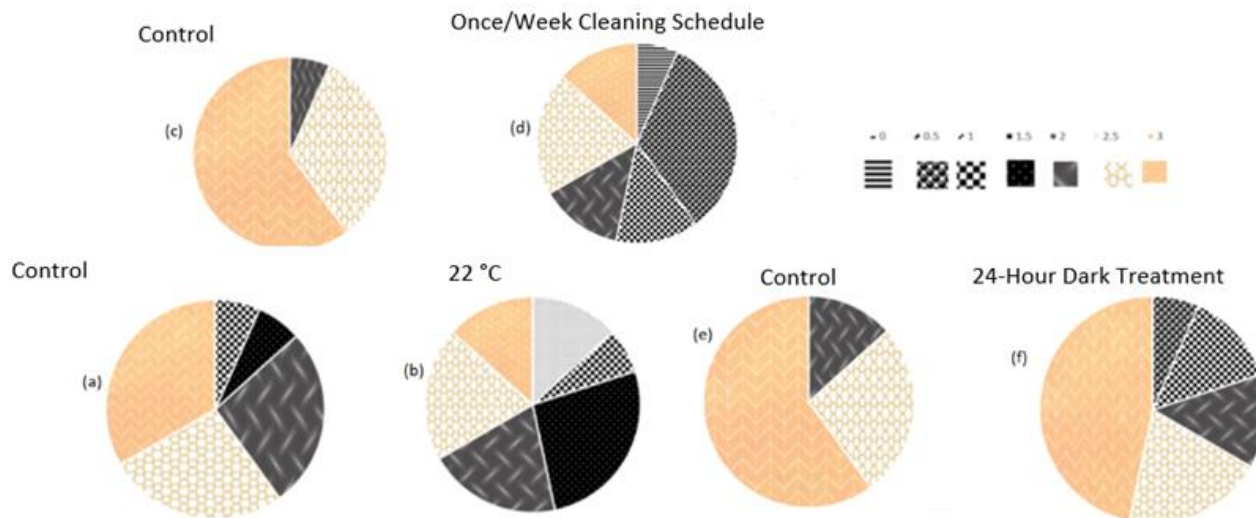
Jamieson, B. G. M. (1981) The Ultrastructure of the Oligochaeta, Academic Press.

Lesiuk, N. M. and C. D. Drewes (1999) Blackworms, blood vessel pulsations, and drug effects. *American Biology Teacher*, 61:48-53.

Harris, M.A., Nordheim, E.V. & Batzli, J.M. (2022) *Process of Science Companion: Data Analysis, Statistics and Experimental Design*. (eBook Edition). L&S Learning Support Services, UW-Madison [Process of Science Series, Book 3 – Simple Book Publishing \(unizin.org\)](https://unizin.org)

RStudio Team (2019). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL <http://www.rstudio.com/>.

Appendix A. Circulation Assay of *L. variegatus* Reared under Varying Environmental Conditions. Pie chart shows the results of the circulation assay of *L. variegatus* reared under a water temperature of (a) 10°C (discarded from analysis as discussed above) and (b) 22°C, (c) twice/week cleaning frequency and (d) once/week cleaning frequency, (e) a 24-hour Light treatment and (f) 24-hour dark treatment. Each pattern represents a different circulation assay score. Lower assay scores (1.5 or below) indicate poor circulation as indicated by amount of red coloration. (n=15). Note that (a) has a significantly different distribution than (c) and (e) despite the fact that they all represent control conditions.



Bioscene: Journal of College Biology Teaching Submission Guidelines

I. Submissions to Bioscene

Bioscene: Journal of College Biology Teaching is a refereed publication of the Association of College and University Biology Educators (ACUBE). Bioscene is published online in May and in print and online in December. Submissions should reflect the interests of the ACUBE membership

- **Articles:** Course and curriculum development, innovative and workable teaching strategies that include some type of assessment of the impact of those strategies on student learning.
- **Innovations:** Laboratory and field studies that work, innovative and money-saving techniques for the lab or classroom. These do not ordinarily include assessment of the techniques' effectiveness on student learning.
- **Perspectives:** Reflections on general topics that include philosophical discussion of biology teaching and other topical aspects of pedagogy as it relates to biology.
- **Reviews:** Web site, software, and book reviews
- **Information:** Technological advice, professional school advice, and funding sources
- **Letters to the Editor:** Letters should deal with pedagogical issues facing college and university biology educators

II. Preparation of Articles, Innovations and Perspectives

Submissions can vary in length, but articles should be between 1500 and 5000 words in length, including references and tables but excluding figures. All pages and lines of the document should be sequentially numbered including the abstract but excluding figure and table legends. Concision, clarity, and originality are desirable. The formats for all submissions are as follows:

- A. **Abstract:** The first page of the manuscript should contain the title of the manuscript, the names of the authors and institutional addresses, a brief abstract (200 words or less) or important points in the manuscript, and keywords in that order.
- B. **Manuscript Text:** The introduction to the manuscript begins on the second page. It should supply sufficient background for readers to appreciate the work without referring to previously published references dealing with the subject. Citations should be reports of credible scientific or pedagogical research.

The body follows the introduction. Articles describing some type of research should be broken into sections with appropriate subheadings including Materials and Methods, Results, and Discussion. Some flexibility is permitted here depending upon the type of article being submitted. Articles describing a laboratory or class exercise that works should be broken into sections following the introduction as procedure, assessment, and discussion.

Acknowledgment of any financial support or personal contributions should be made at the end of the body in an acknowledgement section, with financial acknowledgements preceding personal acknowledgements. If the study required institutional approval such as an Institutional Review Board (IRB), the approval or review number should be included in this section. For example, this study was approved under IRB number 999999. The editor will delete disclaimers and endorsements (government, corporate, etc.)

A variety of writing styles can be used depending upon the type of article. Active voice is encouraged whenever possible. Past tense is recommended for descriptions of events that occurred in the past such as methods, observations, and data collection. Present tense can be used for your conclusions and accepted facts. Because Bioscene has readers from a variety of biological specialties, authors should avoid extremely technical language and define all specialized terms. Other than heading titles, the first word in a sentence or a proper noun, authors should not use capitalization, underlining, italics, or boldface within the text. Authors should not add extra spaces or indentations, nor should they use any hidden editing tools. All weights and measures must be given in the SI (metric) system.

In-text citations should be done in the following manner:

Single Author: "... when fruit flies were reared on media of sugar, tomatoes, and grapes" (Jaenike, 1986).

Two Authors: "...assay was performed as described previously (Roffner & Danzig, 2004).

Multiple Authors: "...similar results have been reported previously (Baehr et al., 1999).

- C. **References:** References cited should appear alphabetically by the author's last name at the end of the manuscript text under the heading references. All references must be from published materials in the literature or the Internet. Authors should use the current APA style when formatting the reference list.

(1) Articles-

(a) **Single author:**

DeBuhr, L. E. (1991). Using Lemna to Study Geometric Population Growth. *The American Biology Teacher* 53(4) 229-232
<https://doi.org/10.2307/4449274>

(b) **Multi-authored three to seven authors:**

Green, H., Goldberg, B., Schwartz, M., & Brown, D. D. (1968). The synthesis of collagen during the development of *Xenopus laevis*. *Developmental Biology*, 18(4), 391-400. [https://doi.org/10.1016/0012-1606\(68\)90048-1](https://doi.org/10.1016/0012-1606(68)90048-1)

(c) **Mutli-authored more than seven authors**

List the first six authors than an ellipsis followed by the last author.

(2) Books-

Bossel, H. (1994). *Modeling and Simulation* (1st ed.). CRC Press.
<https://doi.org/10.1201/9781315275574>

(3) Book chapters-

Glase, J. C., & Zimmerman, M. (1993). Population ecology: Experiments with Protistans. In J. M. Beiswenger (Ed.), *Experiments to Teach Ecology* (pp. 39-82). Washington, DC: Ecological Society of America. Retrieved November 25, 2005 from <https://tiee.esa.org/vol/expv1/protist/protist.pdf>

(4) Web sites-

McKelvey, S. (1995). *Malthusian growth model*. [unpublished manuscript]. Department of Mathematics, Saint Olaf College, Northfield, Minnesota. Retrieved November 25, 2005, from <https://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html>

D. Tables

Tables must be submitted as individual electronic files in Word (2013+) or RTF format. Tables should not be submitted in Excel. Placement of tables should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. All tables must be accompanied by a descriptive legend in the format:

Table 1. A comparison of student pre-test and post-test scores in a non-majors' biology class.

E. Figures

Figures must be submitted as high resolution (≥ 300 dpi) individual electronic files, either TIFF or JPEG. Figures submitted should not be layered as in Photoshop or similar program. No cut and paste figures will be accepted. Placement of figures should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. Figures only include graphs and/or images. Figures consisting entirely of text will not be accepted and must be submitted as tables instead. All figures should be accompanied by a descriptive legend in the format: **Fig. 1. or Figure 1:** Polytene chromosomes of *Drosophila melanogaster*.

III. Letters to the Editor

Letters should be brief (400 words or less) and direct. Letters may be edited for length, clarity, and style. Authors must include institution address, contact phone number, and a signature.

IV. Other Submissions

Reviews and informational submissions may be edited for clarity, length, general interest, and timeliness. Guidelines for citations and references are the same for articles described above.

V. Manuscript Submissions

All manuscripts are to be sent to the editor electronically and must comply with the preparation as described above. Authors must clearly designate which type of article they are submitting (see Section I) or their manuscript will not be considered for publication. Emails should include information such as the title of the article, the number of words in the manuscript, the corresponding author's name, and all co-authors. Each author's name should be accompanied by complete postal and email addresses. Telephone and FAX numbers are optional. Email will be the primary method of communication with the editors of Bioscene.

Communicating authors will receive confirmation of the submission. Manuscripts should be submitted either as a Microsoft Word to facilitate distribution of the manuscript to reviewers and for revisions. A single-email is required to submit electronically, as the review process is not necessarily blind unless requested by an author. If the article has a number of high resolution graphics, separate emails to the editor may be required. The editors recommend that authors complete and remit the [Bioscene Author Checklist](#) with their submission in order to expedite the review process.

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Reviewers will examine the submission for:

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- Novelty: The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

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- B. Making sure that references are formatted appropriately in APA style format shown above.
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