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Cover image: *Sibon nebulatus*

Taken near Bladen Nature Reserve in southern Belize
Taken by: Paul C. Pickhardt, Ph. D.
Lakeland University

Sibon nebulatus commonly called the 'clouded snail-eater' or 'cloudy snail-sucker' is a small, nocturnal snake in the colubridae family. These slender snakes can be found preying upon slugs and snails from southern Mexico, throughout Central America and into northern South America.

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Changing Perspectives on Anatomy & Physiology: From Killer Class to Gateway Course

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Abstract

Anatomy and Physiology should be considered a gateway course due to its challenging scope and key role as a foundational prerequisite for many degree programs. Students often encounter gateway classes early in their college career when they are academically vulnerable due to their lack of university experience. A&P teaching methods are evolving to address these issues and favor more positive outcomes. New approaches include emphasizing understanding of course content (rather than relying on memorization) and creating multi-modal learning opportunities. Utilizing active learning techniques allows students to more directly participate in their education and achieve more favorable results than traditional passive methods. Furthermore, unifying A&P lecture and lab classes into a cohesive "studio model" class taught by one instructor may encourage student collaboration and increase active learning. Implementing a formal supplemental instruction program led by peer facilitators supports struggling students and yields promising results. A renewed focus on improving the teaching skills of gateway instructors is integral in creating a learning environment that maximizes academic success. In this paper, we review special issues and problems associated with A&P instruction. We also discuss how changing perspectives on course organization could improve A&P courses.

Keywords: Anatomy & Physiology Gateway courses STEM Education Active Learning

What Makes Anatomy & Physiology a Killer?

Anatomy & physiology (A&P) courses certainly fall under the rubric of science, technology, engineering and mathematics (STEM). At many colleges and universities, health sciences students comprise a majority of the students enrolled in those courses. This adds complexity to the task of designing and teaching high caliber A&P courses. The implication is not that health sciences students are somehow easier or more difficult to teach. Rather, their programs usually require the courses as prerequisites and often culminate in comprehensive licensure exams. These circumstances draw more interested parties into the mix and create more checks and balances regarding the quality of A&P courses. While these conditions are not exclusive to A&P students, they certainly warrant giving A&P classes a detailed look.

Words and phrases such as "daunting," "content dense," "intimidating," "difficult" and "conceptually challenging" have been used by students, faculty and researchers to describe A&P courses (Johnston et al., 2015; Finn & Campisi 2015). Table 1 offers perspectives of the authors. Both of us are former A&P students; one now teaches the course. Like other lower-level college science courses, A&P may be taught in a format involving a single massive lecture and several smaller lab sections. So, lecture and lab may be taught by separate instructors with differing academic expectations and dissimilar teaching styles (Finn et al., 2017). Students often feel so pressured to maintain a high average that they focus on the final course grade, often at the expense of "owning" the content (Eagleton, 2015).

Johnston et al. (2015) note that health science students enrolled in nursing programs are often older individuals who have not been involved in formal education for a long period of time. In other words, they have "gone back to school." Many are first generation college students. The authors see these trends among other health sciences students as well. Like many other STEM courses, A&P is often taught using traditional pedagogical practices that emphasize rote memorization and minimize student participation (Mattheis & Jensen, 2014; Anderton et al., 2016). Professors habitually bemoan the lack of academic preparation among learners (Finn & Campisi, 2015), while students tend to view A&P as a dull course taught in an environment with a low "sense of community" which lacks encouragement. They sometimes identify these issues as contributing factors for their poor performance (Hoskins et al, 2017). Additionally, students are often very reluctant to seek out academic support (such as tutoring) offered by universities (Thomas et al., 2019). High withdrawal and failure rates contribute to low morale for both teachers and their students. Minority students, low-income students and first-generation college students are often overly represented among students who fail or withdraw from gateway courses (Koch, 2017).

Teacher Perspective	Former Student Perspective
I have been teaching anatomy & physiology, and other college biology courses, for over 25 years. I still absolutely love my job and I still get very excited at the prospect of helping my students learn such an interesting subject. Anatomy & Physiology has always been a hard class to teach and a difficult class in which to be a student. I know both of those things firsthand. Yet, certain aspects of my work have become more predictable over the last several years. I feel privileged to be slated to teach two sections of A&P this fall. Teaching that course has, however, become a trying and emotional experience for me. I'll make an effort on the first day to get my students engaged and motivated. Yet, I'll think to myself "You all have no idea what you've signed up for." I will teach as much about study skills as I do about cells, bones and tissues. I'll have my students draw concept maps. I will remind them to do daily reviews and read their textbook. They will hear my earnest warnings about preparing for the lab practical, yet some of them will still not apply themselves. After the first test, more and more of the students will come to me with stories about which health science program they are applying for and what grade they need in my class. I'll push tutoring. I will continually encourage students to ask questions in class. I will reinforce course material in multiple review sessions. Some students will appear overwhelmed; others will nervously turn pages in a book which they have likely never read. As the weeks go by, some students will find themselves hopelessly behind. I will continue to encourage them and make myself available to help. Unfortunately, some students will not take advantage of this; however, most students who follow the course guidelines will succeed. Of those who fail or withdraw, most will ultimately blame me. Dr. Eddie Lunsford (A&P Teacher), Reflective Journal	I certainly left A & P with a greater knowledge of the inner workings of the human body. Admittedly, I may have forgotten some of the material over time. Yet, the course provided me with both a comprehensive biological overview and an enduring framework for adding new information. I still possess a strong enough knowledge base to recognize when gap in my understanding appears. Having this realization allows me to reinforce any areas that have become unclear. Knowing how to efficiently assimilate new information is an especially valuable skill today due to the accelerated pace of innovation in our society. New industries, technologies, careers and opportunities are created (and disappear) at an unprecedented rate. The old saying that change is the only constant in life may apply now more than ever. The ability to quickly understand new information will very likely provide more career opportunities and greater stability in an ever-changing job market. Enhancing these skills will likely be required for success in the future. As a result, the most valuable takeaway from completing this A&P class may have been learning how to approach the art of learning itself. As students, we were taught how to improve time management and maximize memorization of course material with minimal effort. We were also encouraged to ask questions and discuss any concerns we had. These techniques helped me to develop a calm focus that alleviated the sense of being overwhelmed and allowed me to feel that the course demands were manageable and achievable. As a result, the course provided me with better learning methods and an enhanced confidence in integrating and explaining complex ideas. I am also able to make more informed choices about my health and well-being since completing the class. Michael Diviney (Former A&P Student in Allied Health Program), Reflective writing

Table 1. A comparison of A&P teacher and student perspectives

These circumstances often delay student progress into their chosen majors and/or programs of study (Gultice et al., 2015). Sadly, some A&P instructors have responded by watering down their courses to the point that they are ineffective for the students and their program requirements (Johnston et al., 2015). In what follows, we suggest that A&P courses should be treated as "gateway courses." Though the change is not in name only, gateway courses are getting significant attention in recent educational literature. This perspective should change how A&P courses are designed and taught; as well as how students view their role as an active participant in the learning partnership. As we will establish, the gateway model encourages not only change, but informed change driven by data.

What are Gateway Courses?

We should begin by admitting that the college classes now referred to as "gateway courses" were recently called "killer classes" (Koch, 2017). Students typically enroll in gateway courses early in their studies, often within the first couple of academic terms (Pistilli & Heileman, 2017). Unfortunately, for most students, this is a time of great vulnerability for academic success (Nordell, 2009). Students are frequently placed in this situation because gateway classes are often prerequisites that must be successfully completed before students can enter their academic program (Pistilli & Heileman, 2017). Furthermore, gateway courses tend to have high enrollment relative to each institution's typical class size and student-teacher ratio (Koch, 2017).

Faculty who teach gateway courses often lack basic pedagogical skills, despite the fact that they may be highly respected scientists within their field of expertise (Jensen, 2011; Mattheis & Jensen, 2014). It is unlikely that they struggled much when they were students (Nordell, 2009). Yet, they often find themselves under pressure to improve pass rates in their courses (Pistilli & Heileman, 2017). More often than not, gateway course faculty have little to no skills or experience successfully dealing with struggling students (Norell, 2009).

Students typically struggle a great deal in gateway courses (Pistilli & Heilman, 2017). Specific to STEM gateway classes, Hoskins et al. (2017) report that students often come into classes with only rudimentary study skills. The students tend to rely on study habits that served them well in high school, despite the fact that the college learning model is vastly different and requires students to master much more material while spending far less time in the classroom. Students tend not to understand that much of the responsibility for learning falls squarely on their own shoulders. Also, the students often lack crucial self-assessment skills and are frequently at a loss to adjust their academic strategies when they find that their outdated study habits do not produce favorable results (Nordell, 2009). These factors exacerbate the risk of poor academic performance and contribute to high failure rates. There is a trend toward using institutionally relative rates of D and F letter grades, as well as Incomplete (I) grades and Withdrawal (W) grades to formally identify a gateway course. Incomplete grades are significant in that they may often change to Fs based on school policies (Koch, 2017).

Today more jobs than ever require a college degree. Therefore, college enrollment is generally higher than it has been in years past (Pistilli & Heileman, 2017). All this sets up a scenario where much more is at stake than simply failing a class. Course failures and withdrawals impact financial aid eligibility which, in turn, increases one's risk of dropping out of college (Koch, 2017). Costs of attending college are higher than ever (Pistilli & Heilman, 2017). The logical conclusion is that a great number of unfortunate students run a real risk of not only having their life aspirations dashed, but also leaving school with a mountain of debt and little to show for their efforts. It is at the very least concerning, if not overtly heartbreaking, to see this state of affairs continue unimpeded.

Shifting Perspective & Seeking Solutions

As educators start to view STEM classes as gateway courses, A&P teaching methods are changing. There is a greater emphasis on helping students understand content in lieu of simple memorization (Anderton et al., 2016). The gateway model leads us to view A&P courses for what they are: high-risk classes that are often in need of a major overhaul. In other words, the new emphasis is less about at-risk students and more about fostering a better course framework (Arendale, 2014). In what follows, we will review trends and specific programs being implemented to achieve this goal. These techniques often do not stand alone but work most effectively as part of a comprehensive approach. In fact, what seems to work best is the simple act of providing choices, variety, and multi-modal learning opportunities (Eagleton, 2015; Anderton et al., 2016). Table 2 summarizes the essential recommendations for change.

Changing perspectives from	Changing perspectives to
Targeting at risk students only	Targeting high risk courses
Separating lecture & lab	Integrating the whole course experience
Lecture as primary pedagogical tool	Use of various techniques for teaching
Teacher as content expert	Teacher as content expert with high teaching skills
Students sink or swim	Students are encouraged, coached & nurtured
"Tutoring is available"	Supplemental instruction built into course
Students passively participate in lecture	Students become skilled, active learners
Study skills assumed	Study skills & metacognition are taught
Professor for lecture, assistant for lab	Professor teaches both, supported by SI facilitator
Most feedback for students from graded exams	Regular, constructive, targeted feedback for students
Professor & department hope for a better year	Set goal → implement change → track improvement

Table 2. Recommended patterns of changing perspectives in A&P courses.

Emphasizing active learning.

The concept of active learning is simple but often misunderstood. Active learning is the process of directly engaging students in the learning process. For example, groups of students in a lecture hall who are simply taking notes are likely not participating in active learning. However, students who work in groups and who are challenged to think during class are more actively participating in the learning process. Freeman et al. (2014) completed a meta- analysis concerning the impact of active learning in STEM courses. They found that implementing these classroom strategies greatly bolstered exam scores and course averages when compared to traditionally passive methods. Finn & Campisi (2015) also noted better attitudes, specifically among A&P students (and a higher retention rate) when active learning was fostered. Incorporating active learning does not mean doing entirely away with traditional teaching methods like lecture (Andreton et al. 2016).

Specific examples of active learning opportunities appropriate for A&P courses abound. For example, students may collaborate in small groups to master content objectives (Finn & Campisi, 2015). In the author's classes**,** students work on a semester-long concept-mapping project. Maps are handed in with each unit of study. A bit of class time is sometimes devoted to mapping in groups. Students may elect to hand in a combination of individual and group generated maps. Also, students share half the responsibility for grading their submissions with the teacher.

Lately, there has been a great increase in technological learning aids such as medical imaging programs and simulations that may be used with success. Examples include the Anatomage™ Virtual Dissection Table, Visible Body©, Anatomy & Physiology REVEALED® and many others. In the absence of these items, simple activities like painting muscles or vessels on tee shirts or making clay anatomical models may be pursued (Anderton et al., 2016). Belanger et al. (2018) described an inquiry activity whereby their A&P students not only gained sound skills in scientific processes but also honed their microscopy skills and analytic proficiency. Moreover, the students learned a great deal about the pathophysiology involved in diabetes mellitus. A&P students may also benefit from case-based scenarios. Hilvano et al. (2014) described how the health science students in their study prepared group-based poster presentations. Participants were assessed individually and in cooperative groups. The results included increased content knowledge and better attitudes toward the course. Finally, Dyer & Elsenpeter (2018) remind us of the importance of tracking the success of attempts to foster active learning by completing statistical analyses. Qualitative data, from student questionnaires or focus groups, may assist as well (Hilvano et al. 2014; Finn & Campisi, 2015).

Integrated lecture and lab.

As previously noted, gateway STEM courses, like A&P, are traditionally taught in oversized lectures accompanied by smaller laboratory sections. A growing trend is to integrate both parts of the course into a unified experience (Finn, et al. 2017). At our school, due partly to its smaller size, we have made a choice to do just that. Despite growing enrollment, scarcity of lab space and scheduling challenges, we try to maintain the pattern of teaching lab and lecture in the same room (a laboratory room) and with a single instructor. Finn, et al. (2017) noted that this practice is sometimes referred to as the "studio model." It involves longer class periods and a greater emphasis on collaborative learning. Students tend to view the experience favorably, which may also increase learning. We suggest that even large universities may benefit by experimenting with this model. For example, the course could meet twice per week for three hours, instead of meeting three times per week for an hour-long lecture and then returning for a separate three-hour lab. Combining lab and lecture presents opportunities to implement new teaching strategies and integrate targeted lab activities into the typical routine.

Providing formalized supplemental instruction.

There is a lot to be said for the value of a good tutoring experience in STEM courses and elsewhere. The idea of supplemental instruction (SI) takes that model into new territory (Eroy-Reveles, et al., 2019). Numerous variations on the basic theme exist, but the gist is that the experience is embedded within the course as enrichment instead of being a separate activity for poorly performing students (Arendale, 2014). This leads to a major advantage in diminishing the frequent sense of imputation, and the extra effort involved, in seeking out and utilizing a tutor (Thomas et al., 2019).

In larger universities, graduate students may lead SI the way they currently teach lab sections (Hoskins et al., 2017). Academic peers may also be leaders of SI. Arendale (2014) uses the phrase "Peer Assisted Learning" (PAL) while Finn & Campisi (2015) call the practice "Peer-Led Team Learning" (PLTL). Peer facilitators are required to have recently completed, and excelled at, the course they are leading. In addition, facilitators often receive formal training focusing on the pedagogy of teaching small groups. They may also attend class and lab meetings along with their SI student participants. Enrollees attend regularly scheduled meetings (often weekly) where they collaborate and review material previously presented in class. Some institutions make attending sessions optional, others mandatory. The desired outcome is a comfortable environment where students cooperate with each other and where facilitators pass along their knowledge to help the cohort succeed (Arendale, 2014; Finn & Campisi, 2015). Another component of SI may involve coaching students to develop stronger study skills and better learning strategies (Arendale, 2014). Nordell (2009) notes that metacognitive skills, critical thinking, and self-assessment may create positive outcomes when they are emphasized in STEM courses. To assist with individual studying and SI work, students and facilitators may be provided with clear course objectives, study guides and other handouts. An advanced study organizer, similar to the one shown in Table 3, may help guide students to more effectively manage the complicated course organization. That handout is used in the first author's class. It includes tips for managing the heavy emphasis on microscopy in mastering the course objectives for that particular topic in class. There are also reminders about basic things like reading, reviewing, and keeping track of handouts, as well as where to locate reading assignments. Students frequently need those reminders, particularly during the early weeks of the course.

A single SI session or two may be offered early in the semester or implemented as a regular and ongoing intervention. Nordell (2011) also describes an effective seminar focusing on college study skills that is required for all incoming freshmen. Various colleges have gone so far as to create course-specific supplemental instruction meetings that require attendance. They are listed in the departmental class schedule and generate revenue from tuition (Eroy-Reveles et al., 2019). For example, all students taking a "regular" A&P course may also be required to attend a supplemental co-requisite class. We recognize this may be a challenge, particularly in colleges like ours where degree and certificates programs are already burgeoning with required hours. Yet, the improvements may well justify such an undertaking. In summary, SI programs (such as PLTL and PAL) have demonstrated empirically quantifiable results that may increase pass rates (Finn & Campisi, 2015; Thomas et al., 2019).

Improving instructor preparation and skills.

As documented above, faculty who are involved in a gateway course instructional role may be among those who have the poorest pedagogical skills. This is often due to the fact that they were never required or encouraged to take courses to prepare them to be more skilled and effective in their teaching (Norell, 2009; Jensen, 2011). Mattheis & Jensen (2014) noted that one of the biggest general challenges to improving A&P instruction stems from a resistance to change on the part of instructors. In higher education, there seems to be a pervasive preconception that "teacher training" does not really matter, even (or perhaps especially) for challenging college STEM courses. Jensen (2011) reviews numerous pieces and types of evidence that effectively refute and shatter this myth.

We recommend that all A&P instructors (regardless of their current pedagogical preparation) actively seek out and participate in opportunities to refine their teaching skills. A&P instructors could, for example, enroll in a course or two offered by their university college of education. There are education classes aimed at science teaching methodology, effective classroom testing and measurement, and educational psychology. Chances are good that faculty in education and/or psychology would welcome the opportunity to collaborate with A&P instructors to develop shorter, more targeted workshops that assist with A&P gateway course goals. We encourage A&P faculty to read books, take online courses and/or attend seminars about effective teaching practices. Even the best prepared professor may benefit from enhancing content preparation. For example, simply by becoming a student again, a veteran of A&P instruction may discover an exciting new technology or a unique approach to explain a difficult physiological concept.

Summary

In this paper, we have presented a review of special problems and challenges associated with college and university A&P courses. These challenges encompass not only the student population but also the faculty and entire institutions of learning.

Additionally, we explained the concept of gateway courses and reviewed why A&P is increasingly being thought of in that framework. Finally, we offered several examples, both from the literature, and from our own experiences, to assist others in changing their perspectives on how to best design and deliver a quality A&P gateway course. We encourage professors, department chairs and other interested parties to examine existing pass/fail rates, student averages and student satisfaction surveys in their A&P courses. The gateway model would next require formulating goals for improvement. Finally, selected interventions would be implemented, and their progress tracked. We challenge our colleagues to participate in initiatives designed to improve their own A&P courses. We encourage them to use a variety of qualitative and quantitative measures, and to report their findings to the larger community of college A&P educators and other interested STEM education participants.

Topic 2: Histology & Integument: Pulling it All Together

This is a shorter unit but make sure it does not sneak up on you as you're studying for Topic 1. Plan ahead and budget your time well. Laboratory is particularly important in understanding the histology objectives.

Read and Review	Lab Work
Read Textbook: Use syllabus & objectives. The textbook glossary and index will help too. **Make Concept Maps** as you read **Review daily:** refine concept maps as you review. Look for verb cues on objectives like "list" or "label" or "match" **Preview lab procedures:** See syllabus each week **Mark Progress**: Record reading & review dates on the back of this handout **Emphasize lab as you study**; especially on histology **Stop Studying** on the day before the test. This will help you relax and assist your short-term memory	**Utilize feedback** you got on the previous labs to improve your microscopy diagramming techniques **Use the Lab Procedure** to guide your work; not the exercises or any pages to hand in. **Spend extra time on microscopy work.** Make careful diagrams as you follow the lab procedure. Base your diagrams on what you observe while looking in the microscope, not from micrographs or from someone else's paper. Use lab book, atlases and textbook to help with labeling and identification. **Work collaboratively with your lab group** but make sure you actively participate. **On lab week 4** make sure you study the models of the skin as you work **With any Remaining Time:** Verify your progress with "Lab Practical II Objectives" handout; review models and slides for practice **Begin work on any pages to hand in**: This should be the last thing you use your time for during lab. Collaborate with others but do not copy their work. Look up answers in the lab procedure, textbook or other sources. Have any assigned pages all finished and ready to hand in on the due date. **As noted on the lab schedule** from the Syllabus…think about getting a jump start on studying the skeleton
During Class	**Other Things You Can Do**
Ask questions based on your previous days' review **Follow along** with the skeletal outline during lecture **Make notes** to clarify reading & concept mapping **Participate** by asking questions, watching videos, contributing to discussion **On Test Day:** Avoid review and study on that day. Walk into class with your concept map(s) finished; include your name and numerical grade (zero to 10). Hand them in first thing. Realize that you also should be prepared to continue in the next unit following the test. **REMEMBER:** No late concept maps are accepted. If you're absent send them on or before the test date.	**Ask your teacher** for extra help by e-mail or during an office visit **Study with others** if your schedule allows **Use outside assistance**: Go by the Learning Assistance Center (LAC) and/or ask about tutoring on a regular, or as needed, basis **Use other references:** supplemental books, online resources, YouTube videos **Review histology slides** in the library; they have several but not a complete collection **Plan Ahead:** Don't forget Topic III is forthcoming and needs your attention. **Utilize review questions** in textbook and/or items in lab book which were not assigned.

Table 3. Example of advanced organizer from second A&P topic unit.

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Comparing the Outcomes of “pre-CURE” Compared to Inquiry-based Introductory Biology Labs

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Abstract

Course-based undergraduate research experiences (CUREs) are increasing being taught to undergraduates across institutions and topics and offer an opportunity for more students to participate in authentic research. There are many types of “CUREs” with varying degrees of including all five elements identified by Auchincloss et al. (2014) as defining a CURE course. Even when authentic research labs do not include all the elements of a CURE, they still provide students an opportunity to engage in the process of science and could be an important transition from inquiry-style labs to full CURE labs. In this paper, we call labs that provide research experiences, yet may include lower-stakes, non-iterative or narrowly relevant results “pre-CURE” labs. We sought to assess if students were developing a better understanding of experimental design and scientific argumentation in a pre-CURE vs. a guided-inquiry version of the same introductory biology lab, as evidenced by scientific paper writing assignments. Students in guided-inquiry labs performed better on argumentation themes (p=0.01549) in their lab reports, conceivably because they had narrower variable selection. However, students learned more about experimental design in the pre-CURE course (p=1.77^{-12}). Particularly because the pre-CURE gave the students the opportunity to fail by allowing them to design experiments that did not yield results.

Keywords: pre-CURE, CURE, citizen science, productive failure, laboratory, undergraduate

Introduction

Research experiences are an integral component of education for biology students. Experience conducting research has a major impact on the development of analytical and applied skills and the understanding of the relevant concepts, as well as a long-term impact on the student’s continued passion for and involvement in science (Latzer et al., 2015). It has long been recognized that undergraduate research experiences (UREs) are an important part of training each subsequent generation of scientists (Kinkead, 2012). Apprenticeship has been the classical model for undergraduate research, and positive outcomes are reported for undergraduates who are able to participate in some sort of research endeavor (Gentile, Brenner, and Stephens, 2017). In 2009, the American Association for the Advancement (AAAS) of Science published “Vision and Change,” a call to action to engage undergraduates in authentic science experiences (Woodin et al., 2010). One of the ways that students can participate in research is a course-based undergraduate research experience (CURE) (Brownell and Kloser, 2015).

Dolan (2016) defines CUREs as “learning experiences in which whole classes of students address a research question or problem with unknown outcomes or solutions that are of interest to external stakeholders,” which is in contrast to more traditional apprenticeship-type research experiences that are often more or less one on one. This also differs from an inquiry-based model for a laboratory class since to be a true CURE, as with any scientific research, there is an unknown experimental outcome to the students and scientific community alike (Latzer et al., 2015, Dolan, 2015). CUREs are gaining use (Figure 1). Approximately 307 institutions of higher education, 17 of which are international, are currently registered within CUREnet, a network of programs and people creating CUREs established in 2012 by Erin Dolan (University of Georgia), Dave Micklos (Cold Spring Harbor Laboratory), and Nancy Trautmann (Cornell Lab of Ornithology). CUREnet estimates that at least one third of those are still actively teaching CUREs (*CUREnet*).

One reason why CUREs have become more prevalent lies in the numerous advantages of utilizing CUREs rather than more traditional UREs, such as internships. Many institutions do not possess the resources to involve large numbers of undergraduates in research in an internship capacity (Auchincloss et al., 2014). To circumvent this issue, CUREs have arisen as a popular alternative to apprenticeship

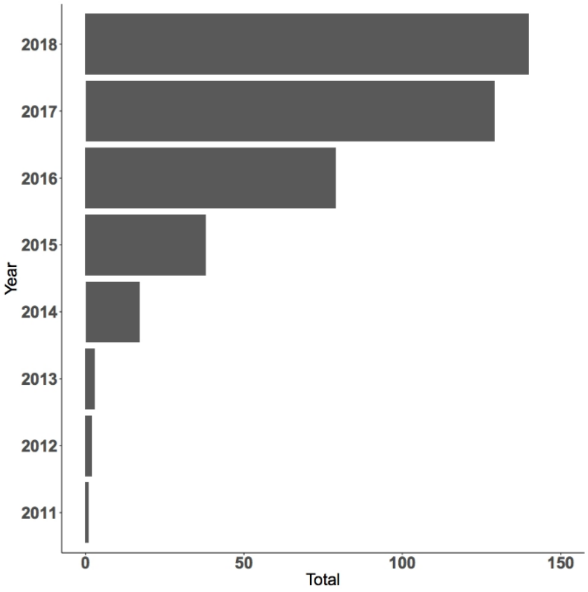

Figure 1. January 2019 Google Scholar advanced search of exact phrase “CUREs” AND “course-based undergraduate research experience" shows a steady increase of hits from the year 2011 until 2018.

research experiences (Bangera and Brownell, 2014). Another advantage to CUREs when compared to the classes they are often replacing (either cookbook labs or directed inquiry-based labs) is that they still engage students in the process of real science as an internship or apprenticeship would while addressing some of the limitations inherent in the latter. Students formulate their own research questions and create their own research designs, which can either result in success or failure. There are unknown outcomes to these research questions, and the results that the students obtain are genuine data that can support their hypotheses (Auchincloss et al., 2014).

However, implementing CUREs is not without its disadvantages and challenges. If students are unprepared for research, they cannot take full advantage of the CURE or URE. This can happen if they are not ready for the empirical process of science and experimental design. In an innovative study on student perceptions of research in 2005, Meyer, Shanahan, and Laugksch found that undergraduate students have problems with a general conceptual understanding of research even after taking standard biology classes. Murtonen (2015) argues that unless students are well-versed in the methodology in their discipline, they will not be fully successful. Additionally, students coming out of cookbook or inquiry-based labs are often not ready for the iterative process of a true CURE that involves potentially failing in their research process (Brownell and Kloser, 2015) and potentially needing to adjust either their research or methodology. Not all in-lab authentic research projects meet the five criteria laid out by Auchincloss et al (2014)—use of scientific practices, discovery, broadly relevant work, collaboration and iteration—yet these research projects still provide students valuable training in authentic research.

These authentic research courses that are not quite CUREs provide students with those foundational skills and understanding necessary to be successful in a full CURE or URE and we call these course-based authentic research projects a pre-CURE. In the context of this discussion, a pre-CURE is defined as a course-based undergraduate research experience that offers the opportunity to participate in the process of authentic science, but does not meet all the criteria of a CURE and/or at a level that is slightly more introductory than a true CURE. These laboratory courses provide authentic research experiences but may be missing iteration and/or the results may not be broadly relevant or applicable to the greater scientific knowledge or community. In other words, the data collected may not be intended for publication or greater communication. The lack of iteration or the limited scope of the results could be due to the limited time available in class for the project or the limited resources available to the course/school. Pre-CURE courses allow students to transition from open inquiry experiments, where the students develop an experiment for a question that has a known answer, to a full CURE, where students spend the course collecting data on a specific research question where the answer is unknown to science.

We expect that the advantages of a pre-CURE will be that the students will walk away feeling more comfortable with engaging in the process of science both through designing and troubleshooting, without the stress of collecting data for a high-stakes experiment. This in turn will allow them to engage in more complex and substantive experimentation in true CURE curriculum models or in UREs without the need to waste valuable time and resources implementing foundational basics. We will examine the advantage of an authentic research experience that does not meet all the CURE criteria, a pre-CURE, compared to an inquiry-based lab, on student’s ability to collect data, analyze data, and troubleshoot problems.

For our pre-CURE, we chose to use a citizen science project as the framework for an authentic research context. Citizen science, which is subsumed under the umbrella of the field of public participation in scientific research (PPSR), engages the public in the process of scientific investigation through one or more steps of the following series of steps: asking a question, collecting data, and interpreting results.

Research that involves citizen science often necessitates the collection of data over a large geographic area or over a long period of time. These projects vary in scale. Some involve only few volunteers, while other span continents. These projects often have the dual objectives of scientific advancement and education. Though contributions of non-scientists to scientific discovery dates back to the time of Galileo or even much earlier, the earliest citizen science projects as they are currently defined date back to the 1800s (Cornell Lab of Ornithology). This sort of democratized approach to involving large numbers of laypeople in the expansion of scientific research represented a new trend in how scientific researchers approached and understood the principles of research outside of the traditional models.

For our independent pre-CURE, we made use of a citizen science project named Budburst. Originally known as "Project BudBurst," Budburst was developed in 2007 to connect citizen scientists with researchers, educators, and horticulturists to investigate plant life cycle events to help better understand impacts humans are having on the environment. We chose this project for the pre-CURE because it was free to participate, did not require any equipment, allowed for data collection at any time of the year, has been implemented in all 50 states by tens of thousands of people (*Budburst*), and, due to the ready availability of trees on campus, allowed students easy access to the research subject. The students designed their own questions regarding the study of leaf senescence or budding: for example, "how does temperature affect budding in flowering dogwood?" They then collected their own data from trees on campus and gathered previously documented data from the Budburst database.

The purpose of this study was to compare learning outcomes between the guided-inquiry version of an introductory biology lab course for majors at East Carolina University and a pre-CURE version of the same course. In this study, we sought to assess if students were developing a better understanding of experimental design and scientific argumentation in the guided inquiry versus the pre-CURE version of the lab. We investigated this by scoring research papers from both versions of the lab for a list of useful target skills with a validated empirical and representational skills rubric for argumentation.

Methods

Prior to the study, we obtained IRB approval and student consent (UMCIRB16-001669 and UMCIRB15-001990). Both a pre-CURE and the guided-inquiry were conducted in second-semester introductory biology labs during the Fall 2016 and an additional pre-CURE was conducted a second time during the Spring of 2017. The instructors of all of the sections, inquiry and pre-CURE, were the same, minimizing the risk of inconsistency posed by such variables as instructor or implementation influences by maintaining continuity. The same instructor also taught all the iterations of the pre-CURE lab. The learning objectives for all the labs was the same and covered both ecology and evolutionary biology themes. Note that the guided-inquiry-activity was geared towards the topic of evolution while the pre-CURE activity focused on ecology; both topics were taught in all second-semester introductory biology lab course.

We began our analyses by assembling the student papers from the guided-inquiry sections (henceforth referred to as the "inquiry lab") and the pre-CURE version of the lab (henceforth referred to as the "pre-CURE lab"). The student paper for the inquiry lab was a write-up about a *SimBio* virtual lab, a virtual simulation where students could manipulate environmental and population parameters to test natural selection (*SimBio*). The final paper for the pre-CURE lab was a paper on the experiment where students designed a research project collecting and using citizen science data from Budburst about leaf senescence (during fall semester) or leaf/flower budding (during spring semester).

Virtual Modeling Activity

Students in the guided-inquiry lab completed a virtual lab activity called Darwinian Snails outside of class in the second week of the semester using the program *SimBio*. The purpose of the Darwinian Snails activity is to help students investigate assumptions behind natural selection. The lab leads the students through simulations within the experimental system of crabs (predator) and snails (prey) following the work of Dr. Robin Seeley on the Gulf of Maine. Students come up with a hypothesis around competition and population density of snails and crabs, then manipulate a set of virtual variables to test their hypothesis. The students can adapt the parameters of the experiment by violating the assumptions of natural selection and investigate if evolution via natural selection still occurs. The virtual lab is broken into six exercises and the students are led through which parameters to change and then are provided with a graph to show the outcome of the experiment. Although each exercise has directions to follow while conducting the computer simulations, the students have the freedom to alter parameters and generate results, giving them the flexibility to run an experiment as well if they desire; this is why we are calling it "guided inquiry" or "inquiry-based". At the conclusion of the experiment, students were assigned a final paper to write up the results from the virtual lab. The instructors then broke the papers down into sections relating to typical divisions found in scientific papers (methodology, results, discussion, etc.). The students were given back each draft with edits and comments, which they then had to revise into one edited final paper.

Budburst Project

The pre-CURE sections used citizen science data from Budburst. Students, in groups of four, designed a project that required data collection from the field and the pulled from the Budburst database. Each group developed a question based on tree phenology (i.e. first bud or leaf senescence) for Greenville, NC, and another location throughout the country, incorporating one abiotic variable (e.g. temperature, rain fall). Students then collected local data and pulled data from databases that met their research question needs. The data were analyzed, and graphs were developed using JMP during the Fall 2016 semester and the provided R markdown files in RStudio during Spring 2017 semester. Finally, each member of the group presented their findings with an individual scientific paper. We designed the module hoping to provide the opportunity for higher-order thinking with the students learning how actual research occurs and experiencing the trials and tribulations of working in groups, and collecting field- and web-based data.

Student demographics

The majority of the students who take this laboratory course and who were included in this study are freshman and sophomores who are STEM majors. It is important to note that while most students are required to have first-semester introductory biology as a pre-requisite to the pre-CURE lab and inquiry lab, exceptions occur and therefore we cannot not guarantee that all students involved in the study had one semester of biology lab prior to this study. The first semester introductory biology course is a guided-inquiry style lab course focused on cell and molecular biology topics and does have one open-inquiry experiment. Therefore, most students entering this course have had the opportunity to create a question, hypothesis, and design an experiment prior to the course.

Study design

We compiled all of the final papers from the three sections and included all papers that were complete (from abstract through discussion sections) for our analysis. This resulted in 19 papers from the Fall 2016 inquiry lab, 18 papers from the Fall 2016 pre-CURE lab, and 18 papers from the Spring 2017 pre-CURE lab.

Using Excel, we randomly assigned each paper an anonymous student identification number and all identifying information about the student was removed. Each paper was then assigned to two out of four potential reviewers using a random number generator in Excel. Two of the reviewers were previous instructors of the course, but identifying information was removed and papers were randomized to minimize bias. The other two were non-instructors and were included to further decrease bias since pairs of reviewers had to come to a consensus on scoring. Reviewers used an adapted and validated rubric based on the Assessment of Scientific Argumentation in the Classroom (ASAC) to evaluate laboratory argumentation skills (Walker et al., 2018, Walker et al., 2019). The rubric was comprised by of 23 target skills that we believed would be useful and were reasonable for science majors to obtain during an introductory biology course (Supplemental Table 1). These skills were determined prior to the start of the study and agreed upon by all the researchers involved as well as external researchers who provided guidance on the development of the rubric. The skills rubric reflects the "ideal" learning objectives that we would hope to see demonstrated by second-semester biology majors.

For each target skill, the rubric asked a question about whether the student demonstrated proficiency of the skill in question. The rubric was entered into Qualtrics (Qualtrics, Provo, UT) and set up as a survey that could be completed. We re-validated the adaptations of the rubric by using it to code randomly selected lab reports and then discussed additions or modifications to the rubric necessary to capture the skills in the lab reports. After we were confident in the rubric, all four reviewers scored the subset of papers assigned to them.

For each question in the rubric, we assessed whether every student demonstrated an acquisition of each target skill in their final paper and scored accordingly in Qualtrics. Once all the results were tabulated, we downloaded the data and compared the results between each pair of reviewers for each student's paper. We identified any discrepancies in the pair of reviewers' answers for each question for every student paper. After identifying the discrepancies, the first step was to verify that we did not simply miss something during the initial scoring process. To do this, reviewers went back through their answers and looked for the examples that the other reviewer had identified to see if they had been overlooked. For those cases where discrepancies still remained, the reviewers met as pairs to discuss the thought process for each set of discrepancies. Reviewers reached 100% inter-rater agreement in cases when assessment was not initially in agreement. In cases where the two reviewers could not reach agreement, a third reviewer was employed to resolve the impasse.

Once the data was reconciled, it was imported into RStudio for analysis. Because the data was not distributed normally (as confirmed by a Shapiro test), we used a Mann-Whitney U Test to assess if there were differences in learning outcomes for the 23 target skills between the students in the inquiry lab and the students in the pre-CURE labs. The data for the two sections of the pre-CURE labs were also compared to each other using the same methods.

Results

Of the 23 target skills, 13 showed a significant difference between the inquiry and pre-CURE labs. We identified four of these target skills as important for future CURE/URE projects. These four skills include: constructing a scientific question, designing an experiment, representing data in a student generated form, and supporting the claim with evidence. Due to their importance in future research success, we discuss these results in greater detail below.

Constructing a scientific question was 83% higher for students in the pre-CURE course compared to the inquiry course (*p*=0.009037) (Figure 2). Designing an experiment was 100% higher for students in the pre-CURE course compared to the inquiry course (*p*=1.77^{-12}) (Figure 2). Representing data in a student generated form was 100% higher for students in the pre-CURE course compared to the inquiry course (*p*=1.25E-09). Supporting the claim with evidence was 43% lower for students in the pre-CURE course compared to the inquiry course *p*=0.01549) (Figure 2).

In addition to the four key factors, nine other elements of interest were significantly different in pre-CURE courses compared to inquiry courses, locating information relevant to a scientific problem (*p*=4.92E-05); designing an experiment that appropriately answered the question (*p*=0.0123); appraising an experiment design; creating an effective figure label (*p*=0.001683); interpreting visual representations of data (*p*=5.66E-06); justifying the claim (*p*=0.002661); identifying additional information needed to support an argument (*p*=0.02457); providing alternative explanations(p-value 0.000969); and using appropriate scientific language (*p*=0.0257).

When comparing the two iterations of the pre-CURE, we found significant differences for 3 of the 23 target skills: locating information relevant to a scientific problem; designing an experiment that appropriately explores the question; and using appropriate scientific language. We found no significant difference between the two iterations and therefore we combined the data from the two iterations.

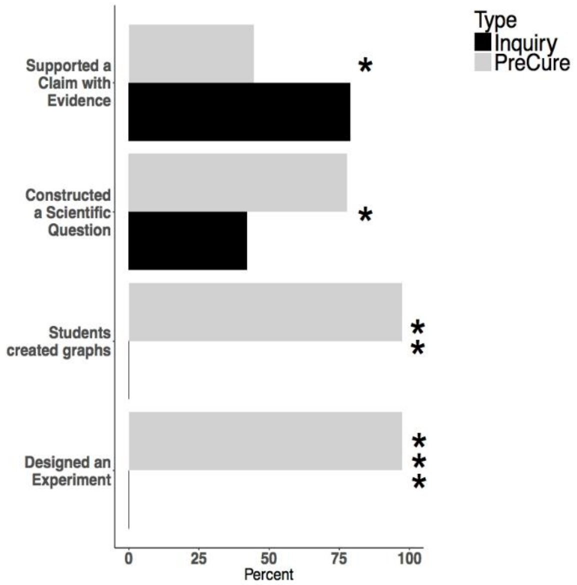

Figure 2. Percentage of assessed students that accurately met target skill for the Inquiry lab and pre-CURE lab. The four skills are: 1) Supported a claim with evidence, 2) Constructed a scientific question, 3) Students created graphs, 4) Designed an experiment. Number of asterisks reflect level of significance (more asterisks = smaller p-value).

In a follow-up three years after the course, we found that 26.33% of students who took the inquiry-style lab section changed their major from a STEM major to a non-STEM major while only 16.7% of students in the pre-CURE lab did the same. More students from the pre-CURE sections also went on to take CURE labs, 16.7% in the pre-CURE sections versus 10.5% in the inquiry-style lab. However, 31.6% of students in the inquiry-lab section were more likely to engage in a traditional undergraduate research experience while only 22.2% of students in the pre-CURE lab did the same.

Discussion

It is our conclusion that citizen science projects provide appropriately scaffolded frameworks for pre-CURE projects for a number of reasons. First, the data are easy to access since they are aggregated in one online database, the utility of which was demonstrated by Budburst. Second, the data are relatively easy to collect, with detailed protocols that are written in a way that allows non-experts to faithfully execute data collection. The advantage of a citizen science project is that it can involve non-scientists, so the level of skill that is required to collect the data is easily accomplished by intro-level biology undergraduate students. These projects offer students the ability to contribute to real science, with low barriers to participation: in the case of Budburst specifically, for example, there is no expensive equipment involved or the need for costly analyses. Finally, the plethora of citizen science projects available allows instructors to choose projects with research questions related to areas of a student's life that are neither abstract nor nebulous (e.g. leaf color change on trees) and fit with the learning objectives of a wide variety of course content.

In this study we sought to investigate if participating in a pre-CURE contributes to an increase in the skills we identified as necessary to be successful in undergraduate research experiences and future upper-level CURE courses. We found that for over half of the target skills that we assessed, there were significant differences between the students who participated in the pre-CURE and those in a traditional inquiry class. Three of these target skills (Figure 2) we see as being very important for students to develop prior to taking a CURE, especially with regards to understanding methodology, the importance of which was highlighted by Murtonen (2015). These target skills are constructing a scientific question, designing an experiment, and representing data in a student generated form. Therefore, it appears that pre-CURE courses may provide students with a greater foundation of skills applicable to science research than the skills taught in traditional inquiry labs.

In the case of designing an experiment and representing data in a student-generated form, the important aspect to note is that the pre-CURE lab presented the students with the opportunity to participate in these steps in a way that the guided inquiry class did not. In the case of graph generation, in the pre-CURE course, the students entered the data into the graphical software of their choice (excel, R, or JMP) and then decide what type of graph to generate to best fit their methodological choices; in contrast, for the inquiry lab, the computer program would automatically generate the relevant graphs at the end of the sections after the students had followed the directions for the simulations. As for experimental design, while the students in the inquiry lab did develop hypotheses and test those hypotheses, they were not asked to design their own experiment; their independence was restricted to selecting a few variables and adjusting the levels of the selected variables, with the virtual lab itself generating the graphs once the settings were selected. Because the pre-CURE lab offered the opportunity to be fully immersed in all steps of the methods, we see this as a beneficial educational experience for these students going forward (Murtonen, 2015).

The last target skill that differed between the two lab treatments demonstrated the ability to support the claim with evidence. While both sets of students struggled with argumentation and science communication, supporting a claim with evidence was done less effectively (43% lower) by students in the pre-CURE course (*p*=0.01549; see Figure 2). In the pre-CURE course, there were a wider range of ecological variables to select from when the students designed their experiment. They could choose any variable they wanted that might affect leaf senescence in the fall/budding in the spring: e.g. amount of sunlight, level of rainfall, etc. In addition to this, nature itself was manipulating these variables; this applied aspect to the experiment led to more diverse outcomes compared to a computer simulation. The less effective examples of students supporting claims with evidence could be due to the challenge of interpreting a broader selection of variables compared to the restrictions imposed by the guided inquiry course. What this means is that the open nature of the pre-CURE course gives more opportunity to fail, but by the same token, it also provides a chance to learn from the failures. Although at first this might sound undesirable, the concept of "desirable difficulties" has seen support in the fields of psychology and mathematics (Bjork, 1994a, 1994b, Kapur and Bielaczyc, 2012). Bjork (1994a, 1994b) found that long-term retention increased when difficulties were introduced because these forced the students to think more closely, and extensively, about the processes involved. Productive (or constructive) failure has also been shown to assist students in problem solving when compared to students who received direct instruction (Kapur and Bielaczyc, 2012). There has been little investigation thus far on the impacts of productive failure in a biology laboratory setting; however, pre-CURE courses could offer researchers the opportunity to investigate this since the nature of a pre-CURE course gives students the opportunities to reason through why a result did not come as expected and what factors might be at work. Similarly, productive failure helps students understand iterative nature of science so when participating in other research projects they would hopefully be better able to cope with the setbacks that come with research.

We saw in increase in the percent of students from the pre-CURE lab course taking CURE labs in the subsequent three years, while inquiry-lab students were more likely to engage in a more traditional undergraduate research experience in the laboratory of a professor. We suspect that these differences are due to the pre-CURE students being aware of the possibility of engaging in authentic research through CURE courses, while inquiry students were not as familiar with this pathway and therefore followed a more traditional research path. However, further follow-up with the students will be needed to determine if this is the underlying cause of the difference in research pathways.

The definition of a CURE is still being discussed within the community of Biology Education Researchers (Corwin et al 2018), but as we decide to what extent all criteria laid out by Auchincloss et al (2015) are necessary for undergraduates to receive a learning benefit from conducting authentic research in laboratory classes, determining the benefit of introducing even limited versions of authentic research, pre-CUREs, can assist programs in making difficult choices around laboratory course reform. From our data, we feel that because of the benefits in helping the students to learn vital scientific processes and communication, and to learn from failures prior to taking a full CURE or participating in research, we recommend implementing pre-CURE modules and courses in early introductory science labs. Therefore, despite results showing students need >36 hrs. of engagement in research to benefit fully from the experience (Shaffer et al. 2014), we found that even a more limited authentic research project within a laboratory class is beneficial to students preparation as scientists.

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Supplemental Table 1. Target Skills used to assess written papers of pre-CURE lab and Inquiry lab students. Notes under good examples are quotes from papers that demonstrate a high score on that target skill.

Target Skills	Good Example from Inquiry	Good Example from PreCURE
Locate information relevant to a scientific problem. i.e. Identify databases to search for information in the field relevant to a problem. (Number of times)	[None utilized]	“. Budburst 2. Weather Underground history database
Construct a relevant/appropriate scientific question for a given problem. i.e. Develop a question that addresses a key issue in a given scientific problem or scenario.	In essence the lab experiment will be testing the evolution of snail by natural selection.	Does [the amount of] rain fall have an effect on the blooming stages of Prunus Serrulata (Japanese Cherry Blossom)?
Generate a hypothesis or make a prediction based on a scientific model. i.e. Identify an appropriate scientific model and apply it to the given problem in developing a hypothesis or making a prediction.	The hypothesis of the lab is that the introduction of the Green European Crabs did impact the shell thickness of the snails as the thinner shells were easily cracked by the crabs thus their population decreased.	Our hypothesis for this question was if the annual temperature continues to increase, we expect to see more green foliage present during autumn.
Design an experiment to test a scientific question. i.e. Develop a study that identifies relevant factors and collects data to effectively examine the problem.	[None created. Followed pre-determined steps]	Five post oaks were selected at various points around campus. Then, on four separate occasions throughout the duration of two weeks, the trees were visited. On the initial visit, coordinates were recorded along with the weather, temperature, and percent coloration for the day. Then pictures were taken of the leaves and overall tree. On the rest of the visits weather, temperature, and percent coloration were recorded in order to track the progression of color change present in the leaves. During each of the three remaining visits photos of the trees were taken in order to compare coloration changes to the previous visit.
Designed an experiment that appropriately answers question. i.e. Used appropriate techniques to answer question.	[None created. Followed pre-determined steps]	Repeated 5 times over 20 days to find the trend.
Appraise an experiment design to identify elements and limitations and how they impact scientific findings/conclusions. i.e. Identify strengths and weaknesses of research design elements (e.g., potential sources of error, variables, experimental controls). (Number of times)	[None created. Followed pre-determined steps]	To start out this experiment, three different species of trees are to be picked, and data will be collected from three trees of each species for a total of nine trees. This stabilizes the data, acting as insurance in case one of the trees is sick and presents false data
Troubleshoot technical issues. i.e. Evaluate a scientific problem to identify possible technical causes. (Number of times)	[None.]	Students had to address everything from hurricanes impacting their study trees to accessing the trees due to construction.
Represent data in a visual form (student generated). i.e. Convert relevant information into an appropriate visual representation given the type of data (count number of graphs/figures). (Number of times)	[None created. SimBio generated them automatically]	Three graphs

Created an effective figure/graph label. i.e. Label gives meaningful information about the data represented. (Number of times)	Figure 1. Flat periwinkle shell thickness after the introduction of European green crabs.	1. Figure 1: Mean percentage of leaves shed at a set date comparing the leaf fall in the mountain and coastal regions of North Carolina. 2. Figure 2: One-way analysis and t-test showing the difference between the mean values of leaves shed in the mountain region versus the coastal region of North Carolina.
Interpret visual representations of data. i.e. Interpret or explain information presented in visual forms. (Number of times)	After being regenerated again the snails still stayed the same showing the same results. (Fig 5.). The shells with the thickness of 6,7, and 8 were the ones left on exercise 1. The snails with less thick shells were mainly eaten because the crabs didn't have to use as much time to try and crack them open. Exercise 2 the shell thickness was generally the same this population never changed because there were no other crabs to reproduce due to having a selective amount of genes. Crabs ate the snails faster during this trial since there was no heritability amongst the snails. In the third exercise mutation would only allow the snails to reach a thickness no higher than 4 inches. Reproducing the snails with this mutation they generally became thick as a population.	"To analyze our data, we chose to create a scatterplot including a line of best fit that compared the temperature measured in Fahrenheit to the color of the leaf measured in wavelengths. The line showed a slope of 0.0115 and an r-squared value of 0.01742 "
Evaluate evidence.	The population of snails without any predatory factors has a random assortment of shell thicknesses. This makes since because no specific shell type is being selected for. The population of the snails being affected by predatory selective pressures, tend to have extreme shell thicknesses, since the crabs could easily devour thinner shelled snails.	The P value calculated with one-way ANOVA analysis showed that Sweet gums were the only species that had a p value below .05. Both the Pine and the Magnolias had p values higher than .05. This means we accept the null hypothesis for Pine and Southern Magnolia and reject the null for Sweetgum.
Statistics techniques utilized. (Chi sq., T test, Correlations, Averages, ANOVA, Other)	[None. The program provided all analyses and graphs without the student's input]	Calculated r squared
Stats techniques were used appropriately for data.	[Since there was no student choice in the analysis, there was no way for them to use inappropriate statistics]	When we looked at our scatter plot, the slope of the line was 0.0115 which if were rounded would be zero. The r-squared value of 0.01742 would also be zero if rounded.

Make a claim based on evidence i.e. Make a claim that answers a question or provides a solution to a problem.	After reviewing my results and gathered information, I noticed a change in the shell thickness overtime judging from the graphs. The shells in the earlier years were less thick as evolution changed them into thicker harder shells. Yes, this snail population over time meets the requirements for evolution through natural selection.	The P value calculated with one-way ANOVA analysis showed that Sweet gums were the only species that had a p value below .05. Both the Pine and the Magnolias had p values higher than .05. This means we accept the null hypothesis for Pine and Southern Magnolia and reject the null for Sweetgum.
Support the claim with evidence. i.e. Gives specific examples.	The assumed hypothesis was that the introduction of The Green European Crabs impacted the population of snails in that the thicker shelled snails had a greater level of fitness. This explanation is justified by the fact that the thin shelled snails' population only decreased upon their arrival.	The P value calculated with one-way ANOVA analysis showed that Sweet gums were the only species that had a p value below .05. Both the Pine and the Magnolias had p values higher than .05. This means we accept the null hypothesis for Pine and Southern Magnolia and reject the null for Sweetgum.
Justify the claim. i.e. Justify why the evidence is appropriate.	Having known about Darwin's three requirements for adaptive evolution, the results supporting natural selection by providing evidence of variance, increased fitness, and heritability were not surprising to me. In each simulation where one or more of the three requirements were removed no evolution appeared, which followed similar logic and was also expected.	While this might show that temperature plays an effect, more data points are needed to determine that. This is a problem that our group experienced in testing our hypothesis.
Identify additional information needed to support an argument. i.e. Explain how new information may contribute to the evaluation of a problem. (Number of times)	These flat periwinkle snails should be studied further to see how they evolve naturally over the coming years. Shells may not be the only thing about the snail populations that change. Traits such as the size of the snail or shell color may also change due to natural selection.	Our result supported our hypothesis but that doesn't mean there were not questionable factors throughout our experiment. For example, the amount of daylight increased by three minutes from day one of collection to day two but there was still evidence in all nine trees of color change. After looking back at our data collection sheet, we realized that the second day was mostly cloudy from the rain in the early morning. This means that the sun radiation was lower than that of the first day. This is most likely the reason for why the increase in percent change in leaf color was present. So, if this experiment were to be carried out for a second time, it may be helpful to take in consideration the amount of radiation the sun is giving off for the days of collection. Upon duplicating this experiment, it would also be helpful to stretch out the data collection process for another two or three weeks. In doing this experiment, there was not enough time to collect the amount of samples needed to give accurate data. Our chart may have been more consistent and possible even have a specific rate of change if we had the time to extend the process of data collection for each of the nine trees.

Provide alternative explanations for results that may have many causes. i.e. Recognize and explain possible alternative interpretations for given data or observations. (Number of times)	[Did not do]	One factor that could have influenced the variability of the data was the constant change of the temperature. It would be at one extreme during the beginning of the week and at the other extreme at the end of the week. Another factor that might have played a role on the strong variability was the aftermath effects of hurricane Matthew on the vegetation around campus. The hurricane brought strong winds and excessive flooding that could have had harmful effects on the trees. This could also explain why some of the trees were already missing a good amount of leaves. It made it hard to determine a precise estimation of coloration for the trees that did not have as many as the others. This could have also skewed the data some since there was not as many leaves to look at for coloration purposes. Early morning frost was another factor that could have affected the overall variability between the trees. Frost indicates cooler temperatures, which signals the trees to stop chlorophyll production.
Integrate and apply knowledge across subdisciplines. i.e. Identify and use concepts from previous courses to interpret given data and observations. (Number of times)	[Did not do]	[Did not do]
Uses appropriate Language. i.e. Uses scientific terms correctly.	[only examples if used if incorrectly]	[only examples if used if incorrectly]
References appropriate literature. i.e. Cites relevant primary literature. (Number of times)	Seeley, Robin Hadlock. 1986. Intense natural selection caused a rapid morphological transition in a living marine snail. Proceedings of the National Academy of Sciences, USA 83: 6897-6901. Trussell, Geoffrey C. 1996. Phenotypic plasticity in an intertidal snail: The role of a common crab predator. Evolution 50: 448-454.	1. Günthardt-Goerg, M. S., Kuster, T. M., Arend, M. and Vollenweider, P. (2013), "Foliage response of young central European oaks to air warming, drought and soil type." Plant Biology, 15: 185-197. 2. Lee, D. W., O'keefe, J., Holbrook, N. M., & Feild, T. S. (2003). "Pigment dynamics and autumn leaf senescence in a new England deciduous forest, eastern USA." Ecological Research, 18(6), 677-694. doi:http://dx.doi.org/10.1111/j.1440-1703.2003.00588.x

Critiques cited literature. (Number of times)	Seeley drilled a whole into different shell types and placed the snails into an ecosystem with a higher or lower level of invasive crabs. Over a few weeks, she examined that the snails with low spiral-shells had a higher survival rate against the European green crab. Seeley concluded that the crabs helped evolved the change in morphology of the snail, but it was natural selection that allowed these variations to occur in the population of snails (Seeley 6897).	Climate change has already affected the growth of some trees. In a study done by a team of scientists from the American Institute of Biological Sciences in 2007, 130 tree species, including some well-known trees such as the Loblolly pine, the sweetgum, and many types of oak, birch, and maple trees, were observed and their tolerance to climate change was determined. Using their data, the scientists have projected that by the end of the century, only one of the tree species that they studied will be able to grow in much of the southern United States (McKenney, Pedlar, Lawrence, Campbell, & Hutchinson, 2007). Although they did not study crepe myrtles directly, a lot of the species have similar growth conditions to crepe myrtles, so examining this data can still provide a prediction for how well they will withstand the projected climate change. This means that, in the next century, crepe myrtles may not be found in the southern United States.

Integrating Case Studies into a Pre-medical Curriculum

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Abstract: Previous research has indicated that the use of case studies is effective for promoting critical thinking, enhancing interest in curricular content, and improving student understanding of core concepts. To prepare students for the challenges of a medical education, the biology faculty at a small, liberal arts college attempts to expose undergraduates to as much clinically relevant content as possible. Clinical cases are used extensively in several courses available to pre-medical biology majors. Here, the integration of clinical cases into three different courses: a 100-level physiology course, a 200-level histology course, and a 300-level biochemistry course is described. The case study method has proven to be extremely flexible. It can be utilized as a laboratory activity, a homework assignment, or an in-class discussion activity.

Key Words: Case study, pre-medical education, problem-based learning

Introduction

Curricular research on undergraduate science and medical education has emphasized the importance of independent learning and problem solving (Burgess et al., 2014; Freeman et al., 2014). In problem-based learning, students often work in teams, pooling their information and insights in order to solve a problem. Groups of students tend to solve problems better than individuals, especially when the groups are diverse and the individual members have some degree of autonomy (Herreid, 2009).

Groups of students working toward a common goal are often the norm when using case studies as a teaching tool. By requiring careful analysis of evidence by a group of students, case studies promote critical thinking (Herreid, 2004). Furthermore, case studies can make abstract content more relevant to group members, enhancing their interest in the subject matter (Gallucci, 2006). Finally, while working through cases, students are encouraged to consider comments and suggestions from all members of the group. The ability to view concepts from new and different perspectives can improve student understanding of essential course material (Smith & Murphy, 1998).

The incorporation of case studies into a course or curriculum can take many forms. A "directed" case study is designed to encourage critical thinking while enhancing student understanding of a specific concept (Cliff & Curtin, 2001). The case is usually accompanied by several relevant questions that students are required to answer. This type of case might also be considered "closed-ended," meaning all the questions have definite correct answers, and all the information students need to answer the questions is easily accessible in textbooks, lecture notes, and/or online resources (Cliff & Nesbitt, 2005). Students may complete the case analysis during class or on their own time. They may work on the case independently or in groups. This type of activity might also be developed into an "interrupted" case study. In an interrupted case, the instructor provides information in segments, allowing students to propose strategies for analyzing the case after receiving only the most superficial information. Once more information is provided, students have the opportunity to incorporate more data into their analyses and refine their hypotheses. This type of activity mimics actual scientific research (Herreid, 2004). A potentially critical aspect of the directed case study, interrupted or not, is the in-class review. Students are required to share their answers with the rest of the class. Sharing predictions and conclusions with their peers allows students to reinforce concepts that are understood, while clarifying any misunderstandings that may have interfered with problem solving (Cliff & Curtin, 2001).

Davis & Elkins College (D&E) is a small, private liberal arts college that emphasizes small class sizes and strong faculty-student interactions. The Department of Biology and Environmental Science at D&E offers multiple specialization tracks for biology majors, including general biology, pre-medical, pre-veterinary, and secondary education. By far, the most popular track is pre-medical, and the department has been very successful in recent years at getting students accepted to medical schools. To prepare our students for the rigors of a medical education, we attempt to expose them to as much clinically relevant content as possible at the undergraduate level. Clinical case studies are utilized extensively in several courses that are available to pre-medical biology majors. The cases tend to be both directed and closed-ended. In some courses, the interrupted case method is employed. Three courses, in particular, rely heavily on clinical case studies: Human Physiology, Functional Histology, and Biochemistry. While none of the courses is required for the biology degree, all three are strongly recommended for our pre-medical students.

Human Physiology

The Human Physiology course is an overview of basic physiology, with particular emphasis on the human nervous system, cardiovascular system, and renal function. It is a 100-level course that also enrolls pre-nursing students and exercise science majors. Lecture sections are relatively large, generally between 60 and 70 students. Laboratory sections, however, are capped at 24 students. Ten clinical case analyses are integrated into the laboratory curriculum. Each lab activity begins with an in-class presentation of the case by the instructor. Introductory information includes the case history, results of a physical exam, and relevant test results. See Table 1 for an example. Following the introduction, students are presented with five questions to answer by the end of the lab period. Students generally work in groups of three or four, using their textbooks and lecture notes to address the questions. The patient introduced in Table 1 is suffering from Bell's palsy. Questions accompanying this case include the following: Which cranial nerve is affected by this disorder? Why is there paralysis only on the left side of her face? What is the potential role of inflammation in this disorder?

Functional Histology

Functional Histology is designed to demonstrate fundamental relationships between microscopic anatomy and physiological function. Students identify specific cells and tissue types, relate microscopic structure to cellular function, and diagnose pathologies on the basis of histological abnormalities. It is a 200-level course, usually enrolling 10-15 biology majors. The lecture and laboratory components of the course are integrated into a "seamless" curriculum, with no breaks in between, as described by Burrowes and Nazario (2008). The class meets twice a week for two hours and 40 minutes. The class begins with lecture material, moves on to relevant lab activities, then back to more lecture, followed by more lab activities. Students analyze five clinical cases over the course of the semester. In lieu of introductory information, students are presented with two histological images of a certain tissue, one normal and one pathological. See Figures 1 and 2 for examples. Students work in groups of two or three

History You are presented with a 45-year-old Caucasian female patient exhibiting muscular paralysis on the entire left side of her face. The symptoms began about a week ago and have progressively gotten worse. The patient is on no medications and does not use alcohol, tobacco, or illegal drugs. There is no indication of family history.
Physical Exam The patient is unable to close her left eye completely and cannot raise her left eyebrow. When smiling, the patient's lips do not curl upward on the left side. However, there is no evidence of sensory loss in the face.
Tests White blood cell count: slightly elevated Urinalysis: normal MRI of brain: normal

Table 1: Introductory information for a Human Physiology clinical case.

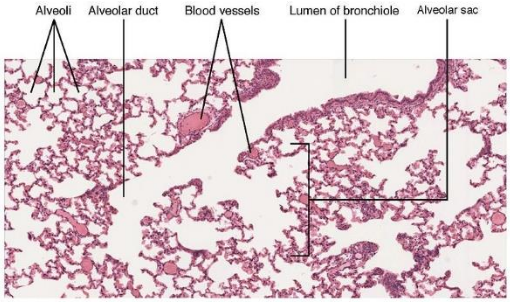

Fig. 1. Normal structures of the respiratory zone (Creative Commons).

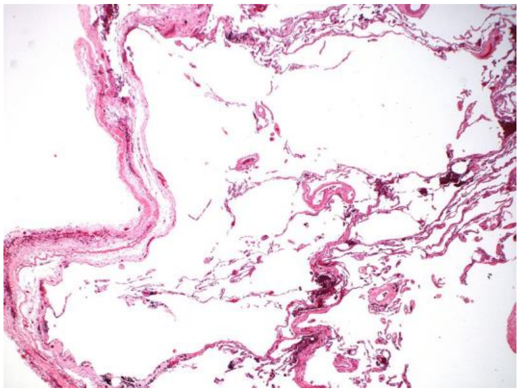

Fig. 2. Panlobular emphysema (Creative Commons).

to answer five questions that deal with the pathology, using only a histology atlas and their lecture notes. The pathology in Figure 2 is panlobular emphysema. Questions accompany this case include the following: What is abnormal about the patient's alveoli? How would this abnormality affect gas exchange? How would this abnormality affect quiet expiration?

Biochemistry

The Biochemistry course is a survey of major biological molecules and basic metabolic pathways. Topics include enzyme kinetics, metabolic regulation of glucose, and membrane transport. It is a 300-level course, generally enrolling 15-20 biology and chemistry majors. The course has no laboratory component, so clinical cases are analyzed during "lecture" time and outside of class as homework assignments. Five case analyses are integrated into the course. Each analysis begins with an in-class presentation of the case by the instructor. Introductory information includes the case history, results of a physical exam, and relevant test results. See Table 2 for an example. Classrooms are not modular, making it difficult to divide students into groups. Instead, three or four preliminary questions regarding the case are discussed as a class. Individual students provide input, and we talk through the analysis until we reach a consensus on answers to the preliminary questions. The patient introduced in Table 2 is suffering from Alzheimer's disease. Preliminary questions for this case include the following: What is your preliminary diagnosis? Who is at risk for this particular condition? What areas of the brain are affected? Once preliminary questions are sorted out, students are given a homework assignment. They are welcome to work individually or in pairs, using textbooks, lecture notes, and approved internet resources to complete the assignment, which is due at the beginning of the next class. All information obtained from online resources has to be cited appropriately, according to APA guidelines. For the case introduced in Table 2, the homework assignment consists of the following question and parenthetical disclaimer: How are ApoE, tau, and beta-amyloid proteins associated with Alzheimer's disease? (This is a 300-level biochemistry class. Don't be afraid to get into molecular interactions.) At the next class meeting, selected students share their findings with their peers. Since they may use different resources to complete the assignment, findings may vary. We compare and contrast the presented responses as a class and eventually reach a consensus on answers to the homework questions

Conclusion

Small-group learning has become extremely popular in medical schools in recent years (Burgess et al., 2014), and the clinical case report is one of the primary teaching tools utilized in medical education (Florek & Dellavalle, 2016). In an effort to prepare our pre-medical students for the active learning associated with current medical education, we provide multiple opportunities for them to experience clinical case teaching.

The case study method is extremely flexible. It can be utilized as a laboratory-based activity for small groups of students, as a discussion activity during lectures, and as a homework assignment for individuals or small groups. It is an efficient tool for promoting critical thinking, stimulating interest, and reinforcing course content.

History A 75-year-old Caucasian female is brought to your office by her daughter. While visiting for the holidays, the daughter noticed that her mother had lost a significant amount of weight in the past six months. Furthermore, she indicates that her mother has become increasingly irritable, fatigued, and forgetful.
Physical Exam The patient's heart rate is 74 bpm, and her blood pressure is 118/76. The patient is significantly underweight. She is 5 feet, 2 inches tall and weighs 96 pounds, giving her a BMI of 17.6. She is unable to identify her grandchildren and is unaware of the current date.
Tests Blood work indicates that the patient is anemic and dehydrated. A PET scan suggests possible amyloid plaque accumulation in the patient's brain.

Table 2. Introductory information for a Biochemistry clinical case.

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The Whole is Greater than the Sum of the Parts: A Research Poster Project Provides an Integrative Framework for Learning Across Foundation Courses in Biology

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Abstract

The integration of ideas, defined as the process by which students organize and connect new knowledge for deeper understanding, is essential for lifelong learning. (Government of Canda, Employment and Social Development Canada, 2017; Rateau, Kaufman, & Cletzer, 2015). Integration across sub-disciplines in biology requires an understanding of organizational scales (molecular to ecosystems) and time frames (physiological to evolutionary), and how they inter-relate. The challenge lies in allowing students opportunity to integrate knowledge, given that sub-disciplines are taught in relative isolation through individual courses. To promote integration, we designed a poster assignment in which ~700 students in three foundation courses worked together (130 groups) to investigate empirical research in multiple sub-disciplines. While a major goal was to enrich understanding by integrating knowledge, we also sought to develop transferable skills (e.g. teamwork, information literacy). Hence, this cross-course assignment provides benefits that exceed that of equivalent assignments in individual courses; we believe that *the whole is greater than the sum of the parts*. Assignment grades indicated that the majority (81%) of students successfully met or exceeded our expectations. This assignment lends support to the positive impact of learning communities, is easily adapted to other disciplines, and aligns with calls for educational reform advocating for curiosity-driven learning (American Association for the Advancement of Science, 2011; Bradforth et al., 2015).

Keywords: research poster assignment, foundation courses, teamwork, scientific communication, knowledge integration, information literacy, learning communities.

Introduction

Creating curricular learning communities in which students co-enrolled in multiple courses work collaboratively on a learning activity, has been shown to enhance student engagement, fostering both academic and social connections among students (Kingston, MacCartney, & Miller, 2014; Kuh, 2003). Such communities in biology courses align with a constructivist approach to knowledge acquisition (Cakir, 2008); students are encouraged to pursue their own line of scientific inquiry to *construct* their understanding of a topic by connecting new ideas to existing knowledge, while using peers to support their learning. There is significant evidence that argues for the importance of collaborative group projects in stimulating deep learning (Tanner, Chatman, & Allen, 2003; Walton & Baker, 2009). We believe that engaging in collaborative teamwork is essential for students to hone interpersonal skills and gain experience in resolving group dynamics challenges, skills critical to students' academic performance and career success beyond university. Drawing inspiration from the evidence based on learning communities, our goal was to design an assignment in which students work collaboratively to integrate knowledge from different sub-disciplines of biology to create a research poster on a topic of interest to the group. As advocated for by educational reformists such as Weimer (2013), this assignment places the responsibility of learning on student groups, shifting the role of instructors to that of facilitators in a student-centered learning environment.

Learning goals:

The learning goals for the research poster assignment are listed here and we elaborate on the rationale for each below.

1. Integrate knowledge across various biological sub-disciplines.
2. Communicate scientific concepts and ideas effectively in both oral and written forms.
3. Work collaboratively with diverse group members while managing workload, time, and group dynamics.
4. Acquire information literacy skills (such as searching, evaluating, and critically reading scientific sources) and academic skills (such as formulating research questions, thinking critically and creatively, and respecting academic integrity).

1. **Integration of knowledge**

Studies examining learning communities show that integration of concepts leads to enhanced conceptual frameworks and deeper learning (Chaplin & Hartung, 2012). Hence, a major goal of this assignment was to allow students to recognize and highlight the links between different sub fields of biology. This would allow them to gain some experience in the cross-disciplinary nature of scientific inquiry and importantly, avert inert knowledge building that results from teaching in disciplinary silos. It was our goal to encourage students to explore a topic in biology for which insight can be gained by considering empirical research from at least two different fields of study (as represented by the six required, second year undergraduate courses in the Department of Biological Sciences at the University of Toronto, Scarborough (UTSC)). This assignment was designed as a mandatory component of each of three, required second year (known as B-level at our institution) courses in each of the Fall and Winter semesters (see note). Students registered in any of the three courses in each semester were grouped together for this assignment, allowing us to maximize the benefits to students enrolled in core courses with distinct disciplinary learning goals that nonetheless shared skill development goals (such as knowledge integration, communication etc.). As per this design, successful posters will pose an interesting question, clearly and concisely outline evidence from the primary literature in (at least) two different fields, and effectively communicate how integrating knowledge from these fields enhances understanding of their topic.

2. **Communication**

The effective communication of information to an intelligent, but naïve, audience is a critical skill in many professions. Professional communication may take many forms, from informal to formal, and also demands that the ideas being presented are supported by evidence, so that the audience receiving the information can properly assess the merit of the ideas. It has been shown that one of the reasons why teamwork is so desirable for university students is because of the substantial gains in communication skills that can be attributed to collaborative work (Oakley, Hanna, Kuzmyn, & Felder, 2007; Riebe, Girardi, & Whitsed, 2016). Hence, helping student teams develop scientific communication skills by creating an informative scientific poster was a major learning outcome for our assignment. Similar group project approaches have been successfully employed to promote communication skill development, albeit within individual courses (Walton & Baker, 2009). In requiring students to create a poster containing both text and pertinent visual images, it was our hope that students would also become more proficient at evaluating visual information presented in scientific articles.

3. **Teamwork**

The ability to work well as part of a team is an essential transferable skill for future employment of university graduates (Riebe et al., 2016). Productive teamwork is also indispensable to research groups and collaborative efforts in biology (Gibert, Tozer, & Westoby, 2017). Knowing how to deal with any issues that may

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Note: Fall term curses: Cell Biology, Animal Physiology, Ecology
Winter term courses: Molecular Aspects of Cellular genetic processes, Plants& Society, Evolutionary Biology

arise as part of a team and understanding what personal strengths one brings to teamwork are students who work in teams, especially at large academic institutions, achieve higher academic performance, with significant benefits to their mental health and social integration (Roseth, Johnson, & Johnson, 2008; Strom & Strom, 2011). We were sensitive to student perspectives reported in the literature that suggested that social loafing (or "free riding") is one of the factors that govern their trepidation towards team projects (Gottschall & Garcia-Bayonas, 2008). Hence, we provided resources and a dedicated tutorial on effective teamwork and dealing with group dynamics issues, checked in with groups that reported group dynamics issues and created an explicit social loafing penalty (a penalty of up to 5 of the 10% value of the assignment) that could be applied by the teaching assistant (TA) and instructors, as we deemed fair in individual cases. There is evidence that students sort into homogenous groups (typically based on perceived academic ability, which may correlate with other demographic factors) when allowed to self populate teams for collaborative work (Freeman, Theobald, Crowe, & Wenderoth, 2017). While there are arguments for and against homogenous groups in biology courses (Jensen & Lawson, 2011; Manske, Hecking, Hoppe, Chounta, & Werneburg, 2015)(see note), we chose to constitute teams randomly in order to reflect the demographic and academic diversity of our student population.

4. **Information literacy**

Effective communication in the sciences requires proficient information literacy skills, which is also a key facet of lifelong learning (Crawford, Irving, Higgison, & Foreman, 2013). We see this as students' ability to mine databases, identify appropriate sources, evaluate the information presented in these sources and cite such sources accurately in their written synthesis (standards of the ACRL Information Literacy Network: [http://www.ala.org/acrl/sites/ala.org.acrl/files/content/issues/infolit/framework1.pdf)](http://www.ala.org/acrl/sites/ala.org.acrl/files/content/issues/infolit/framework1.pdf). We scaffolded this assignment with online scientific information literacy modules developed by liaison librarians at UTSC and assessed students' basic understanding and ability to mine the literature through an online quiz. The librarians and our colleagues at the Writing Centre generated a dedicated online research guide for the assignment, which included concise information on topics such as brainstorming keywords, critical to becoming a good team player. It is no surprise that large-scale studies have found that formulating research questions, citation management and plagiarism. It was our goal to help students become more confident in their ability to identify, seek and use necessary information from scientific sources and as a result become comfortable with the authentic research discourse of biology. As reported by others, we hoped this type of skills instruction would improve the quality of student-led research (Kingsley et al., 2011; Stevens & Campbell, 2008).

Assignment structure:

An information document for this assignment that included learning goals, details of the scaffolding, support, weekly expectations and final assessment was provided to students at the beginning of each academic semester (see Supporting Materials). Figure 1A is an infographic that summarizes the expectations and general assignment structure. Figure 1B provides a breakdown of various mini-deadlines and deliverables that students were required to complete over the 12-week timeline of the assignment

The model required coordination between course instructors, including scheduling of joint tutorials and scaffolding sessions for students enrolled across the three courses in each semester. We provide further details of the assignment elements and logistics below.

1. **Scaffolding tutorials**: We began with a tutorial in week 2 that set out the expectations for the assignment. Students had the opportunity to ask questions and learn about the supports available to them during the semester. A second scaffolding tutorial in week 3 involved meeting teammates and engaging in team building activities to identify different academic strengths and personal traits of their teams. Faculty presented some ideas on effective group processes and how to address group dynamics issues that may arise. Notably, we communicated the importance of building teamwork skills both for academic and future career success. In week 5, we held an unstructured tutorial in which groups could consult with faculty and the TA about any questions around topic selection. In weeks 8 and 11, unstructured group work tutorials allowed students to gather as a team in a large lecture hall (>450 student capacity), providing

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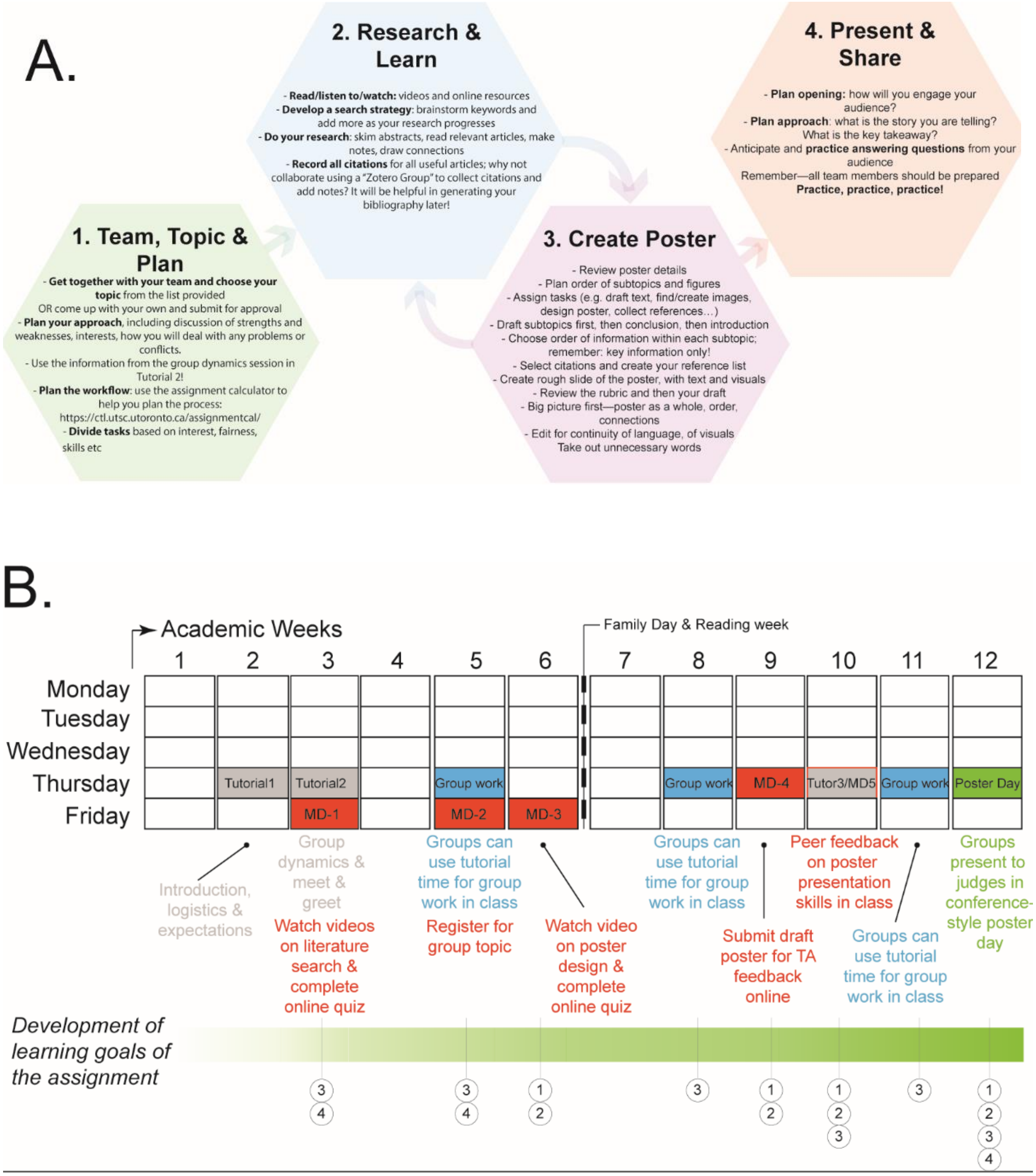
Note: Fall term curses: Cell Biology, Animal Physiology, Ecology
Winter term courses: Molecular Aspects of Cellular genetic processes, Plants& Society, Evolutionary Biology



1. Team, Topic & Plan

- **Get together with your team and choose your topic** from the list provided
OR come up with your own and submit for approval
- **Plan your approach**, including discussion of strengths and weaknesses, interests, how you will deal with any problems or conflicts.
- Use the information from the group dynamics session in Tutorial 2!
- **Plan the workflow**: use the assignment calculator to help you plan the process: https://ctl.utsc.utoronto.ca/assignmentcal/
- **Divide tasks** based on interest, fairness, skills etc

2. Research & Learn

- **Read/listen to/watch:** videos and online resources
- **Develop a search strategy**: brainstorm keywords and add more as your research progresses
- **Do your research**: skim abstracts, read relevant articles, make notes, draw connections
- **Record all citations** for all useful articles; why not collaborate using a "Zotero Group" to collect citations and add notes? It will be helpful in generating your bibliography later!

3. Create Poster

- Review poster details
- Plan order of subtopics and figures
- Assign tasks (e.g. draft text, find/create images, design poster, collect references…)
- Draft subtopics first, then conclusion, then introduction
- Choose order of information within each subtopic; remember: key information only!
- Select citations and create your reference list
- Create rough slide of the poster, with text and visuals
- Review the rubric and then your draft
- Big picture first—poster as a whole, order, connections
- Edit for continuity of language, of visuals
Take out unnecessary words

4. Present & Share

- **Plan opening:** how will you engage your audience?
- **Plan approach**: what is the story you are telling? What is the key takeaway?
- Anticipate and **practice answering questions** from your audience
Remember—all team members should be prepared
Practice, practice, practice!

Figure 1 – An overview of the design and expectations of the poster assignment. A. This infographic provides an overview of the structure and expectations of the assignment. It provides students with a big picture summary of expectations, but also doubles as a guide or checklist throughout the semester. B. A timeline that summarizes the tutorials, group work sessions and deliverables (mini-deadlines, MD) of the assignment as implemented over the 12-week semester. Descriptions of the scaffolding tutorials, mini-deadlines and their links to the assignment's learning outcomes are provided below the timeline. Learning outcomes key: (1) = integration of knowledge, (2) = communication, (3) = teamwork, and (4) = information literacy.

both designated time and space for group discussions prior to important deadlines. This was intended to ameliorate the challenges that groups often face when they have to coordinate schedules and find available campus workspace in order to collaborate.

2 **Mini-deadlines**: The assignment required four deliverables over the semester prior to the final poster submission.

1. A quiz integrated into an online module on information literacy was available to students on our learning management system in week 3. This was intended to provide students with the necessary skills to search the literature for their project.
2. The second deliverable in week 5 was a group-based sign up for a specific research topic. We provided some topic choices and used the SignUpGenius platform for this mini-deadline (see Topic selection below).
3. In week 6, students were required to view an online video on creating research posters and then complete a quiz on the learning management system that tested their understanding of the basic parameters of effective poster design. We felt that this would equip students with a better understanding of the type of information that they should be seeking from the literature to create an effective poster.
4. The final mini-deadline in week 9 required students to submit final poster drafts. The assignment TAs and TAs of the participating courses provided formative feedback on the research posters (using the criteria in the evaluation rubric). On rare instances where groups reported a lack of contribution from specific members, the faculty and TA assigned social loafing penalties, as detailed in the teamwork section above. We ensured that TA feedback was provided to students by the end of week 10, such that there was still sufficient time to revise their work prior to the poster day in week 12.

3 **Topic selection**: We provided students with a list of topics with links to both primary literature and secondary sources for each topic. Students were nevertheless expected to conduct a survey of the primary scientific literature and make reference to at least six published papers in total, equally split across the sub-disciplines through which they would explore their chosen topic. Students were asked to explore a topic from at least two of the three possible perspectives represented by the three required courses in each term. Groups were provided significant free rein over topic selection and the instructors particularly emphasized their desire for students to go "off" the topic list provided; we were keen to ensure that students had a sense of ownership and autonomy right from the topic selection phase of the project. Students registered their topic and if choosing from the topic list provided, up to five groups could choose the same topic. We used the SignUpGenius platform (https://www.signupgenius.com/) for topic registration. Only two groups out of 130 chose topics from outside of our list.

4 **Assignment support:** The collaborative efforts of instructors, liaison librarians and Writing Centre staff in developing skills were intended to promote campus supports and resources often underutilized by students. Students were made aware that liaison librarians and Writing Centre staff were available for group consultations and feedback sessions respectively. A dedicated course site was established on our learning management system in order to provide resources for students. Students were supported by a project-specific TA, who coordinated all assignment-related logistics and took the lead in providing feedback on student work, organizing the final poster day and coordinating final grades. In addition, we had a few additional hours of TA support from TAs in each of the participating courses in order to provide formative feedback to students. A staff member managed all grades administration and provided general logistical support.

5 **Peer feedback session**: Studies that have incorporated peer-review and editing sessions in biology research projects have suggested that when students make keen observations to attempt to improve their peers' work, they often bring the same keen eye to their own work, resulting in an overall improved editing process (Carpenter & Pappenfus, 2009; Kolber, 2011). This served as one of the motivations to include an in-person peer feedback session in which groups took turns presenting their posters to two other groups. The students rated each other using the same grading rubric that would be used by judges in the final evaluation. While students could receive valuable feedback on the design, clarity, and effectiveness of their posters, we felt that this was also an opportunity for students to practice their oral presentation skills. We held this session in Week 10, two weeks prior to the final evaluation, as this would provide groups with sufficient time to edit and print their revised posters.

6 **Rubric development**: The rubric used for grading posters is provided in the Supporting Materials. In general, we aligned this rubric with our learning outcomes, thereby assessing knowledge integration, oral (and written) scientific communication, working as an effective group and information literacy. Given that this type of conference style presentation day (see point 7 below) requires a large number of judges, we created a very simplified grading system in which students could meet, fall below or exceed the expectations of the judges. Judges provided written

7 comments when students were below or above expectations. The grading rubric was designed in such a way that groups scoring 80% (i.e. 8/10) would be seen as meeting our expectations for solid integration of knowledge and evidence of effective communication, teamwork and information literacy skills. For each criterion where students were assessed as "above my expectation", 1% was added to the students' grade (i.e. added to 80%); while for each criterion where students were assessed as "below my expectation", an additional 1% was deducted from the students' grade. Therefore, students who exceed expectations for every criterion received 100%, and students who failed to meet expectations for every criterion received 60%. In the case where an evaluator felt that the poster deserved a grade lower than 60%, they would justify their decision in the comments along with the assigned grade. Each poster was judged at least twice and we generally see good consensus between the judges; however, we do not currently have means to ensure interrater reliability across the team of judges. A limitation of this approach is that some groups may suffer "harsher" judges than others.

8 **Final evaluation**: The assignment culminated in a poster day in which ~130 groups (composed of ~5-6 students) presented their work to judges drawn from graduate students, post-doctoral fellows, teaching technicians and faculty from the department. The poster day was held in a large event space equipped with ~35 poster boards similar to that used in academic conferences and included two, two-hour sessions of poster presentations (~65 posters per session). A total of ~40 judges participated in the poster day and each poster was judged 2-3 times.

Outcomes:

Studies suggest that skill development sessions improve students' critical thinking and ability to better understand the process of scientific inquiry (Chaplin & Hartung, 2012; Sato et al., 2014). While we did not overtly assess these potential outcomes, the majority of student posters presented claims from a variety of primary sources that were supported and critically evaluated. A distribution of grades from the pilot offering of the assignment is shown in Figure 2, indicating that majority of students met our learning goals. Unsolicited feedback from faculty and graduate student judges suggested that students were proud to present their research posters and actively engaged in discussion with regards to future work around their chosen topic, providing evidence that this assignment serves to engage students through its learner-centered design. (see note)

Conclusions and Recommendations:

We have presented our design of an integrative research poster assignment in biology intended to promote both transferable skill-development and growth towards budding biologists who are informed consumers of scientific literature. The performance of the majority of the students in this assignment is indicative of effective ability to both mine the scientific literature and to effectively communicate relevant information in both written and oral formats, by integrating ideas from different sub-fields of biology. This is similar to student reported gains in scientific communication skills when working on open-ended group research projects in related fields (Julien, Lexis, Schuijers, Samiric, & McDonald, 2012; Walton & Baker, 2009).

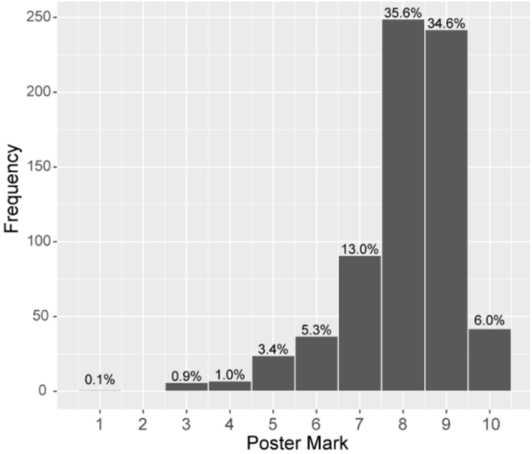


Figure 2 – Student performance in the assignment. The histogram shows the distribution of individual student grades in the assignment on a ten-point scale. Note that a score of 8 out of 10 was set as "meeting expectations" in our context and is detailed in the grading rubric (Supplementary Materials).

Some of the unique features of this assignment are that it is a required assignment for a large cohort of Biology program students registered in second year foundation courses and that collaborative work is encouraged among students enrolled across courses in biology. While other effective examples of integrative and interdisciplinary assignment approaches can be found in the literature, most report on smaller, upper-level courses, rather than large foundation ones (e.g. Jacques-Fricke, Hubert, & Miller, 2009; Liotta & Almeida, 2005). A linked course model developed at the University of Guelph is closely related to the design and rationale of our assignment (Husband et al., 2015). While their model offers further integration of courses through jointly mapped learning outcomes, small group seminars and other online content, our approach seeks to distil the integrative and skill development components into a single collaborative assignment. We believe that this pedagogy allows us to model scientific collaborations while promoting knowledge integration and building communication, teamwork and information literary skills.

This assignment could be used in its current form by biology instructors and could be easily adapted to other disciplines. To facilitate implementation of this assignment by other instructors, the syllabus style information document, grading rubric and sample topics are provided as part of the supporting information. Large student cohorts like ours can successfully work through this assignment format if TA support and some additional departmental and institutional resources (librarian support, large classrooms for group work, poster boards for the final presentation, faculty and graduate student time for poster judging etc.) are made available. We would recommend that a judges' briefing (or training) session be incorporated by others hoping to adopt this assignment and this is also one of our future objectives. In addition, instructors may consider using posthoc statistical corrections to correct for "harshness of judging" factors in the final evaluations. Investment in the resource requirements listed above could be considered negligible, given the significant anticipated learning gains for students. Indeed, this design of an assignment that transcends individual foundation courses could be seen as a means to not duplicate instructor time and resources in individual courses. Notably, this successful approach to assignment design, including contributions from liaison librarians, faculty and graduate students, advocates for collaboration in designing teaching and learning innovations in higher education.

Finally, we believe that this collaborative assignment mimics the goals of establishing learning communities (Andrade, 2007; Zhao & Kuh, 2004). In requiring students enrolled across courses to collaborate and interact beyond the classroom, we have created authentic opportunities for academic (knowledge integration) and transferable skill development within the social context of student teams. Several studies have suggested that students that participate in learning communities are more likely to embrace diversity, engage in peer-based learning environments and successfully complete their degree (Bean, 1988; Popiolek, Fine, & Eilman, 2013; Whitt, Edison, Pascarella, Terenzini, & Nora, 2001). In future years, it would be interesting to measure the impact of this assignment as a learning community on students' personal development and academic success.

Acknowledgements:

We thank Dr. Andrew Mason, Chair of the Department of Biological Sciences, for approving critical departmental supports including the assignment TA, rental of poster boards, additional admin support, and most importantly, for believing in the pedagogical value of this project. We thank all members of the department who enthusiastically supported student learning by coming out for several hours on poster day to serve as judges. We thank Adon Irani and Dina Soliman for their help in creating complex group structures across courses and for supporting this assignment's site on our learning management system. Finally, we thank the students enrolled in our second year core courses during the pilot year, who despite skepticism around mandatory group assignments, worked incredibly hard to meet our high expectations. In this manuscript, we are proud and grateful to be able to showcase the rewarding experience that these students have afforded us.

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***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 only in May and in print in December. Submissions should reflect the interests of the membership of ACUBE. Appropriate submissions include:

- 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. This includes references and tables, but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. Topics designated as acceptable as articles are described above. 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 the 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 from view 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 within the text should appear alphabetically by the author's last name at the end of the manuscript text under the heading references. All references must be cited in the text and come from published materials in the literature or the Internet. Authors should use the current APA style when formatting the reference list.

D. Example citations are below.

(1) Articles-

(a) Single author:

DeBuhr, L. E. (2012). Using Lemna to Study Geometric Population Growth. *The American Biology Teacher*. 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

(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.). New York, NY: A K Peters/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 from https://tiee.esa.org/vol/expv1/protist/protist.pdf

(4) Web sites-

McKelvey, S. (1995). Malthusian growth model. Retrieved November 25, 2005, from https://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html

E. Tables

Tables should be submitted as individual electronic files in Word (2013+) or RTF format. 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 using the following format:

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

F. Figures

Figures should be submitted as **high resolution** (≥ 300dpi) individual electronic files, either TIFF or JPEG. 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. No figures put together using a cut and past method will be accepted. All figures should be accompanied by a descriptive legend using the following format:

Fig. 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 same guidelines for text, figure and table 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, as well as telephone and FAX numbers. 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 or RTF (Rich Text File) 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.

VI. Editorial Review and Acceptance

For manuscripts to be sent out for review, at least one author must be a member of ACUBE. Otherwise, by submitting the manuscript without membership, the corresponding author agrees to page charges. Charges will be the membership fee at the time of submission per page. Once the authors' membership or page charge status has been cleared, the manuscripts will be sent to two anonymous reviewers as coordinated through the Editorial Board. Reviewer names and affiliation will be withheld from the authors. The associate editors will examine the article for compliance with the guidelines stated above. If the manuscript is not in compliance or the authors have not agreed to the page cost provisions stated above, manuscripts will be returned to authors until compliance is met or the page cost conditions have been met. Reviewers will examine the submission for:

- **Suitability:** The manuscript relates to teaching biology at the college and university level.
- **Coherence:** The manuscript is well-written with a minimum of typographical errors, spelling and grammatical errors, with the information presented in an organized and thoughtful manner.
- **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.

Once the article has been reviewed, the corresponding author will receive a notification of whether the article has been accepted for publication in *Bioscene*. All notices will be accompanied by suggestions and comments from the reviewers. The author must address all of the reviewers' comments and suggestions using the original document and **track changes** for any consideration of a resubmission and acceptance. Revisions and resubmission should be made within six months. Manuscripts resubmitted beyond the six-month window will be treated as a new submission. Should manuscripts requiring revision be resubmitted without corrections, the associate editors will return the article until the requested revisions have been made. Upon acceptance, the article will appear in *Bioscene* and will be posted on the ACUBE website. Time from acceptance to publication may take between twelve and eighteen months.

VII. Revision Checklist

Manuscripts will be returned to authors for failure to follow through on the following:

A. Send a copy of the revised article using track changes for text changes back to the associate editor, along with an email stating how reviewers' concerns were addressed.
B. Make sure that references are formatted appropriately in APA style format.
C. Make sure that recommended changes have been made or a clear explanation as to why they were not.
D. Figures and legends sent separately, but placement in manuscript should be clearly delimited.

VIII. Editorial Policy and Copyright

It is the policy of *Bioscene* that authors retain copyright of their published material.

ACUBE

Association of College & University Biology Educators

Call for Registration and Proposals for the 64th Annual ACUBE Meeting!
Oct 24-25th, 2020
Online via Zoom

Registration is now open for the annual ACUBE meeting. Now in its 64th year, this meeting gathers biology educators from colleges and universities across the country and beyond for a highly dynamic and interactive conference. In line with ACUBE's mission, we come together to incubate new and innovative teaching ideas, to discuss strategies to involve student research in the biology curriculum, to improve advising and mentoring skills, to become informed about and contribute to the scholarship of teaching and learning, and to develop and recognize excellence in teaching. Participants present from the whole spectrum of subdisciplines within biology. Come to be inspired and leave energized! We hope you will join us for this exciting and highly collaborative gathering of colleagues dedicated to teaching excellence in biology.

Registration is free for all current ACUBE members. Membership costs are as follows:

- Regular $45
- Student $15
- Retired/Emeritus $5

To renew your membership, please visit https://www.acube.org/membership/.

For non-members, registration costs are:

- Regular $50
- Student $20
- Retired/Emeritus $10
- Sponsor presentations $75

To complete your registration, please visit https://www.acube.org/annual-meeting/ and follow the registration instructions. **Registration closes at 12 pm CST, October 22nd 2020.**

You are also invited to submit a proposal to present at the 64th Annual ACUBE meeting. If you are interested in presenting at the meeting, please read the following instructions. Please note that abstract submission and registration are separate.

We welcome abstracts from all attendees. Regardless of your professional level, you can share your best teaching ideas and biology education research with colleagues! We welcome proposals on any topic related to college and university biology education.

DEADLINE: Attendees interested in presenting their work at ACUBE should submit their abstract by 5 pm CST, **September 1, 2020**. Abstracts received after the deadline may still be considered if there is room in the meeting schedule.

ABSTRACT GUIDELINES: Your abstract should clearly and concisely describe what you will present. If you are presenting a learning activity or lab exercise, describe the activity, intended student population and how the activity is used in the classroom or lab. If you are presenting biology education research, describe the research question or problem, research design and analysis. Formal assessment of a learning activity or approach is not required but the activity or approach should have been implemented at least once in the classroom or lab. Your abstract should include no more than 350 words.

HOW to SUBMIT: If you are interested in submitting an abstract, please visit https://www.acube.org/annual-meeting/ and follow the abstract submission instructions. If you are a student and interested in being considered for the Carlock award (http://www.acube.org/carlock-award/), please indicate this on the submission page.

PROPOSAL FORMATS:

20 minute oral presentations

Typical talks given in the 20 minute time slots are overviews or ideas. Successful 20 minute talks tend to present a summary or single concept. If your presentation has a lot of data and/or you are looking for feedback from attendees, consider the 40 minute time slot.

40 minute oral presentations or roundtable discussions

Oral presentations that attempt to discuss data work best in 40 minute time slots. This allows time to fully explain your pedagogical question, methods, and results as well as leaves time for attendees to ask questions. Roundtables are opportunities for extended discussion on a specific topic of interest in a small group setting. Roundtables are excellent venues for giving and receiving targeted feedback, engaging in in-depth discussions, and meeting colleagues with similar interests.

80 minute oral presentations

These time slots are reserved for those wishing to present a workshop that trains attendees.

Posters

Posters are welcome on any biology education topic, and ACUBE's poster sessions are some of the liveliest aspects of our Annual Meeting. The author(s) host informal sessions about their work which can be about an innovative teaching idea or approach or biology education research. Posters must be 48” by 36” and be submitted as a PDF to christina.wills@rockhurst.edu by 5 pm CST on Friday October 16th. Posters will be placed online on a password protected ACUBE webpage for attendees to view prior to the meeting. During the poster Zoom session, each poster presenter will be given a breakout room where attendees may visit to ask questions.

If you have any questions concerning the annual meeting, please contact:
Local arrangements chair: Christina Wills, Ph.D., at christina.wills@rockhurst.edu
Program chair: Jessica Allen, Ph.D., at jessica.allen@rockhurst.edu

If you have not renewed your annual ACUBE membership for 2020 and are interested in doing so, please visit http://www.acube.org/membership/.

Thank you,
ACUBE Governance