Bioscene
Journal of College Biology Teaching

Volume 46(2)

December 2020

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Journal of College Biology Teaching

Volume 46(2) **December 2020**

ISSN 1539-2422

A Peer-Reviewed Journal of the

Association of College and University Biology Educators

Editor-in-Chief:
Robert W. Yost
Indiana University – Purdue University Indianapolis

An archive of all publications of the Association of College and University Biology Educators (ACUBE) can be found at http://acube.org/bioscene

Bioscene is published in May (online) and December (online and in paper format). Manuscripts submitted for consideration by Bioscene should follow the guidelines for submission.

Cover image:
African Elephant or African Bush Elephant *[Loxodonta africana]*

Location:
Kruger National Park, South Africa

Photographer:
Michelle Yost-Rowe

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65th ANNUAL MEETING

ACUBE is optimistically planning for an in-person meeting at the University of Portland in Portland, OR on October 14-15, 2021.

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A Publication of the Association of College and University Biology Educators

ACUBE Mission Statement

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

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

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involve student research in the biology curriculum;

advise and mentor students in and out of the classroom;

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enhance scholarship through our international, peer-reviewed journal, *Bioscene*.

Articles

The Influence of Habitat Complexity on Crayfish Foraging Behavior

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Abstract

I teach an animal behavior course where students conduct independent research projects; however, using live animals for research is challenging at a small university. Often, students choose to conduct a laboratory project over a field project believing that it will be easier to observe animals and control variables, but it can be difficult and expensive to acquire and maintain animals. If students work with vertebrates, there are added complications such as obtaining Institutional Animal Care and Use Committee (IACUC) approval and training. Additionally, following IACUC regulations often involves resources that we do not have. Because of these complications, I suggest to students that they consider an invertebrate species for their projects. In particular, crayfish are a species that are easy to obtain and care for, have low mortality, and exhibit interesting behavior that can be observed over several weeks. This article describes an inquiry-based research activity examining the influence of habitat complexity on crayfish foraging. This activity is well suited for students in ecology, animal behavior, or invertebrate biology classes and gives students flexibility in the hypothesis they test and the methods they use, while providing a framework that lets them successfully complete a behavior project.

Keywords: Habitat complexity, habitat structure, animal behavior, crayfish, aggression, foraging behavior, invertebrate biology

Introduction to Habitat Complexity and Crayfish Behavior

Crayfish are freshwater crustaceans that live in a variety of shallow habitats (streams, lakes, marshes, and swamps). They are opportunistic omnivores, and their diet includes macrophytes, algae, detritus, invertebrates, and small fish. Crayfish can be quite aggressive toward each other and will chase, push, and grab at one another (Baird et al. 2006). Crayfish generally live in structurally complex habitats such as rocky areas of rivers, and vegetated littoral zones of lakes. Habitat complexity refers to the physical structure of the environment. For example, the littoral zone of a lake is generally more structurally complex than the open water limnetic zone. Often, in the littoral zone, there are rocks, woody debris, and rooted plants of a variety of shapes and sizes.

Previous research has shown that habitat complexity can influence prey density, interactions between predators and prey, and foraging rates of predators (Savino and Stein 1982, 1989, Gotceitas and Colgan 1987, 1989, Diehl 1988, Gotceitas 1990, Nystrom and Perez 1998). Previous studies where stem density has been manipulated have found that an increase in habitat complexity generally results in a decrease in foraging rate due to physical interference making it difficult for predators to find prey (Savino and Stein 1982, 1989, Gotceitas and Colgan 1987, 1989, Diehl 1988, Gotceitas 1990). Some studies have found that foraging gains are maximized at intermediate levels of structural complexity (Crowder and Cooper 1979, 1982) due to the interaction between the effects of dense vegetation on prey density, maneuverability and visibility. However, habitat complexity can also influence interactions between foragers. Studies examining the influence of habitat complexity among foragers that are aggressive toward one another have found that as habitat complexity increases, the aggressive interactions between foragers decrease, resulting in the amount eaten per forager increasing (Basquill and Grant 1998, Corkum and Cronin 2004).

General Methods

Format of Research Projects

I prefer to have students pick their own hypothesis and develop their own methods, rather than telling them what to do as it provides students with experience developing a hypothesis and designing their own experiment- which is something that students rarely get to do. Also, this makes the project truly "theirs" and they become more vested in their projects. I find that the crayfish projects work best when students collaborate in groups of three or four. Working in groups enables students to divide up the work so that they can collect sufficient data to allow them to conduct statistical analysis and draw meaningful conclusions. I have found that groups larger than four students tend to increase the probability of conflicts between group members over equity of workload. Additionally, if students work in groups it means that the instructor has a more reasonable number of projects to oversee.

I first provide students with background information on crayfish behavior and habitat complexity, then I ask students to conduct a literature search and write a 2-3 page summary of a local crayfish species, and the influence of habitat complexity on crayfish behavior. After going over their summaries with them, I ask groups to come up with a hypothesis to test regarding the influence of habitat complexity on crayfish foraging behavior. Once students have developed a hypothesis that they plan to test, and their hypothesis has been approved by me, they design an experiment to test their hypothesis. Next, I require that students submit a scientific research proposal. Students are given a detailed handout that outlines how to write a research proposal (Appendix). In the handout I explain that they need an introduction with supporting background literature, and a detailed methods section including a discussion of proposed statistical analysis. I also ask them to include a list of required items, and a detailed calendar outlining what the group will do each week (including set up, animal acclimation, data collection, data analysis, and preparation for presentation of results). Requiring a formal research proposal helps students structure their ideas and prevents students from jumping ahead and making major mistakes in their experimental design.

After reading their proposals, I meet with each group to discuss their projects and make suggestions to their hypothesis and experimental design. I then ask groups to revise their proposals based upon that discussion. After groups rewrite their proposals, I then meet with groups again. Students do not begin data collection until their proposals have been reviewed and approved. Before students begin their projects, I ensure that they have background knowledge on how to care for their animals, have worked out the details of their experimental design, know what data they will record, have an idea of how they will analyze their data, and understand what results will support their hypothesis.

Suggestions and Helpful Hints for Crayfish Research Projects

While students should develop their own hypothesis and experimental design, they may need some assistance. Below I outline some helpful suggestions to consider when discussing projects with each group.

Students should design an experiment to examine the influence of habitat complexity on crayfish foraging behavior. They can do this by manipulating structural complexity in the crayfish's habitat. Exactly how they do this will depend on what hypothesis they choose to address. For example, they could choose to increase structural complexity by adding different densities of plants to tanks. They could use either field-collected aquatic plants, artificial aquatic plants obtained from pet stores, or simulated plants (by using nylon rope pieces tied to nets and anchored in the substrate). Alternatively, students could increase structural complexity by changing the abundance of hiding places. This can be achieved by using small, inverted clay pots placed throughout the tank, by adding medium-sized rocks (roughly 5 cm in diameter), by adding pieces of bricks, or by piling up rocks to create rock caves. They could also compare the influence of different types of complexity (e.g. field-collected plants versus artificial rope pieces, or plants versus rocks). There are many different hypotheses that can be easily tested.

Small crayfish can either be purchased through a biological supply company, or field-caught from local aquatic habitats using hand-held dip nets. Preferably, crayfish should be approximately similar in size. We use both male and female crayfish and randomly assign crayfish to tanks. Students will need sufficient crayfish to provide replicates. If crayfish are field-caught, then they should be returned to the location where they were obtained at the end of the project.

Crayfish are relatively easy to maintain in the lab as they can survive a wide range of water conditions. Tanks should be set up several days before the crayfish are obtained. Crayfish can be housed in tanks containing aerated dechlorinated water. Students should decide on the number of crayfish to place in each tank (which will depend upon their hypothesis), keeping in mind that the tank size needed will depend upon how many crayfish are placed in each tank. Generally, you need a tank large enough to hold 3-10 gallons per crayfish because crayfish can be aggressive. I suggest using two similarly sized crayfish per 10-20 gallon tank. The bottom of the tanks can be lined with washed aquarium gravel to a depth of 2.5 cm and filled with water to a depth of approximately 15 cm. If aeration is not used, crayfish must be given a structure that they can climb up on (e.g. rock) to get out of the water so that they can obtain sufficient oxygen. Water filters are not necessary, but partial water changes (25%) should be done weekly. Water temperature should be between 18-23 C (room temperature). Crayfish can be kept under a light regime of approximately 14hL:10hD. Crayfish should be given approximately a week to acclimate to the lab prior to the beginning of experiments. During the acclimation period, crayfish can be fed sinking shrimp pellets ad lib (which can be purchased from pet stores). It is often useful to set up a larger holding tank (e.g. 20 gallons) to house extra crayfish that may be needed if any die, and as a place to house crayfish if they are switched between treatments. Crayfish can be individually identified by drying a small region on their back with a paper towel and using nail polish to paint a number on their carapace. Students should ensure that the nail polish is dry before returning crayfish to their tanks.

Students can set up treatment tanks depending upon what their specific hypothesis is. For example, if students want to test the hypothesis that increasing plant density influences crayfish foraging, then they could set up three different treatments that vary in plant density. All tanks would be set up exactly the same (same size tanks, same number of crayfish per tank, etc.) with the only difference between the tanks being plant density. Control tanks would not have any plants added, low-plant-density tanks might have two artificial plants per tank, and high-plant-density tanks might have six artificial plants per tank.

Students will need to decide how many replicates to conduct, how long to run trials, and what data to collect. After students have decided upon a hypothesis to test, set up their habitats, and allowed the crayfish to acclimate to the lab, they can begin their experiments. Prior to each feeding trial, crayfish should be deprived of food for 24 hours to ensure that they are hungry. During each trial, equal amounts of food should be placed in the center of each tank. We've had good results using sinking shrimp pellets or redworms as food choices, but there are many possible foods that can be used such as cut-up fresh spinach, cabbage, cucumbers or carrots. After each feeding trial has been conducted, crayfish can be given an additional 5 minutes to feed, and then leftover food should be removed with a net so as not to foul the tanks.

Students should decide what data they will record, but they may need some assistance to ensure that they collect appropriate data for analysis. It is generally useful to have students record latency (time (s) that it takes for crayfish to capture the first food item), the number of food items captured, and the total length of time spent foraging (from when food is first placed until when the last food item is captured). Later, students can calculate capture rate. (# eaten/time).

Results and Discussion

This exercise gives students an opportunity to statistically analyze data. I conduct this project in my class after students have been introduced to statistical analyses. I meet with each group to discuss appropriate data analysis. Graphing the data will help students visualize their results.

Students can graph the results to determine:

1) if average latency (s) decreases as the level of habitat complexity increases (Figure 1)

2) if average capture rate (#/s) increases as the level of habitat complexity increases (Figure 2)

Students can statistically analyze the data to determine whether:

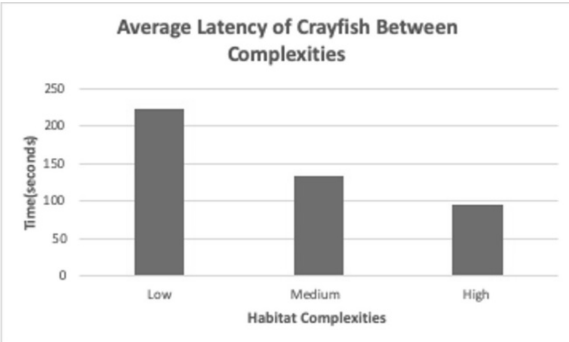
1) average latency significantly changes with increasing habitat complexity

2) average capture rate significantly changes with increasing habitat complexity

Generally, my students have found that as habitat complexity increases, latency significantly decreases, and capture rate significantly increases. However, as in any science experiment, students don't always find what they predict they will find, and this is a great opportunity to discuss with students all of the reasons why they may find results that differ from their predictions. After analyzing their data, I have students present their results in an oral presentation to the class, in a poster presentation at our collegewide poster symposium, and as a full written report.

Figure 1

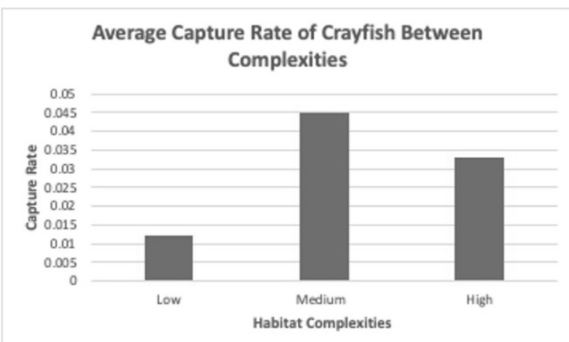
An example of one group's results



The average latency (time it takes to capture the first food item) for crayfish foraging in low, medium, and high complexity treatments. The results showed that there was a significant decrease in latency with increasing habitat complexity (ANOVA p<.05).

Figure 2

An example of one group's results



The average capture rate (worms eaten/second) for crayfish foraging in low, medium, and high complexity treatments. The average capture rates in the medium and high-density treatments were significantly higher than the average capture rate in the low-density treatment (ANOVA p<0.05).

Conclusion

It can be very challenging to find animal behavior research projects that are doable. This exercise provides an opportunity for students to design and conduct independent research projects and analyze and summarize their results. This exercise provides students with flexibility regarding what hypothesis they test, and what methods they use, while providing a framework that helps them successfully complete a behavior project.

References

Baird, H.P., Patullo, B.W. & Macmillan, D.L. (2006). Reducing aggression between freshwater crayfish (*Cherax destructor* Clark: Decapoda, Parastacidae) by increasing habitat complexity. *Aquaculture Research*, 37,1419-1428.

Basquill, S.P. & Grant. J.W.A. (1998). An increase in habitat complexity reduces aggression and monopolization of food by zebra fish (*Danio rerio*). *Canadian Journal of Zoology*, 76, 770-772.

Crowder, L.B. & Cooper, W.E.(1982). Habitat complexity and the interaction between bluegills and their prey. *Ecology*, 63, 1802-1813.

Corkum, L.D., & Cronin, D.J. (2004). Habitat complexity reduces aggression and enhances consumption in crayfish. *Journal of Ethology*, 22, 23-27.

Diehl, S. (1988). Foraging efficiency of three freshwater fishes: effects of structural complexity and light. *Oikos*, 53, 207-214.

Gotceitas, V. & P. Colgan. (1987). Selection between densities of artificial vegetation by young bluegills avoiding predation. *Transactions of the American Fisheries Society*, 116: 40-49.

Gotceitas, V. (1990). Variation in plant stem density and its effects on foraging success of juvenile bluegill sunfish. *Environmental Biology of Fishes*, 27, 63-70.

Gotceitas, V. & Colgan, P. (1989). Predator foraging success and habitat complexity: a quantitative test of the threshold hypothesis. *Oecologia*, 80:158-166.

Nystrom, P., & Perez, J.R. (1998). Crayfish predation on the common pond snail (*Lymnaea stagnalis*): the effect of habitat complexity and snail size on foraging efficiency. *Hydrobiologia*, 368, 201-208.

Mittlebach, G.G. (1981). Foraging efficiency and body size: a study of optimal diet and habitat use by bluegills. *Ecology*, 62, 1370-1386.

Savino, J.F. & Stein, R.A. (1982). Predator-prey interaction between largemouth bass and bluegills as influenced by simulated submersed vegetation. *Transactions of the American Fisheries Society*, 111, 225-266.

Savino, J.F. & Stein. R.A. (1989). Behavior of fish predators and their prey: habitat choice between open water and dense vegetation. *Environmental Biology of Fishes*, 24, 287-293.

APPENDIX: Handout on Writing a Research Proposal

ADVICE ON WRITING A SCIENTIFIC RESEARCH PROPOSAL

Each group must hand in a formal type-written (double spaced) research proposal for their project. This research proposal should include:

1) A title for your project (it should be descriptive and concise).

2) An introduction section providing:

   a) **Introductory material** on your topic and the animal species you intend to study (you will need to research the literature and present background theory from the scientific literature). Address the purpose of your project and put your project in context by discussing what is known about the species you plan to research and the behavior you plan to address.

   b) **Your hypotheses and predictions.** What hypotheses do you plan to test? Depending on your question, you may have one hypothesis that you will test, or you may have several hypotheses. What are your predictions?

3) A methods section outlining the **methods you will use**. This should be **very detailed** and written as it would be in a scientific lab report (in paragraph format). You should also include a paragraph or two carefully explaining: **what data you will collect** and **how you will statistically analyze the data**.

   Be sure to include:

   Details of all experimental procedures

   Where the project will be conducted

   Specific details of how animals will be housed and cared for (if a lab project)

   Explanation of what data will be collected

   Explanation of what variables will be calculated how the data will be analyzed (including specific statistical tests).

   If the proposed research involves the use of vertebrates, approval of the Institutional Animal Care and Use Committee must be obtained, and training must be completed.

4) A **<u>complete</u> list of items needed** including sizes of tanks/cages, and the quantity of each item (this will help me know what we need to purchase).

5) A **detailed time schedule**. Look at the syllabus and see how much time you have. Then plan out a week-by-week schedule of exactly what you will do.

   For example (for a fish foraging experiment):

   Week 1 (date): Set up aquaria, introduce fish into tanks, allow fish to acclimate for one week, collect prey to be used, design data collection sheets.

   Week 2 (date): Experiment 1: Provide each fish with prey assemblage. Fish will see the same prey assemblage each day, for seven days in a row. At the end of each day, tanks will be cleaned. Data on the number and type of each prey captured will be collected. etc.

6) A **literature cited** section.

Designing a New Course with a Spring Break Study Abroad Research Experience Benefits STEM Commuter Students

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Abstract

To increase our students' access to study abroad opportunities, a full semester course was designed that embedded a study abroad trip to Belize during spring break. The course fulfills both an upper level science course for both biology and biotechnology majors and an elective course for the Global Studies minor. Ten students enrolled in the course, and students' financial aid packages covered all or partial cost of the trip for seven students. The students were divided into four groups to study the coral reef, mangrove forest, and either the rain forest of Belmopan or Punta Gorda. Guest speakers came to class prior to the trip and provided information on the flora, fauna, and marine ecosystems of Central America. In Belize, students completed a research experience, learned about Mayan and Garifuna culture, and traveled extensively within the country. In addition to learning about the ecosystems and culture of Belize, many stated they learned more about themselves and felt more prepared to step out of their comfort zones to travel internationally again. After this positive learning experience all students agreed that they would recommend the course to a friend. The students wrote blogs and presented their research findings in poster and video format at the Undergraduate Research Conference (URC).

Key words: short-term study abroad, commuter students, research-experience, full semester course, pedagogy

Introduction

Study abroad experiences have long been defined as an example of a high-impact educational practice (Kuh & Schneider, 2008; Ruth et al., 2019). The overall goal of the experience is to make students more globalized citizens and increase their intercultural knowledge (Hser 2005; Lewis & Niesebaum, 2005; Czerwionka et al., 2015). Additional benefits of participating in study abroad include personal growth and increase in employability (Trower & Lehman, 2017). Incorporating a research experience into short-term study abroad provides students access to research that may not be available to them on their college campus (Ruth et al., 2019). The number of American students pursing study abroad opportunities continues to grow, from 262,416 students traveling in 2007-2008, to 341,751 students in 2017-2018 (The Institute of International Education, 2019, Redden, 2018). The largest group of study abroad students are students majoring in STEM fields, which have steadily increased from 17.6% in 2007-2008 to 25.6% in 2017-18 (The Institute of International Education, 2019). In the 2017-2018 school year, 38.5 percent of all students who studied abroad enrolled in summer study abroad courses (The Institute of International Education, 2019). Many students choose to do this because the experience does not conflict with required courses traditionally offered only during fall or spring semesters.

However, the summer study abroad model is not as popular with our students as it is for those at other institutions because our students are working full time in the summer. Most of the students at our college are commuters and live at home with their parents. In our BA of Biological Sciences and BS of Biotechnology programs, 38% of students are "first generation" and 8% of students are veterans. In addition to full time course work, most also work part time jobs during the academic year. When asked many of our students are unaware of the study abroad opportunities available to them, or believe they are unable to afford such programs.

The goal of the creation of this new science course was to increase access to study abroad experiences for our commuter students. Short term study abroad offerings of less than two weeks have been growing in popularity in recent years from 8.3 % of overall students studying abroad in 2010-2011 to 12% in 2016-2017 (The Institute of International Education, 2019). The advantage of short-term study abroad is students do not miss class, there is no negative impact on academic progress to degree and it is more affordable (Smith & Mitry, 2008). Our new full semester course, BSCI 620 Global Science Explorations, embeds study abroad into the spring break week, allowing students to travel to Belize and complete a field research experience on tropical ecosystems of Central America. The study abroad fee was created as a course fee which can be included into students' financial aid packages. In 2017 this was the only study abroad course offered by our college (there was one course added in 2018). The overall goal of creating this course is to provide science majors the opportunity to travel outside of the US, experience new cultures, complete a field research experience and reflect on their learning.

Methods

Course design

The new course (BSCI 620) fulfills an upper-level biological science concentration course for our BA in Biological Sciences major and an advanced biology course for our BS in Biotechnology major. It is also an elective course for the Global Studies minor. The only prerequisite is one year of biology, Principles of Biology I and Principle of Biology II. All enrolled students are required to participate in the spring break trip to Belize, and the study abroad fee can potentially be covered in their financial aid packages. The course was presented and approved by the college and university curriculum committees.

Learning Objectives

Students will:

Perform background research and design a research experience to investigate internationally

Investigate, collect and analyze information on their research experience studied internationally

Experience different cultures of people and investigate their relationships with their native flora and fauna.

Design, create, illustrate and present the results of their research experience and personal experience in different formats

The learning objectives were designed so that they could be fulfilled in future offerings of the course that would travel to different countries not just the initial destination of Belize.

Choosing a Tour Company and Study Abroad Site

There are many companies that offer short term study abroad trips. The three main factors that were used to choose a company were location, itinerary and cost. Central America was the region chosen because the short flight would ensure maximum time in the country for the one-week spring break. Belize was chosen because the tour company's itinerary (Appendix I), was more academic in nature than the other options and the high value of the US dollar would make it more affordable for the students. Once the contract with the university was signed, the faculty director made direct contact with the on-site guide via email and shared the course syllabus. Together, they modified the trip to meet the learning objectives of the course. In order to make the course more affordable, the students were booked into bedrooms of two to four students.

Student Recruitment

At the beginning of the fall semester fliers announcing an information session were put up around campus, a slide was placed on the kiosks in the student commons and science faculty announced the session details in their classes. Twenty students attended the session. The Faculty Coordinator, the Financial Aid Director, the Study Abroad Coordinator, and the Department Chair attended the meeting to answer questions. It was important to give the students one price that included airfare, room, meals, and onsite transportation so that they could determine the affordability before registering for the course. Students were also told to bring tip money on the trip for the bus driver and guide, as well as a small amount of spending money. The Financial Aid Director encouraged all students to make individual appointments with her so that each student's financial situation could be examined. Both hepatitis A and typhoid vaccines were recommended but not required as per the Centers for Disease Control and Prevention website (CDC.gov). Students were told to make an appointment with the travel clinic far in advance to ensure they would be able to obtain the vaccines. All students who did not have passports were told to apply for one by January 1 to ensure they would be able to obtain one prior to travel.

Research Experience Designed

This assignment was designed to be an introduction to field research as time was limited and each group was provided only one day at their designated site in Belize. The term research experience was used in the place of research project. After direct consultation with the on-site tour guide prior to the trip, four research sites were chosen: two rain forest sites, the red mangrove forest, and the coral reef. The students were asked to pick their first and second choice of research interest and were accordingly placed into groups of two and three students based on their answers. Each of the four groups performed preliminary research to gain background knowledge and to design a research question to investigate while on site. It was stressed that they should prepare a backup research question, as field research can be unpredictable.

International Travel Registry and Insurance

All participants registered their complete itinerary with the university travel registry. Students registered for the co-requisite course INCO 589 Study Abroad Experience-Short which has a small fee that pays for the student's enrollment in the University travel registry and provides each student with trip insurance. This course is not credit bearing. The travel insurance provided by the tour company was waived.

Guest Speakers Enhanced Trip Preparation

1. Trip to NH Audubon Society

The class went to NH Audubon Society and met with an ornithologist who trained them to use binoculars and to use specific birdwatching techniques.

2. Wildlife Tour Guide

The guide came to class and presented information on his experiences traveling to Central and South America. He taught the students how to hike in the jungle, birdwatch, observe wildlife, and experience new cultures.

3. Physician Assistant (PA), Alumna

Our alumna completed one of her PA rotations in Belize. She provided insight into living in Belize. She talked about the culture, the food, the weather, and her experience working in their healthcare system.

4. Infection Preventionist Nurse, Alumna

Our alumna provided information on precautions that needed to be taken when traveling abroad. Specific precautions of food borne illness and insect borne diseases were highlighted.

5. Postdoctoral Research Fellow

Our Postdoctoral Research Fellow focused very specifically on her current research on the Mangrove Forests and Marine Ecosystem of Central America.

Class Assignments Prior to Trip

Students participated in the annual NH Audubon Backyard Bird Count (https://www.nhaudubon.org/backyard-winter-bird-survey/) and submitted their results to Audubon and their course instructor. Each week, they wrote reflections on what they learned from each guest speaker. They also created a bibliography of articles on their research area prior to their trip.

Spring Break Trip

While in Belize, four research experiences were completed: The cohune palm as a keystone species, Mayan jungle survival skills, the importance of mangroves on the marine ecosystem and the mutualistic relationship between marine life and the coral reef. All students wrote field notes and recorded birds sighted daily at every research site in their Rite in the Rain All-Weather Journals. They visited Mayan ruins, a Mayan chocolate factory, had a Garifuna drum lesson and concert, and hiked in the jungle (daytime and nighttime).

Post Trip Assignments

Class time after spring break was spent designing and creating their research presentations. Each student group presented a poster on their research experience at the Undergraduate Research Conference (URC). Each group also created a five-minute narrated Point of View (POV) Video of their personal experience and participated in the video competition at the URC Cinema Arts Day. The individual blog assignment was limited to 600 words and the prompt was Describe the experience from your point-of-view to put readers in your shoes. Be creative and feel free to use your voice. The blogs were posted on the college website and the UNH Center for International Engagement and Global Studies website.

Students were surveyed prior to and after their trip to Belize. This project was approved by the University of New Hampshire Board of Institutional Review, and informed consent was obtained from all participants (UNH-IRB #: 6623).

Results

Demographics and Pre-trip Expectations

Ten students enrolled in the first time-offering of the course: eight seniors, one junior and one sophomore. The demographics of the course were diverse in age with one student < 21, six students 21-22, two students > 23 and one > 30 (Table 1). Four of the students were designated as First Generation and one Veteran. Most of the students (6) were white, with one White-Native American, one Hispanic and one Asian (Table 2). Of the ten students, four had never traveled outside the U.S. before, and obtained their first passports prior to the trip. The remaining students had traveled abroad with family. For four students, the cost of the trip was covered by their financial aid package, and three additional students received partial coverage for the trip through their financial aid package. This paper focuses on the creation and first offering of the course. Due to the initial success the course was offered again in 2019 and eight students traveled to Belize; the 2020 course was headed for Iceland when their trip was cancelled 48 hours in advance of their departure due to the COVID-19 global pandemic (Table 1, Table 2).

In the pretest survey (Appendix II) prior to the trip, students stated their overall expectations were to learn more about Mayan culture (7/10 students, 70%); to have new experiences (5/10, 50%) (such as snorkeling, night hiking); and to learn more about the diverse flora and fauna of Belize (10/10,100%). There was some trepidation about getting out of their comfort zone, as one student stated "I plan on gaining new perspectives on what life is like outside of our cushy American lifestyle. The thought of being in such a different place is kind of intimidating but I am looking forward to fully immersing myself in that culture and environment."

Undergraduate Research Conference (URC) Presentations

Each student research group presented their research in poster format at the URC: Red Mangroves of Placencia Belize, Coral Reef of Placencia Belize, Our UnBelizeable Survival Experience: Punta Gorda, Belize, and The Broadleaf Forest of Belmopan Belize and they answered a variety of questions during the session. At the URC Cinema Arts Day each group introduced the POV videos they created and after the screening answered questions from the audience. This assignment focused on their personal experience in Belize and showed the places they visited, the people they met, the flora and fauna they examined, and the food they ate. The videos were narrated by the student creators and provided insight on the positive impact of their experiences. Both the posters and videos were met with a lot of interest from the respective audiences.

Table 1

Student demographics 2017-2020

Year	#	Woman	Man	Other	Age				Veteran	First Gen
					<21	21-22	23-30	>30		
2017	10	8	2	0	1	6	2	1	1	4
2019	8	6	2	0	0	2	4	2	1	3
2020	10	9	1	0	3	4	2	1	0	6

Table 2

Student demographics 2017-2020

Year	White	Asian	Black	White, Native American	Hispanic	Unknown
2017	6	1	0	1	2	
2019	5	1	0	0	1	1
2020	9	0	1	0	0	

Student Blogs

The blogs were analyzed using thematic analysis (Vaughn & Turner, 2016) and seven common themes emerged. Theme1: Nervous to Travel Abroad. Two students (2/10, 20%) indicated they were nervous about traveling abroad. One of these had never traveled outside the US. Theme 2: Excitement to Travel Abroad. A few students (3/20, 30%) were very excited and this theme is best illustrated by the following quote "Hearing their [guest speakers] stories made me crave the moment when we finally got to leave home and travel to Belize". Theme 3: Meeting the Belizean People. Most of the students (7/10, 70%) mentioned how kind and polite the Belizeans were "I loved how cordial and respectful Belizeans are, I was welcomed everywhere we went". Theme 4: Culture. All the students (10/10, 100%) mentioned the Mayan and Garifuna culture and their appreciation for the knowledge gained through their direct experiences about the cultures through music, food, visiting historical sites and guided activities. Theme 5: Research Experience. All students (10/10, 100%) mentioned their research experience in their blogs. "I was most excited about snorkeling in the mangroves, which was my environment of study. It was unlike anything I had ever seen. Like a different planet just below the water line". Theme 6: Advice to Future Students. Almost all the students (9/10, 90%) made advisory statements for future students to take this class. "You will learn more than you ever intended to, especially with a class. It's one thing to learn lessons in class, but to live what you are learning and to make memories is far greater than any words on a page". Theme 7: Value added. Most of the students (9/10, 90%) ended their blogs with statements about their positive experience. "Traveling changes your perspective of the world, makes you appreciate not only your life but others more as well, and helps you see why trying to preserve and protect the earth is so important". The blogs were posted on the college website and on the University's Global Education website. The blogs demonstrated that this short trip to Belize had a high impact on the students and they met the learning objectives of the course.

Students were surveyed (Appendix II) after they returned from spring break and reported that all would recommend the course and travel abroad again (Table 3). When asked to reflect on their experience and state what they learned about themselves, it appears they were initially nervous but became more confident trying new things (Table 4). All students stated that this opportunity enhanced their undergraduate experience by gaining a different perspective of the world, acknowledging the extravagance of life in the US and making new friends (Table 5). For most of the students (9/10, 90%), this was their first and only research experience of their undergraduate career. Students stated that their research experience met (6/10, 60%) or exceeded their expectations (4/10, 40%) (Table 6). Overall, the course fulfilled the goals of the faculty creator, as the group learned a lot about themselves, their research experience site, the country of Belize, and its people.

Conclusion and Next Steps

This course successfully filled a need to provide the opportunity for science majors to study abroad without interfering with their curricular plan or spring semester courses. The goal of creating a course to increase access to study abroad experiences for our commuter students was achieved and due to its initial success, it has been offered two more times (Table 1, 2). For all but one student this was their first research experience. Skills gained by students were taking field notes, bird identification and observing marine life while snorkeling. From the faculty perspective, obtaining approval for the new course started one year prior to the recruitment of students. Traveling with the students and seeing their joy and excitement each day was a very rewarding experience.

The next goal is to encourage more faculty at our college to use this model to take students abroad for spring break. For students who have never traveled abroad a one-week experience is less daunting than a full semester or summer study abroad experience. Traveling to Central America is also more cost effective than to Europe where many study abroad experiences are set. By making the study abroad fee a course fee allows students to potentially have the trip covered by their financial aid package. When creating a similar course make sure to include meals, flights, tips and transportation all in one price. This strategy eliminates any frustration from the students as no additional costs are incurred during their trip. As we were in the jungle most of the trip students needed very little spending money.

While during the COVID-19 global pandemic study abroad programs have been cancelled or postponed it is important to note it takes an estimate of 1-1.5 years to find a study abroad vendor, create a new course, obtain approval from the college curriculum committee and study abroad office. So, by starting to plan now will enable your students to study abroad when the world is open to them.

Table 3

Posttest data that demonstrates students are likely to study abroad again

Question 13: Has this experience increased or decreased the likelihood you will travel abroad again? Explain.
“Increased, I barely left New England my whole life and never been outside of the Northeast. It opened my eyes to a whole new world.”
“Increased. I can still feel the joy that the beauty and culture of Belize gave me. I fell in love with the country. I crave more experiences traveling abroad.” (Note: she traveled to Thailand for vacation by herself after graduation)
“Increased. I have always loved traveling, and this just added to my curiosity of other cultures.” (Note: this premed student spent her gap year living in Thailand teaching elementary students English)
“This experience has made me catch the travel abroad bug! We’ve only been home for a week and I already want to go back to Belize!”
“It has definitely increased the likelihood of traveling abroad again. I’ve always wanted to travel, but never had the chance to. This trip has really opened my eyes about the importance of traveling and learning about the world around me.”
“I will definitely study abroad again. Why not! Do it now while you are able. So happy I did this experience. It was a lot of fun and the sights were breathtaking”.
“It increased it! Going abroad was amazing (to the point that I didn’t want to come back that soon). I’m looking forward to going abroad again sometime soon”.
“I mean I always love traveling so I guess increase. Its amazing to see different lifestyles. Never confine yourself to one way of thinking expand your mind, grow, do, learn that’s what life is all about”.
“I would without a doubt travel abroad again”.
“Increased my likelihood because the more I do it, the more comfortable I am. I also enjoy the learning, the diversity, the uniqueness, and the collection of passport stamps”.

Table 4

Posttest data students learn more about themselves after this study abroad experience

Question 8: Through this study abroad experience what did you learn about yourself?
“I learned that I am more willing to try new things that I am not familiar with. I ate a termite, went on a night hike and explored a cave; all examples of actions I typically would not think to do in New Hampshire.”
“I learned how easy it was to make friends, once I let my guard down.”
“I learned that I am very adventurous and love nature. I also found that I love the different cultural foods that can’t be found around here.”
“From this study abroad experience, I learned I need to start pushing outside of my comfort zone more. I would usually never take a class like this let alone go to a foreign country with a class of people I hardly knew! I am so glad that I finally got the courage to go and do it and now nothing is going to get in my way of taking amazing experiences like this again!”
“I learned to take risks. I also am more appreciative of what I have before me. The Mayans have very little and yet they seem pretty happy.”
“I enjoy learning about the way of living of different cultures and how their perspective is different from mine.”
“I was very nervous heading into the trip, but I found myself becoming less and less every day and eventually every situation we found ourselves in was a blast.”
“I learned that I really love learning about culture. It has always interested me but experiencing it in person was surreal. It’s amazing to learn about life and how different it was before our time. I also learned that my love for nature only goes to a certain extent. I’m also not entirely sure if I would be able to survive in a jungle”.
“I learned that I am always up for an adventure. I will say yes to almost all new experiences that present themselves to me. I also learned to take time to get to know locals to get a more authentic perspective of their lifestyle”.
“I learned that bugs don’t creep me out as much as I thought they would. I also learned that I was able to adapt pretty quickly to such a different lifestyle. I was very nervous heading into the trip, but I found myself becoming less every day and eventually every situation we found ourselves in was a blast”.

Table 5

Posttest data demonstrates that students' overall undergraduate experience is enhanced

Question 12: How has this study abroad experience enhanced your overall undergraduate experience?
"Before taking this class I did not have much of a social life on campus. UNH Manchester is a commuter school so I did my work and left. If I hadn't taken this class, I wouldn't have gotten close to these people that I can now call my friends."
"It has made all the difference. Undergrad has been stressful (still is), but this experience really did top off my senior year. Being able to travel with my professors who I consider my mentors and being able to gain knowledge that I couldn't have gotten in the States, has made this an unforgettable year for me."
"This study abroad experience enhanced my overall undergraduate experience by giving me something very unique to it. I don't know many people who get to go abroad to begin with so I think it gives me a competitive edge how well rounded I can be."
"It was my favorite class by far and its enhanced my undergraduate person by giving me a different perspective on the world. We live such extravagant lives while others struggle but still live life to the fullest-unbreakable attitudes-and I think that's so beautiful and makes me feel blessed for the life I live and to try and become a more positive person."
"It gave me another kind of learning rather than just sitting in a classroom. We got to apply what we learned in real life which was something many people don't get."
"I love biology! So, when I was on the trip and saw the acacia tree, wildlife and other plants and ecosystems it truly connected the loose ends that I once have learned in Principles of Biology. This experience was both educational and adventureful."
"This has enhanced my undergraduate experience by giving me a different perspective of the world."
"This study abroad experience was the perfect way to cap off my senior year. It was 8 days of pure adventure that I will never be able to replicate. I will remember this trip forever.
"It took me out of my mundane biology/work lifestyle for a change. I have a greater appreciation for the opportunities I have been provided in life and by my school. Hopefully my future work will show that."
"I think I learned about myself too much and found out that I like to go to places that I never been. This is a great thing for my undergraduate experience because I have a story to tell & even consider taking courses w/options similar to the ones given in this course".

Table 6

Posttest data students' reflections on their research experience

Question 4: Did this research experience meet your expectations?
"I learned to go into this experience with an open mind. My experience was better than I expected."
"I think this trip was amazing, but maybe include more research tools and methods."
"It did. I was very pleased & happy with everything that took place in this experience. I think I learned a lot more than I anticipated."
"It exceeded them. I had so much fun & learned so much more than I could have hoped. We had amazing guides who were willing & interested to share knowledge."
"Yes and then some! I thought I'd only get to observe mangroves from shore or on a boat. When I realized I was going to snorkel around a mangrove island, I was ecstatic. Plus, all the cultural and historical information, I learned about Belize was a bonus."
"Yes, this experience met all my expectations! I have not had much experience in doing field work and this opened my eyes to a whole new and exciting world of research."
"Yes, it did. I've never performed research prior to this and for a first time experience it definitely will be hard to top for other research trips."
"The research did meet my expectations as an end result".
"It did, we had to change our entire research project from birds to ways to survive in the jungle, which we didn't mind. We learned a lot about the environment and ourselves that day".
"The research experience met my expectations".

Overall, this new course fulfilled the goals of the faculty creator, the learning objectives of the course and the group learned a lot about themselves, their research experience site, the country of Belize, and its people. The next offering will be spring 2022 with a trip to Costa Rica.

Acknowledgements

Thank you to the students who participated in this class and to our guide in Belize Efrain Cocum who taught us so much about his beautiful country. A special thanks to Dr. Annie Donahue her helpful comments.

References

Czerwionka, L., Artamonova, T. & Barbosa, M. (2015). Intercultural knowledge development: Evidence from student interviews during short-term study abroad. International Journal of Intercultural Relations, 49, 80-99.

Hser, M.P. (2005). Campus internationalization: A study of American universities' internationalization efforts. International Education, 35(1), 35-48.

Kuh, G.D., & Schneider, C.G. (2008). High-impact educational practices: What they are, who has access to them, and why they matter. Association of American Colleges and Universities, Washington D.C.. 44p.

Lewis, TL & Niesenbaum, R.A. (June 3, 2005). The Benefits of Short-Term Study Abroad. Chronicle of Higher Education, 51(39), https://www.chronicle.com/article/The-Benefits-of-Short-Term/22274

The Institute of International Education (2019) U.S. Study Abroad, 2019 Open Doors Report. ,https://www.iie.org/en/Research-and-Insights/Open-Doors/Data/US-Study-Abroad/Duration-of-Study-Abroad

Redden E. (November 13, 2018). Study Abroad Numbers Grow. Inside Higher Ed. https://www.insidehighered.com/news/2018/11/13/study-abroad-numbers-continue-grow-driven-continued-growth-short-term-programs

Ruth, A., Brewis A., Blasco D. & Wutich, A. (2019). Long-Term Benefits of Short-Term Research-Integrated Study Abroad. Journal of Studies in International Education, 23(2), 265-280. https://doi.org/10.1177/1028315318786448

Smith DE, & Mitry, D.J. (2008). Benefits of Study-Abroad and Creating Opportunities: The Case for Short-Term Programs. Journal of Research in Innovative Teaching, 1(1), 236-246.

Trower H., & Lehmann, W. (2017). Strategic escapes: Negotiating motivations of personal growth and instrumental benefits in the decision to study abroad. British Educational Research Journal, 43(2), 275–289. https://doi.org/10.1002/berj.3258

Vaught P., & Turner, C. (2016). Decoding via Coding: Analyzing Qualitative Text Data Through Thematic Coding and Survey Methodologies. Journal of Library Administration, 56, 41–51. https://doi.org/10.1080/01930826.2015.1105035

The Effects of Smartphones on Multiple Dimensions of Student Learning and Engagement in an Introductory Biology Laboratory

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Abstract

Faculty at all types of colleges and universities struggle with how smartphone use may enhance or diminish their pedagogy, in part because evidence-based data is lacking for most types of classrooms. Thus, we conducted a thorough investigation in an introductory biology lab course to determine how smartphones affected myriad aspects of student learning and engagement. There were no significant differences in exam scores, the amount of time spent studying, occasions students were off task, or questions asked to the instructor. There were, however, significant differences in several measures of engagement and time management; students allowed to use their smartphones spent 64% less time in peer-to-peer interactions, 46% less time taking notes, 70% less time handling specimens, and 31% less time in lab compared to students who were not allowed to use smartphones. Because these behaviors, in particular peer engagement and note taking, are fundamental skills best developed early in a successful undergraduate career, our results suggest smartphone use should be minimized in introductory biology laboratories.

Introduction

The debate regarding if and when to use smartphones in college classrooms is now almost as common as the dissension of 'breadth vs. depth'. Faculty across all types of colleges and universities struggle with student smartphone use and how it may enhance or diminish their real time or remote pedagogy. Evidence-based data are necessary because the use of smartphones is one of the most unifying and pervasive features of current college students; 96% of US Americans aged 18-29 have not just a cellphone, but a smartphone capable of accessing the internet (Mobile Fact Sheet, 2019). Ten years ago it was predicted that by 2020 mobile phones would become primary means for the internet access for students (Caverly et al., 2009), and it is doubtful current faculty would disagree that this prediction has materialized.

Many studies have demonstrated the benefits of encouraging and integrating smartphone use in large lecture-based classrooms, as their technology has been shown to increase student engagement and participation. Smartphones allow students to access information quickly from a familiar platform, have that information readily available, and can be invaluable to students where English is a second language (Metruk, 2019). Additionally, student response systems such as polling apps provide copious opportunities for immediate and valuable formative and summative assessment (UCISA, 2014; Kent, 2019). In small student-centered courses smartphone technology can also augment student learning; apps that measure anything from leaf shapes (Leafsnap) to Earth's magnetic field (Magnetometer sensor) to QR codes in chemistry labs (Kasperkey's) have been vetted tools for student learning and engagement (William & Pence, 2011; Arabasi & Al-Taani, 2016). Apps can also increase student inclusion (Thomas et al., 2013), and in some cases especially for students with disabilities (Bouck et al., 2016). Moreover, students find smartphones to be convenient, portable, and Earth friendly (Anshari et al., 2017), and many college and university administrators have expanded on these student perceptions and developed their own mobile applications (e.g., MyUT for the University of Texas or UPMobile for the University of Portland). Indeed, smartphones have the potential to reach a wide variety of learning styles and address issues in equity and diversity (Epstein & Bequette, 2013).

There is also a wide body of literature that suggests smartphone use hinders academic performance. Weimer (2014) showed that students who used their devices during class took fewer notes and had poorer recall than students who abstained. Lepp et al.'s (2015) study of 500 undergraduate students showed that students who spend more time on their phone had lower grades, and this was true for phone use both in and out of class. Students can be more distracted from class, specifically from multi-tasking or texting on their smartphones (Grinols & Rajesh, 2014) and their use can increase cheating (Srikanth & Asmatulu, 2013). And perhaps most convincing, Kim et al. (2019) observed first year college students for 14 weeks and found that students spent ~25% of class time distracted by their smartphones, and that those distractions occur every 3-4 minutes and last approximately one minute in duration.

Whether the use of smartphones in the classroom enhances or detracts from student learning appears to be context-dependent. This suggests that determining where (i.e., in which types of classrooms) smartphones would be an enrichment to learning is a key question. In STEM, the hands-on experiences in laboratories are a critical part of their college curriculum. For most biology majors, their college career usually begins with a year introductory biology sequence that exposes students to a broad and comprehensive list of biological topics. The major topics include cellular and molecular biology, genetics, ecology, and evolution. Regardless of the order in which students are exposed to the topics, the sequence serves as a foundation for the content of upper-division coursework (i.e., "you learned this in intro") as well as the starting place to practice skills such as effective note taking, group work, lab protocols, time management, etc. Ideally, students exit their introductory sequence with not only a foundation of knowledge, but with an understanding that learning is a process; it begins with preparing for class, participating in the multi-facets of the class (or lab), continues after class, and is interdigitated with both formative and summative assessment. With that learning process in mind, we aimed to explore how smartphone use affects multiple aspects of learning and engagement for an introductory biology laboratory. We used a unit of the ecology and evolution semester where, in addition to other skills or factors that are shared with the cellular and molecular biology semester, students can use their smartphones to take pictures of specimens. The dependent variables included a wide variety of student behaviors that demonstrated individual engagement with the material, engagement with others, and/or independent study time and time management. We hypothesized that smartphone use would negatively impact all measured aspects of student learning and engagement.

Methods

Data were collected in four sections of Introductory Ecology and Evolution Laboratory (BIO 278 [A-D]), all taught in the same semester by the same instructor (Dizney). This is a one-credit lab taught once a week for three hours, with 20-22 students per section. Classroom observations occurred during a four-week unit on the vertebrate taxonomy and ecology at the University of Portland, both on the main campus and the Franz River Campus. The Franz River Campus is a relatively undeveloped 34-acre river-front site adjacent to the main campus in North Portland, Oregon. The two learning outcomes of this unit are: 1) learning the common and scientific names of the common vertebrate species of the river and main campus and 2) use a dichotomous key to correctly identify mammalian skulls to species. In Week 1 students were exposed to half the material, in Week 2 the students took a practical and engaged in ecological research, in Week 3 students were exposed to the other half of the material, and in Week 4 the students again took a practical (not cumulative) and went into the field to engage in ecological research.

The four lab sections were divided into two treatment groups with two replications each: treatment group 1 was allowed to use their smartphones for Week 1 but not Week 3 (sections A and B) and treatment group 2 was allowed to use their smartphones for Week 3 but not Week 1 (sections C and D). Thus, all students were given (and tested upon) half the material under "smartphone allowed" conditions and half the material under "smartphone not allowed" conditions. Although the definition of smartphone is not universal (Litchfield, 2010), for this study we defined a smartphone to be any device capable of connecting to the internet and taking photographs.

After an introductory lecture, students were read the IRB consent as well as specific instructions for lab. Briefly, a 30-minute PowerPoint presentation was given to remind students of the classification system used in vertebrate biology, to explain and practice using a dichotomous key, to show pictures of skull features used in the dichotomous key made specifically for this lab, and to explain how they would be assessed. At the end of the presentation instructions were given on how the lab would be conducted with the following prompt, “Today is an independent lab, modeled after the labs you will experience in your upper division biology courses. The way you structure lab today is up to you. I am here to answer questions, but you will determine how to go about learning the specimens”. The laboratory room was organized into four stations: three with vertebrate specimens and materials (skulls, pelts, taxidermy forms, dichotomous keys, etc.) and one station with a practice practical. Students were free to move through the stations in any order and at their own pace. Throughout the entire lab the instructor was available but did not initiate any contact with students. Upon leaving lab, students self-reported how much time they planned on studying for the practical and the exact time they left lab (moderated by a TA). Although self-reporting is known to have validity concerns, we had no other practical means to collect this data. On each practical there was an ungraded question for students to self-report the actual amount of time spent studying for each practical. These three variables (time in lab and time planned or actually spent studying) were used to gauge time management.

The observer (Prestholdt) used a COPUS-style rubric that recorded individual student behaviors every five minutes (Smith et al., 2017). At each interval, ten possible behaviors were recorded: handling specimens/materials, taking notes/drawing (either on paper or electronically), independently studying/reviewing, engaging in a peer-to-peer interaction about the material, taking pictures of specimens/materials with their smartphone, off-task either on their smartphone or with peers (i.e., gossiping), engaging in a question/discussion with instructor, taking the practice practical, or out of the room. If a student was doing two behaviors at the same time (e.g., handing specimens and drawing), both were recorded (no student was observed doing more than two behaviors at once). To compare means of the smartphone to no-smartphone data t-tests were used. We omitted from statistical analysis students who arrived late, left early, did not take both practicals, or chose to not use a cell phone when allowed (n = 5). Ultimately, 71 students were included in the final analysis.

Results

There were no significant differences in practical scores or any engagement metric between lab sections, so data was combined across lab sections for the same treatment. There was also no significant difference between scores for practical 1 and practical 2 (t-test $p = 0.97$) so the data from the two practicals were combined for further analysis.

There were no significant differences between the practical exam scores of students that were or were not allowed to use their smartphones (see Table 1). This was true for comparisons of individual raw scores as well as through comparisons how their practical score deviated from the mean practical score when they used and did not use their smartphones. There were also no significant differences in the amount of time students self-reported that they planned to study or actually studied (both $p > 0.5$, see Table 1). And although both occurred minimally, there were no differences between the number of questions asked to instructor or the occasions students were off-task. Data that were dependent on the physical use of a smartphone (i.e., off task on their smartphones or taking pictures with their smartphones) were all statistically significant (see Table 1).

There were however significant differences in the time spent handling specimens, taking notes, engaging with peers, and the total time spent in class (all $p < 0.0001$, see Table 1). Students allowed to use their smartphones were observed to handle specimens 70% less, engaged in peer-to-peer interactions 64% less, taking notes 46% less, and spent 31% less time in lab.

Discussion

This study investigated aspects of student learning and engagement in an introductory biology laboratory that fall into three broad categories: engagement with the course content (handling specimens, note taking, etc.), engagement with other humans (instructor or peers), and time management and accountability (exams scores, time studying and in lab, etc.). While we hypothesized that the use of smartphones would negatively impact all measured aspects of student learning and engagement in this introductory biology unit, our results suggest smartphones affect only a sub-set in each category.

Our study revealed no differences in time management (outside of class) or grades. This is consistent with other college studies that have found

Table 1

Comparisons of dimensions of student learning when allowed or prohibited from using a smartphone during lab. With the exception of practical exam score, hours studying, and total minutes spent in lab, the mean and standard deviation represent the number of five-minute time intervals students were observed doing that behavior

	no Smartphone use $\bar{X}$ (SD)	Smartphone use $\bar{X}$ (SD)	t-test p value
Practical exam score	81% (15%)	82% (13%)	0.65
Planned hours of studying	2.8 (1.3)	2.7 (1.1)	0.53
Actual hours of studying	2.7 (1.2)	2.8 (1.4)	0.62
Engaging with instructor	0.2 (.5)	0.1 (.4)	0.47
Practice practical station	0.2 (.5)	0.1 (.4)	0.11
Off-task	0.8 (2.0)	0.6 (1.1)	0.11
Studying in lab	0.8 (1.8)	0.4 (.7)	0.07
Handling specimens	2.0 (1.8)	0.6 (.9)	<.0001
Peer-to-peer interactions	1.4 (1.3)	0.5 (.9)	<.0001
Note taking	3.7 (2.3)	2.0 (2.0)	<.0001
Total minutes in lab	47.1 (20.5)	32.7 (16.9)	<.0001
On smartphone	0.1 (.4)	0.6 (.8)	0.0001
Taking pictures on smartphone	0 (0)	1.6 (1.1)	<.0001

no correlation with grades (Martin, 2010; U of NH, 2010; Hochberg et al., 2018). We also found no significant differences with other anticipated negative effects of smartphone use, such as time spent studying in lab (p = 0.07), amount of engagement with the instructor (p = 0.47), time spent on a practice practical (p = 0.11), or amount of time students were off task (p = 0.11). However, our study revealed drastic differences in student engagement with the material and with each other; when students were prevented from using their smartphones they were observed handling specimens 30% more, spent 54% more time taking notes, engaging with their peers 36% more, and spent 69% more time in lab. These differences could translate into enormous increases in student engagement over the course of a quarter or semester, and likely impact habits in upper-division coursework.

Perhaps most concerning for our future graduates is the drastic difference in time students spent in lab and engaged in peer-to-peer interactions (~30% and ~65%, respectively). Although these results would likely vary tremendously with other cultural campus norms, if the prevention of device use translates into any increase in student engagement, this should be a major consideration for instructors and how they design and implement their learning objectives.

There are three obvious directions for future work. The first is expand the current study to non-cadaver based anatomy labs in all realms of vertebrate, invertebrate, and botanical specimens. The second is to conduct a parallel study in the other units of introductory biology such as genetics and cellular and molecular biology. The skills of these labs often include microscopy, pipetting, gel electrophoresis, etc., where mandatory personal protective equipment and/or lab safety protocols prohibit the use of smartphones; it would be interesting to design a study in these scenarios that elucidated the role of lab equipment and protocols on peer engagement. The third is to follow two cohorts of students from intro to their upper division courses; do the smartphone habits students acquire as freshman perpetuate throughout their career? That is, it is possible the norms they practice as freshman (compared to sophomores or juniors) have a disproportionate effect on their ability to make good judgement calls about the use of (or abstinence of) their smartphone. Both of these studies would provide additional evidence-based data on what aspects of student learning and engagement are negatively or positively affected by smartphone use.

In conclusion, our study suggests that smartphone use has no effect on grades and time spent studying, but profound effects on some subsets Of student learning and engagement such as peer engagement and note taking. Many college educators find peer engagement and note taking to be critical and fundamental skills that should be introduced and enforced early in the curriculum; peer to peer learning promotes active learning and helps build relationships while note taking helps students focus on material as well as increase their ability to outline or summarize material. Because these skills are often as important, if not more so, for a successful college career and beyond, our study suggests smartphone use should be minimized in some types of introductory biology laboratories.

Acknowledgements

We thank the University of Portland IRB Review Board (IRB00006544) and one anonymous reviewer for very helpful comments and revisions to our manuscript.

References

Anshari, M., Almunawar, M.N., Shahrill, M., Wicaksono D.K. & Huda, M. (2017). Smartphones usage in the classrooms: Learning aid or interference? Education and Information Technologies, 22, 3063-3079.

Arabasi, S. & Al-TaanI, H. (2016). Measuring the Earth's magnetic field dip angle using a smartphone-aided setup: a simple experiment for introductory physics laboratories. European Journal of Physics, 38(2), 025201.

Bouck, E.C., Satsangi., R., & Flanaga, S. (2016).Focus on Inclusive Education: Evaluation Apps for Students with Disabilities: Supporting Academic Access and Success. Journal of Childhood Education, 92(4), 324-328.

Caverly, D.C., Ward, A.R., & Caverly, M.J. (2009). Techtalk: Mobile learning and access. Journal of Developmental Education, 33(1), 38.

Chen, B. Liu, F., Ding, Ying, X., Wang, L., & Wen, Y. (2017).Gender differences in factors associated with smartphone addiction: a cross sectional study among medical college students. BMC Psychiatry, 17(341). https://doi.org/10.1186/s12888-017-1503-z

Elhai, J.D., Rozgonjuk, D., Yilkdirim, C., Algharaibeh, A.M., & Alafnan, A.A. (2019). Worry and anger are

of student learning and engagement such as peer engagement and note taking. Many college educators

associated with latent classes of problematic smartphone use severity among college students. Journal of Affective Disorders, 246, 209-216.

Epstein, J. & Bequette, A. (2013). Smart phone applications in clinical practice. Journal of Mental Health Counselin, 35(4):, 283-295.

Grinols, A.B. & Rajesh, R. (2014). Multitasking with Smartphones in the College Classroom. Business and Professional Communication Quarterly, 77(1), 89-95.

Hochberg, K., Kuhn, J., & Muller, A. (2018). Using Smartphones as Experimental Tools – Effects on Interest, Curiosity, and Learning in Physics Education. Journal of Science Education and Technology, 27,385-403.

Jeong, H. & Lee, Y. (2015.).Smartphone Addiction and Empathy among Nursing Students. Advanced Science and Technology Letters, 88, 224-228.

Kim, I., Kim, R., Kim, D., Kim, K., Han, P.H., Lee, G., & Lee, U. (2019). Understanding smartphone usage in college classrooms: A long-term measurement study. Computers & Education, 141, 103611.

Kent, D. (2019). Plickers and the Pedagogical Practicality of Fast Formative Assessment. The Journal of Teaching English with Technology, 3, 90-104.

Lepp, A., Barkley, A.C., & Karpinski, C. (2014). The relationship between cell phone use, academic performance, anxiety, and Satisfaction with Life in college students, Computers in Human Behavior, 31,343-350.

Berger, T. (2013). Students who use cellphones more get lower grades. http://blog.chron.com/sciguy/2013/12/study - students-who-use-cellphones-more-get-lower-grades/

Litchfield, S. (2010). Defining the smartphone. http://www. allaboutsymbian. com/features/item/Defining_the_Smartphone.php.

Martin, C. (2010). Cellphone Use and Concentration During Class. Available at Whittemore School: http://www.unh.edu/news/docs/2010CellphoneUsageStudy. pdf.

Metruk, R. (2019). The call of the MALL: the use of smartphones in Higher Education. A literature review. Revising Contemporary Dilemas: Education, Politics, and Values, 3(52), 1-23.

"Mobile Fact Sheet". Pew Research Center, Washington, D.C. (2019) https://www.pewresearch.org/internet/fact-sheet/mobile/

Park, N. & Lee, H. (2012). Social Implications of Smartphone Use: Korean College Students' Smartphone Use on Psychological Well-Being. Cyberpsychology, Behavior, and Social Networking, 15(9), 491-497.

Srikanth, M. & Asmatulu, R. (2013). Modern cheating techniques, their adverse effects on engineering education and preventions. International Journal of Mechanical Engineering Education, 42(2), 1-12.

Thomas, K.M., O'bannon, B.W., & Bolton, N. (2013). Cell phones in the classroom: Teachers' perspectives of inclusion, benefits, and barriers. Computers in the Schools, 30(4), 295-308.

UCISA. (2014). Mobile learning: How mobile technologies can enhance the learning experience. University and Colleges Information Systems Association.

Wang, J.L., Wang, H.Z., Gaskin, J., & Wang, L.H. (2015). The role of stress and motivation in problematic smartphone use among college students. Computers in Human Behavior, 53, 181-188.

Weimer, M. (2014, January 8).The Age of Distraction: Getting Students to Put Away Their Phones and Focus on Learning. Retrieved from Faculty Focus: http://www.facultyfocus.com/articles/teachi ng-professor-blog/the-age-of-distraction- getting-students-to-put-away-their-phones- and-focus-on-learning/

William, A. AND H. Pence. (2011). Smartphones: a powerful tool in the chemistry classroom. Journal of Chemistry Education, 88(6), 683-686.

Wilmer, H.H., Sherman, L.E., & Chein, J.M. (2017). Smartphones and Cognition: A Review of Research Exploring the Links between Mobile Technology Habits and Cognitive Functioning. Frontiers in Psychology, 8, 605.

Modulators of Test-Enhanced Learning in Post-Secondary Biology

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Abstract

Cognitive scientists and psychology researchers have given growing attention to evidence of the testing effect, that is, the improvement of students' recall through memory-retrieval practice in the form of quizzes and exams. While laboratory experiments consistently show dramatic positive effects on learning through the testing effect, discipline-specific education researchers have sought to generalize these findings in real, instead of simulated classrooms. Our objective in this review was to survey recent findings on the testing effect in post-secondary biology education and synthesize how those findings may modulate learning in the post-secondary biology classroom. We found that: (a) Increased exam frequency increases the testing effect; (b) Corrective feedback on exams may enhance the testing effect; (c) Incentives, such as points, may decrease the positive outcome of learning through the testing effect, though little research in actual classrooms on this widely used practice is found; (d) Individual differences in student achievement and preparation may moderate the effect. We consider how further research on the testing effect may be useful for instructors' decisions regarding its use.

Introduction

In recent decades, science education reform has involved stronger collaboration between cognitive and education researchers interested in applying their findings from laboratory research to subject-specific disciplines. Discipline-based education research (DBER) is central to the effort at the post-secondary level (e.g., Carpenter et al., 2016). Several principles of learning from cognitive-science laboratory studies have hypothetical applications for instructional practice in STEM classrooms. In this article, we review the recent findings on one such principle of learning for application in post-secondary biology education —the testing effect.

The testing effect is the improvement of students' learning through classroom testing. It is also known as retrieval practice, practice quizzing, or test-enhanced learning (for a review see Roediger & Butler, 2011). For example, information that appears on a quiz will more likely be recalled later than information not tested. Terms such as test, exam, and quiz are most commonly associated with assessment in education. In simple language, assessment is the measurement of how much students have learned of what the teacher has taught. In this way, assessment informs teachers of the effectiveness of their instruction in terms of student learning (Black & Wiliam, 1998). Even though an exam on previously presented content is sometimes considered, in itself, a neutral learning event, researchers in cognitive psychology, education and neurobiology have reported that learning may be enhanced when it is retrieved through testing (Roediger & Karpicke, 2006). Specifically, retrieving information from memory may enhance the cues for future retrieval.

A recent resurgence of research on this topic has been largely conducted in cognitive-science laboratories in controlled studies (Roediger & Butler, 2011) using varied material, including word pairs (Carrier & Pashler, 1992; Karpicke & Roediger, 2008), general facts (Butler et al., 2008), trivia (McDaniel & Fisher, 1991), and textual passages (Kang et al., 2007). Researchers have also examined the differential effects of the testing effect using varied assessment formats, including multiple-choice items (Marsh et al., 2007), open- and closed-book items (Agarwal et al., 2008), and inference items (Karpicke, 2012). The results of a multitude of studies on the testing effect have been featured in confirmatory meta-analyses (Bangert-Drowns et al., 1991; Phelps, 2012; Rowland, 2014; Schwieren et al., 2017). Officials at the Institute of Education Sciences, sponsored by the US Department of Education, have recommended the adoption of testing and retrieval practice at all levels of education, including the post-secondary level (Pashler et al., 2007).

The extent to which research on the testing effect applies to learning biology at the post secondary level is critical in making decisions in its use

(Daniel, 2012). Given both the consistent findings on the testing effect in laboratory studies, and researchers' confidence in recommending the method as a means of improving student learning, there is a growing motivation to understand the mechanistic boundaries that may influence the testing effect as it applies to learning in discipline-specific classrooms. Perhaps due to the demand for STEM education reform, the body of testing effect literature in recent years has expanded to include information pertinent to the application of the testing effect in post-secondary biology classrooms. A summary of the testing effect in biology education at the post-secondary level is not found in the current literature. Here we present an overview of the testing effect specifically in post-secondary biology education and discuss the implications for further research and application of the testing effect. The key questions being addressed are:

- How does the classroom structure of assessment influence learning through the testing effect in biology education?
- How does assessment format and content influence learning through the testing effect in biology education?
- What student characteristics influence learning through the testing effect in biology education?

How does the classroom structure of assessment influence the testing effect in biology education?

Assessment frequency

Researchers have found a positive relationship between the higher frequency of classroom assessments and academic achievement (Phelps, 2012). The importance of testing frequency has also been shown more specifically in biology education research at the university-level. For example, frequent quizzing improved learning outcomes in post-secondary biology over standard unit exams (Bailey et al., 2017). Haak et al. (2011) also implemented a highly structured course design in an introductory biology course based on daily and weekly assessments in problem-solving, data analysis, and other higher-order cognitive skills. The design was associated with improved performance in all students enrolled in the course and reduced the performance gap between socioculturally disadvantaged and non-disadvantaged students. In a final example, Pape-Lindstrom et al. (2018) measured an increase in student performance in a community college biology course when they implemented frequent pre-class online and open-book reading assessments.

Overall, increased frequency of testing experiences appears to improve learning. The increased frequency of assessment has been reported as positively correlated with lower course-failure rates, higher course point totals, and higher scores on midterm assessments (Freeman et al., 2007) as well as increased academic motivation (Healy et al., 2017). Importantly, Leeming (2002) surveyed University of Memphis students and reported their greater satisfaction with courses that included more frequent assessments. Students also indicated that they learned more as a result. By simply increasing the frequency and number of exam experiences instructors can enhance the testing effect in the biology classroom for students.

Assessment Incentives

Incentives in terms of assessment scores and points are commonly used to motivate students and may have an influence on the testing effect. However, researchers typically have not treated classroom incentives per se as an experimental variable with regard to the testing effect. Hinze and Rapp (2014) awarded monetary compensation to lab study participants based on performance. Subjects scored relatively lower on high-stakes biology exams than low-stakes biology exams. The current application of incentives in the biology education classroom studies on the testing effect is varied and a clear understanding of the implications with regard to the testing effect is not well- defined in the literature. While researchers intuitively recommend low-stakes quizzing as an important safeguard against student test-anxiety in post-secondary biology, particularly on mid-course formative assessments, little classroom research has addressed this idea experimentally. In one exception, St. Clair et.al. (2020) found no difference between students' performance on exams with high- and low- incentive levels (21% vs 10% of the course points total on exams) in an introductory college-level biology course. Further research on classroom incentives and learning through the testing effect will be important to understand the interaction between more extreme levels of course incentives and the testing effect.

Traditional post-secondary courses frequently assess students in two ways: Formative assessment that communicates learning progress to both a student as well as the instructor

Traditional post-secondary courses frequently assess students in two ways: Formative assessment that communicates learning progress to both a student as well as the instructor, and summative assessment that in generally is performed at the end of a course to measure overall mastery of course material. A course instructor may remove the incentives from a formative assessment and make the experience voluntary. Student self-reported voluntary use of self-testing is correlated with increased student achievement (Hartwig & Dunlosky, 2012). Specifically, in university-level biology, Carpenter et al. (2017) reported that students who opted for quizzes as a review tool in a general-biology course scored higher on the initial examination in the course than those students who selected reading-based review instead. Subsequently, researchers promoted quiz completion using a classroom presentation of the differential outcome on examination performance. Increasingly more students participated in voluntary assessment practice prior to each subsequent examination, producing higher mean scores on the examinations. Others have modeled effective optional learning strategies (Rodriguez et al.,2018) and offered voluntary workshops promoting the testing effect as a learning strategy in large post-secondary biology courses (Stanger-Hall et al., 2011). Both strategies led to improved student learning. Peat and Franklin (2003) found no differences in the learning of students who participated in a voluntary quiz activity and those who did not. Yet, in a follow-up study, Peat et al. (2005) found an increase in mean summative exam score in voluntary second-year student participants compared to first year voluntary student participants.

Assessment Feedback

Informing students of the assessment items they missed and the correct answer to those items is generally referred to as feedback and is an influential factor in the testing effect (Kang et al, 2007). Retrieval practice is effective without feedback, but feedback enhances learning with the testing effect (Pashler et al., 2005; Lavigne & Risko, 2018). Jacoby et al. (2010) found that feedback enabled bird classification with fewer exam experiences. In another study, researchers displayed feedback to subjects following initial fill-in-the-blank items with process-based biology concepts (e.g., stages of mitosis) and found an increase in performance on final fill-in-the blank questions when feedback was given (Pan et al., 2019). The majority of studies on the testing effect and biology learning use feedback as a consistent part of testing, and the empirical evidence from laboratory studies seem to support this practice, yet relatively few studies exist that examine the effects of feedback on the testing effect specifically in the biology classroom. More work in this area is needed to understand the role of feedback on the testing effect in biology education.

How does assessment format and cognitive skill influence the testing effect?

Assessment Format

The initial test format may influence the final test success (Kang et al., 2007). According to Glover (1989), short answer, and fill-in-the-blank item formats both increased the testing effect over multiple-choice and true-or-false formats. However, Little and Bjork (2015) found that multiple-choice items were more effective when they contained strong distractor options and feedback. More specifically, Pagliarulo reported that multiple-choice and short answer assessment formats could be useful on complex biology content (2011). Hinze (2010) assessed post-secondary students on biology content in laboratory experiments and found that cued-recall assessment format (a sentence that includes pertinent content preceding the assessment item) improved performance on memory items while removing the cues from recall items made retrieval practice more difficult and less effective. Presumably, generating information on one's own, if successful, could increase the effectiveness of free-recall assessment items over cued-recall assessment items (Carpenter & DeLosh, 2006), yet there is an inherent balance between increasing effortful processing and overloading a student's ability to successfully do the task (see Pyc & Rawson, 2009). More research needs to be done specifically in post-secondary biology classrooms with regard to item type and the effectiveness of the testing effect to bring about student learning.

Assessment and cognitive skills

Although many instructors seek to develop high-level cognitive thinking in their students, most assessment items are specific to memory retrieval of subject content rather than application, analysis, evaluation, and creativity (Momsen et al., 2010). As such, quiz and exam questions that are related in content subject-material but do not focus on the same specific learning outcome or concept may not show a testing effect (Nguyen & McDaniel, 2015).

biology, it appears that the standard procedure of using quiz questions from the test bank provided by ancillary sources (e.g. textbook companies) may not benefit student performance unless the summative exam questions are closely tied to the targeted learning outcomes created for the course and taught by the instructor (Wooldridge et al., 2014). Instructors should pay specific attention to coordinating intended learning outcomes with assessment items to enable learning through the testing effect.

Researchers argue for the strength of the testing effect with complex material (Karpicke & Aue, 2015; Rawson, 2015; Burns, 2010). Jensen et al. (2014) found routine quizzing requiring application, analysis, and evaluation of biology material could be useful in promoting both conceptual and higher-order skills performance on the final exam in a biology class. Agarwal (2011) reported that a match in initial and final cognitive processing on assessment items (e.g. quizzed and tested on a specific skill) benefits long-term higher-order skills in learning biology. Further research is needed on the testing effect using complex material learning in biology in the post-secondary level classroom including valuable reasoning skills used in scientific discovery and problem solving.

What student characteristics influence the testing effect in biology?

Test Anxiety

Test anxiety is common among undergraduate students. In a survey, Gerwing (2015) found that 38.5% of student respondents reported test anxiety. High test anxiety typically is associated with poorer test performance, test avoidance, loss of motivation, decreased memory retrieval, and impaired attention (Wolf & Smith, 1995; Zeidner, 2005). In the laboratory, Tse and Pu (2012) replicated the testing effect using word pairs while also measuring attention to relevant detail and test anxiety. They found that students who scored lower on attention to relevant detail but higher in test anxiety made more errors on average on the final assessment. England et al. (2017) surveyed learners in undergraduate biology courses that featured active learning pedagogy including in-class clickers. High-test anxiety accompanied lower self-reported GPA and a weaker intention to persist in the biology major.

By contrast, moderate test anxiety may enhance assessment performance (Keeley et al., 2008). A majority of students report decreased test anxiety when they use retrieval practice (Agarwal et al., 2014) and low-stakes in-class quizzing (Khanna, 2015) to prepare for a summative course assessment. A clear picture of the relationship between individual learners' test anxiety, the testing effect, and biology material in a college classroom is weakly defined in the literature, partially due to the variable nature of individual students and their reaction to test experiences. Clearly isolating variables in the ecologically complex classroom is challenging yet needed to further clarify the mechanisms surrounding these commonly experienced pedagogical tools.

Individual Student Differences in Academic Performance

Researchers have begun to study individual student performance differences and the testing effect. While some researchers have demonstrated the benefit of quizzing in biology to students of diverse academic abilities (Orr & Foster, 2013; Pape-Lindstrom et al, 2014), Hubbard and Couch (2018) found that the use of in-class clickers benefited high-performing students more than low-performing students. Carpenter et al. (2016) found that among undergraduate biology learners, all benefited from the use of frequent assessment, but high-performing students benefited more from it than mid- and low-performing students. Bailey et al. (2017) studied increased quiz frequency and categorized students into learning history. They found that mid- and late-learners (those who did not show mastery until the second half of the course) comprised 24% of the class and specifically benefited more from the increased assessment frequency. Butler (2010) found that repeated testing produced improved average success on assessment items with biology inference questions if prior learning of individuals was included in the model. Individual differences in student prior learning and academic ability may impact the outcome of learning biology through the testing effect.

Conclusion

The application of research findings from cognitive psychology to post-secondary classrooms may yield significant benefits in STEM education reform. The evidence supporting the testing effect in particular may enable learning for students in post-secondary biology classrooms. Increased test frequency influences the testing effect in the biology classroom and is the most obvious recommendation for immediate classroom application of the testing effect. Exam feedback has effectively been shown to be an influential moderator of the testing effect in the literature, though no specific study in this search has experimentally applied feedback to a biology classroom.

Course incentives, such as points or stakes also may affect the result of the testing effect in the biology classroom. Current application of incentives in biology education research is varied and there is not a clear understanding of the interaction with the testing effect and points. Cognitive psychology researchers recommend low-stakes quizzing as an important preventive for student test-anxiety in post-secondary biology, though little classroom research has addressed this idea experimentally. Further empirical work on classroom incentives, such as points and learning through the testing effect will be important to understand the interaction.

The influence of individual learner achievement on the testing effect in biology is also a consideration in the success of students in STEM and its application to the postsecondary classroom overall. Students experience test-anxiety, but the influence of anxiety on the testing effect in post-secondary biology is not thoroughly demonstrated. Early work shows that most students can benefit from testing, though it seems that learners embody varied characteristics that may modify learning through the testing effect. Continued experimental application of the testing effect in classroom settings may illuminate mechanistic boundaries to varied learners.

The connection between content, cognitive process and coordinated learning outcomes on the initial and final exam may impact the testing effect. Biology instructors can accentuate exam experiences by ensuring that the required cognitive skills in both formative and summative exam items align with the designated learning outcomes in the course. Practice retrieval, and in many cases, practice processing, on an exam, if successful, could increase the effectiveness of learning through tests, yet there may be an balance between increasing effortful processing and overloading a student's ability to successfully do the task.

Research efforts will continue to illuminate and support reforms in STEM education. The testing effect is a promising principle of learning that has the potential to aid post-secondary biology teaching. Effective instruction needed for deep application and conceptual knowledge in biology education will require further understanding of the mechanistic boundaries of the testing effect as they apply to the biology classroom.

References

Agarwal, P. (2011) Examining the Relationship Between Fact Learning and Higher Order Learning via Retrieval Practice . (Doctoral Dissertation). Retrieved from https://openscholarship.wustl.edu/etd/546

Agarwal, P. K., D'Antonio, L., Roediger, H. L., McDermott, K. B., & McDaniel, M. A. (2014). Classroom-based programs of retrieval practice reduce middle school and high school students' test anxiety. Journal of Applied Research in Memory and Cognition, 3(3), 131–139. doi:10.1016/j.jarmac.2014.07.002

Agarwal, P. K., Karpicke, J. D., Kang, S. H. K., Roediger, H. L., & McDermott, K. B. (2008). Examining the testing effect with open- and closed-book tests. Applied Cognitive Psychology, 22(7), 861–876. doi.org/10.1002/acp.1391

Bailey, E. G., Jensen, J., Nelson, J., Wiberg, H. K., & Bell, J. D. (2017). Weekly Formative Exams and Creative Grading Enhance Student Learning in an Introductory Biology Course. CBE - Life Sciences Education, 16(1), ar2. doi: 10.1187/cbe.16-02-0104

Bangert-Drowns, R. L., Kulik, C.-L. C., Kulik, J. A., & Morgan, M. (1991). The Instructional Effect of Feedback in Test-Like Events. Review of Educational Research, 61(2), 213–238. doi:10.3102/00346543061002213

Black, P., & Wiliam, D. (1998). Assessment and Classroom Learning. Assessment in Education: Principles, Policy & Practice, 5(1), 7–74. doi:10.1080/0969595980050102

Butler, A. C. (2010). Repeated testing produces superior transfer of learning relative to repeated studying. Journal of Experimental Psychology: Learning, Memory, and Cognition, 36(5), 1118–1133. doi:10.1037/a0019902

Butler, A. C., Karpicke, J. D., & Roediger, H. L. I. (2008). Correcting a metacognitive error: Feedback increases retention of low-confidence correct responses. Journal of Experimental Psychology: Learning, Memory, and Cognition, 34(4), 918–928. doi:10.1037/0278-7393.34.4.918

Carpenter, S.K. & Delosh, E.L. (2006). Impoverished cue support enhances subsequent retention: Support for the elaborative retrieval explanation of the testing effect. Memory & Cognition, 34(2), 268-276. https://doi.org/10.3758/BF03193405

Carpenter, S. K., Lund, T. J., Coffman, C. R., Armstrong, P. I., Lamm, M. H., & Reason, R. D. (2016). A classroom study on the relationship between student achievement and retrieval-enhanced learning. Educational Psychology Review, 28(2), 353–375. doi:10.1186/s41235-017-0078-z

Carpenter, S. K., Rahman, S., Lund, T. J. S., Armstrong, P. I., Lamm, M. H., Reason, R. D., & Coffman, C. R. (2017). Students' Use of Optional Online Reviews and Its Relationship to Summative Assessment Outcomes in Introductory Biology. CBE Life Sciences Education, 16(2). doi:10.1187/cbe.16-06-0205

Carrier, M., & Pashler, H. (1992). The influence of retrieval on retention. Memory & Cognition, 20(6), 633–642. doi:10.3758/BF03202713

Daniel, D. B. (2012). Promising principles: Translating the science of learning to educational practice. Journal of Applied Research in Memory and Cognition, 1(4), 251–253. https://doi.org/10.1016/j.jarmac.2012.10.004

England, B. J., Brigati, J. R., & Schussler, E. E. (2017). Student anxiety in introductory biology classrooms: Perceptions about active learning and persistence in the major. PLOS ONE, 12(8), e0182506. doi;10.1371/journal.pone.0182506

Gerwing, T. G., Rash, J. A., Allen Gerwing, A. M., Bramble, B., & Landine, J. (2015). Perceptions and Incidence of Test Anxiety. Canadian Journal for the Scholarship of Teaching and Learning, 6(3) 1–17. doi:10.5206/cjsotl-rcacea.2015.3.3

Glover, J. A. (1989). The "testing" phenomenon: Not gone but nearly forgotten. Journal of Educational Psychology, 81(3), 392–399. doi:10.1037/0022-0663.81.3.392

Haak, D. C., HilleRisLambers, J., Pitre, E., & Freeman, S. (2011). Increased structure and active learning reduce the achievement gap in introductory biology. Science, 332(6034), 1213–1216. doi:10.1126/science.1204820

Hartwig, M. K., & Dunlosky, J. (2012). Study strategies of college students: Are self-testing and scheduling related to achievement? Psychonomic Bulletin & Review, 19(1), 126–134. doi:10.3758/s13423-011-0181-y

Healy, A. F., Jones, M., Lalchandani, L. A., & Tack, L. A. (2017). Timing of quizzes during learning: Effects on motivation and retention. Journal of Experimental Psychology: Applied, 23(2), 128–137. doi:10.1037/xap0000123

Hinze, S. R. (2010). The influence of retrieval practice on memory and comprehension of science texts (Order No. 3431210). Available from ProQuest Dissertations & Theses Global; Social Science Premium Collection. (807672924). Retrieved from https://lib.byu.edu/remoteauth/?url=https://search.proquest.com/docview/807672924?accountid=4488

Hinze, S. R., & Rapp, D. N. (2014). Retrieval (Sometimes) Enhances Learning: Performance Pressure Reduces the Benefits of Retrieval Practice. Applied Cognitive Psychology, 28(4), 597–606. doi:10.1002/acp.3032

Hubbard, J. K., & Couch, B. A. (2018). The positive effect of in-class clicker questions on later exams depends on initial student performance level but not question format. Computers & Education, 120, 1–12. doi:10.1016/j.compedu.2018.01.008

Jacoby, L. L., Wahlheim, C. N., & Coane, J. H. (2010). Test-enhanced learning of natural concepts: Effects on recognition memory, classification, and metacognition. Journal of Experimental Psychology: Learning, Memory, and Cognition, 36(6), 1441–1451. doi:10.1037/a0020636

Jensen, J. L., McDaniel, M. A., Woodard, S. M., & Kummer, T. A. (2014). Teaching to the Test or Testing to Teach: Exams Requiring Higher Order Thinking Skills Encourage Greater Conceptual Understanding. Educational Psychology Review, 26(2), 307–329. doi:10.1007/s10648-013-9248-9

Kang, S. H. K., McDermott, K. B., & Roediger, H. L. (2007). Test format and corrective feedback modify the effect of testing on long-term retention. European Journal of Cognitive Psychology, 19(4–5), 528–558. doi:10.1080/09541440601056620

Karpicke, J. (2012). Retrieval-Based Learning: Active Retrieval Promotes Meaningful Learning. Current Directions in Psychological Science, 21(3), 157-163. Retrieved from http://www.jstor.org/stable/23213127

Karpicke, J. D., & Aue, W. R. (2015). The Testing Effect Is Alive and Well with Complex Materials. Educational Psychology Review, 27(2), 317–326. doi:10.1007/s10648-015-9309-3

Karpicke, J. D., & Roediger, H. L., III. (2008). Repeated Retrieval during Learning Is the Key to Long-Term Retention. Journal of Memory and Language, 57(2), 151–162. doi:10.1016/j.jml.2006.09.004

Keeley, J., Zayac, R., & Correia, C. (2015). Curvilinear Relationships Between Statistics Anxiety and Performance Among Undergraduate Students: Evidence for Optimal Anxiety. Statistics Education Research Journal, 7(1), 1-15.

Khanna, M. M. (2015). Ungraded Pop Quizzes: Test-Enhanced Learning Without All the Anxiety. Teaching of Psychology, 42(2), 174–178. doi:10.1177/0098628315573144

Lavigne, E., & Risko, E. F. (2018). Optimizing the use of interpolated tests: The influence of interpolated test lag. Scholarship of Teaching and Learning in Psychology, 4(4), 211–221. doi:10.1037/stl0000118

Leeming, F. C. (2002). The Exam-A-Day Procedure Improves Performance in Psychology Classes. Teaching of Psychology, 29(3), 210–212. doi:10.1207/S15328023TOP2903_06

Little, J. L., & Bjork, E. L. (2015). Optimizing multiple-choice tests as tools for learning. Memory & Cognition, 43(1), 14–26. doi:10.3758/s13421-014-0452-8

Marsh, E. J., Roediger, H. L., Bjork, R. A., & Bjork, E. L. (2007). The memorial consequences of multiple-choice testing. Psychonomic Bulletin & Review, 14(2), 194–199. doi:10.3758/BF03194051

McDaniel, M. A., & Fisher, R. P. (1991). Tests and test feedback as learning sources. Contemporary Educational Psychology, 16(2), 192–201. doi:10.1016/0361-476X(91)90037-L

Momsen, J. L., Long, T. M., Wyse, S. A., & Ebert-May, D. (2010). Just the Facts? Introductory Undergraduate Biology Courses Focus on Low-Level Cognitive Skills. CBE—Life Sciences Education, 9(4), 435–440. doi:10.1187/cbe.10-01-0001

Nguyen, K., & McDaniel, M. A. (2015). Using Quizzing to Assist Student Learning in the Classroom: The Good, the Bad, and the Ugly. Teaching of Psychology, 42(1), 87–92. doi:10.1177/0098628314562685

Oliver, M., Renken, M., & Williams, J. J. (2018). Revising Biology Misconceptions Using Retrieval Practice and Explanation Prompts.

Orr, R., & Foster, S. (2013). Increasing Student Success Using Online Quizzing in Introductory (Majors) Biology. CBE-Life Sciences Education, 12(3), 509. doi:10.1187/cbe.12-10-0183

Pagliarulo, C. L. (2011). Testing Effect and Complex Comprehension in a Large Introductory Undergraduate Biology Course (Doctoral Dissertation). Retrieved from https://repository.arizona.edu/handle/10150/202773

Pan, S. C., Hutter, S. A., D'Andrea, D., Unwalla, D., & Rickard, T. C. (2019). In search of transfer following cued recall practice: The case of process-based biology concepts. Applied Cognitive Psychology, 1-17. doi:10.1002/acp.3506

Pape-Lindstrom, P., Eddy, S., & Freeman, S. (2018). Reading Quizzes Improve Exam Scores for Community College Students. CBE Life Sciences Education, 17(2). doi:10.1187/cbe.17-08-0160

Pashler, H., Bain, P., Bottge, B., Graesser, A., Koedinger, K., McDaniel, M., and Metcalfe, J. (2007) Organizing Instruction and Study to Improve Student Learning (NCER 2007-2004). Washington, DC: National Center for Education Research, Institute of Education Sciences, U.S. Department of Education. Retrieved from http://ncer.ed.gov.

Pashler, H., Cepeda, N. J, Wixted, J. T, & Rohrer, D. (2005). When does feedback facilitate learning of words? Journal of Experimental Psychology-Learning Memory and Cognition, 31(1), 3-8. Retrieved from https://escholarship.org/uc/item/7fg8h6zq

Pyc, M. A., & Rawson, K. A. (2009). Testing the retrieval effort hypothesis: Does greater difficulty correctly recalling information lead to higher levels of memory? Journal of Memory and Language, 60(4), 437–447. doi.org/10.1016/j.jml.2009.01.004

Rawson, K. A. (2015). The Status of the Testing Effect for Complex Materials: Still a Winner. Educational Psychology Review, 27(2), 327–331. doi:10.1007/s10648-015-9308-4

Roediger, H. L., & Karpicke, J. D. (2006). Test-Enhanced Learning: Taking Memory Tests Improves Long-Term Retention. Psychological Science, 17(3), 249–255. doi:10.1111/j.1467-9280.2006.01693.x

Roediger, H., & Butler, A. C. (2011). The critical role of retrieval practice in long-term retention. Trends in Cognitive Sciences, 15(1), 20–27. doi:10.1016/j.tics.2010.09.003

Rowland, C. A. (2014). The effect of testing versus restudy on retention: A meta-analytic review of the testing effect. Psychological Bulletin, 140(6), 1432-1463. doi:10.1037/a0037559

Schwieren, J., Barenberg, J., & Dutke, S. (2017). The Testing Effect in the Psychology Classroom: A Meta-Analytic Perspective. Psychology Learning & Teaching, 16(2), 179–196. doi:10.1177/1475725717695149

Stanger-Hall, K. F., Shockley, F. W., & Wilson, R. E. (2011). Teaching Students How to Study: A Workshop on Information Processing and Self-Testing Helps Students Learn. CBE-Life Sciences Education, 10(2), 187–198. doi.org/10.1187/cbe.10-11-0142

St.Clair, B.E., Putnam, P., Miller, H.L., Larsen, R., & Jensen, J.L. (in-press) Test-enhanced learning and assessment incentives: a study in a post-secondary biology course. CBE-LSE

Tse, C.-S., & Pu, X. (2012). The effectiveness of test-enhanced learning depends on trait test anxiety and working-memory capacity. Journal of Experimental Psychology: Applied, 18(3), 253–264. doi:10.1037/a0029190

Wooldridge, C. L., Bugg, J. M., McDaniel, M. A., & Liu, Y. (2014). The testing effect with authentic educational materials: A cautionary note. Journal of Applied Research in Memory and Cognition, 3(3), 214–221. doi:10.1016/j.jarmac.2014.07.001

Wise, S. L., & DeMars, C. E. (2005). Low Examinee Effort in Low-Stakes Assessment: Problems and Potential Solutions. Educational Assessment, 10(1), 1–17. doi:10.1207/s15326977ea1001_1

Wolf, L. F., & Smith, J. K. (1995). The Consequence of Consequence: Motivation, Anxiety, and Test Performance. Applied Measurement in Education, 8(3), 227. doi:10.1207/s15324818ame0803_3

Zeidner, M. (1998). Test Anxiety: The State of the Art. Springer Science & Business Media.

Using algal microcosms in introductory biology lab.
I: The influence of nutrient levels on the biodiversity of an ecological community

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Abstract

The protection of earth's biodiversity requires a sophisticated understanding of how human activities can affect the relative abundances of species in natural ecological communities. Here, we report on an introductory biology laboratory activity in which students quantified biodiversity while investigating one of the most important controls on the biodiversity of an ecosystem: nutrient availability. Students established microcosms of six species of phytoplankton ("algae") in 50-mL beakers and exposed them to five different levels of inorganic nutrients. After two weeks, students used hemocytometers to count cells and compare the relative abundances of the algal species (i.e., their community composition) at different nutrient levels. The effect of nutrient level on biodiversity (measured by Simpson's reciprocal index) was significantly curvilinear, and best described as "U-shaped." Specifically, the algal community was most diverse at the lowest nutrient level, least diverse with a small amount of added nutrients, and intermediate in diversity at the highest nutrient levels. This convenient, quantitative investigation provided students an opportunity to consider how anthropogenic influxes of nutrients into ecosystems can lead to eutrophication, and how this phenomenon can have negative effects by decreasing the biodiversity of ecological communities.

Keywords: biodiversity, eutrophication, microcosm, nutrient availability, phytoplankton, species richness, structured inquiry

Introduction

The central goals of conservation biology include identifying threats to biodiversity and evaluating methods for protecting biodiversity within ecosystems (Perrings et al., 2011; Pereira et al., 2012). In order to accomplish these goals, biologists need to be able to quantify biodiversity in a consistent and easily communicated fashion (Jacobs et al., 2014). The biodiversity of a biological community encompasses two main components: 1) the number of different taxa (e.g., species or genera) and 2) the relative abundances of the different taxa. These components are respectively called "richness" and "evenness." Statisticians have devised numerous methods to take into account both richness and evenness in a single index of biodiversity. Among the most common is the Simpson's reciprocal index, which was employed in the laboratory activity described in this paper.

One of the fundamental drivers of biodiversity in an ecosystem is the level of resources, such as inorganic nutrients, available to organisms (Huston, 1980; Wilson & Tilman, 1991; Stevens & Carson, 2002; Worm et al., 2002; Passy, 2008; Cardinale et al., 2009a; Cardinale et al., 2009b). A relatively nutrient-rich environment is likely to support more individuals, and is thus likely be more productive, than a nutrient-poor environment. In turn, it is natural to expect a positive relationship between nutrient levels and biodiversity in an ecosystem (Srivastava & Lawton, 1998; Dodson et al., 2000). However, the reverse can also be true. For instance, consider what happens when large quantities of nitrogen or phosphorus are released into lakes or estuaries. Populations of a few species of algae may take advantage of the nutrient abundance and irrupt in a phenomenon called eutrophication (Smith & Schindler, 2009; Chislock et al., 2013; Ansari & Gill, 2014). The total number of organisms in the ecosystem may increase, but only for a few species, and at the expense of individuals of other species. Thus, the biodiversity of a community can shrink with increased levels of nutrients. The expected shape of the relationship between resources and biodiversity is still an active area of research, with numerous examples of positive, negative, and hump-shaped relationships in different ecosystems (Guo & Berry, 1998; Waide et al., 1999; Dodson et al., 2000; Mittelbach et al., 2001; Fraser et al., 2015; Grace et al., 2016; Wang, 2017).

In this paper, we report on an experiment that we have used successfully at an introductory biology level on the biodiversity of a community of phytoplankton (i.e., “algae”). After an introduction to the relevant concepts related to ecosystem productivity, biodiversity, and the algae, students were asked to brainstorm research questions, hypotheses, and potential experimental methods in their lab groups (3-4 students). Then through a whole-class discussion, the instructors guided students to an agreed-upon set of questions and experimental protocols to address the questions. Specifically, students constructed microcosms of six species of algae at five different nutrient levels in 50-mL glass beakers, and they sampled the community using hemocytometers after two weeks of growth. Students addressed three main questions with their data: 1) How did the community composition (i.e., relative abundances of the six species) vary across environmental conditions? 2) Did nutrient level affect biodiversity (as quantified by richness, evenness, and the Simpson’s reciprocal index)? and 3) What is the shape of the relationship between nutrient levels and biodiversity?

The intended learning outcomes for this project were that students should be able to do the following: 1) use a diversity index to quantify the biodiversity of an ecological community; 2) communicate the rationale for why nutrient levels might have a range of effects on the biodiversity of an ecosystem; 3) employ aspects of the scientific method in a structured-inquiry experiment to address an important ecological question; 4) perform statistical analyses and construct professional-quality graphs using Excel; and 5) interpret and communicate the results and their broader implications. Their achievement of these learning outcomes was assessed through the presentation of a research poster to communicate their findings.

Materials and Methods

Course overview

The microcosm experiments described here (and in a companion paper: Wise & Collins, this issue) are the principal laboratory activities of the introductory biology course BIOL 180 (Exploring Biological Diversity) at Roanoke College, a selective liberal arts institution of ~2,000 students in Salem, VA, USA. BIOL 180 is one of a sequence of three introductory courses for Biology majors, but it is also taken by some non-majors for whom this is their only biology course. Versions of these microcosm experiments have been used in 16 sections of BIOL 180 since 2015. This course meets for three two-hour periods per week, and the class is capped at 24 students. The design and data reported in this paper are from a version of the experiment used in the fall semester of 2018 in a section with 14 students.

Phytoplankton Species

Six freshwater phytoplankton species across six different genera were chosen for inclusion in the microcosm experiment (Table 1) and were obtained from a commercial supplier (Carolina Biological Supply Company, Burlington, NC, USA). This set of species included four green algae, two of which are charophytes of the family Desmidaceae, and two of which are chlorophytes of two different families. The set also included one euglenozoan and one cyanobacterium. Each species was maintained in stock culture containing an equal mix of tap water and deionized water, to which one 20-mL tube of AlgaGro® Concentrated Medium (Carolina Biological Supply Company, Burlington, NC, USA) was added per 980 mL of water.

Setting up the Microcosms

Five different nutrient-level treatments were initiated by adding the following numbers of 20-mL tubes of AlgaGro® Concentrated Medium per liter of

Table 1.

Taxonomic information for the phytoplankton species included in this study

Genus	Superkindom[1]	Phylum/Division	Family
Ankistrodesmus	Archaeplastida	Chlorophyta	Selenastraceae
Cosmarium	Archaeplastida	Charophyta	Desmidaceae
Euglena	Excavata	Euglenozoa	Euglenaceae
Gloeocapsa	Bacteria	Cyanobacteria	Chroococcaceae
Scenedesmus	Archaeplastida	Chlorophyta	Scenedesmaceae
Staurastrum	Archaeplastida	Charophyta	Desmidaceae

[1] Eukaryotic superkingdoms are as designated in Morris et al. (2016). Bacteria are at the taxonomic level of kingdom and/or domain.

aqueous medium: 3, 2.25, 1.5, 0.75, or 0 tubes.

As with the stock cultures, these growth media contained equal parts tap water and distilled water. Each microcosm consisted of a 50-mL glass beaker containing 30 mL of growth medium plus 1 mL of stock cultures of each of the six algal species. Students transferred the samples from the stock cultures using 1-mL pipettes. To prevent contamination of samples, a separate pipette was used for each stock solution. Each pipette was conspicuously labeled by genus name, and students were instructed to double-check that the name on a pipette matched the name on the stock-culture beaker before making a transfer to their microcosms.

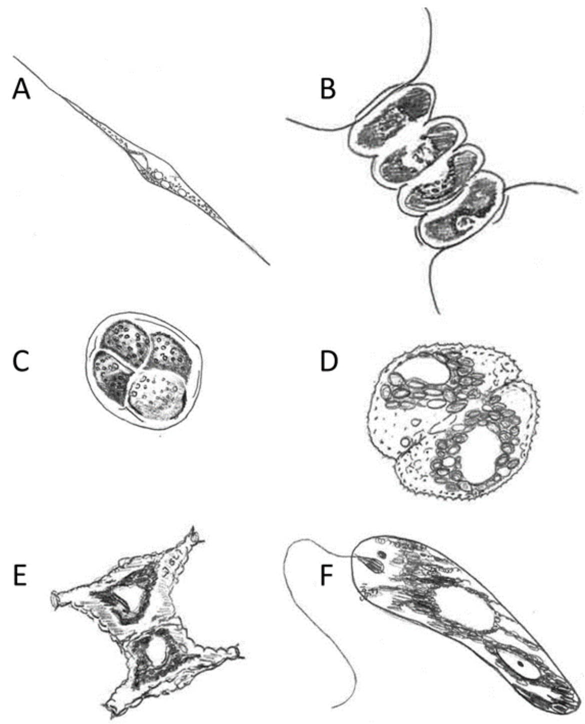
The class was split into five groups of students, and each group prepared two replicates of microcosms at each nutrient level (for a total of 10 microcosms per student group). Students covered each beaker with cellophane wrap to prevent evaporation, secured the wrap with a rubber band, and punched three small ventilation holes in the wrap using dissecting needles. The beakers were placed on a tray on a rack of shelves under constant fluorescent light for 14 days. The light was provided by four wide-spectrum tubes (F40 PL/AQ-ECO bulbs, General Electric), mounted ~40 cm above the shelf. The beakers were gently shaken daily to prevent permanent settling.

Identifying and Counting the Phytoplankton

Our main experimental goal was to quantify the relative abundances of the six species in each microcosm. (A secondary goal was to quantify the effect of nutrient level on the densities of individuals.) To practice identifications, students made wet mounts and sketches of each species from the stock cultures. The six species we used are relatively easy to tell apart, but the colonial nature of some of the species presented a small challenge for counting (Fig. 1). For instance, when individuals of *Gloeocapsa* divide, they temporarily remain clustered within a gelatinous sheath. Most often, we found *Gloeocapsa* in groups of four, but the groups can be much larger. Similarly, individuals of *Scenedesmus* are often found in chains of four (or more) individuals. For consistency, students should count individual cells that make up the colonies. Single individuals of two other species (*Cosmina* and *Staurastrum*) are composed of two symmetrical "semicells." These two desmids pose the most difficulty for students to distinguish, but a cell of *Cosmina* appears as a pair of semicircles, while the semicells of *Staurastrum* are more angular, and depending on its orientation, an individual may look like a triangle or star, or—more whimsically—a butterfly or a pair of samosas. For consistency, students should count a pair of semicells as a single individual.

Figure 1

Key for identifying and counting the six phytoplankton genera in the microcosm experiment



A) single individual of *Ankistrodesmus*. B) single colony of four individuals of *Scenedesmus*. C) four individuals of *Gloeocapsa*, together in a gelatinous sheath. D) single individual *Cosmina*, composed of two semicells. E) single individual of *Staurastrum*, composed of two semicells F) individual of *Euglena*, the only organisms likely to be moving in the sample. Illustration by Frances E. Bosch.

To count cells, we employed disposable plastic hemocytometers (C-Chip DHC-N01, INCYTO, Korea). Each hemocytometer slide has two wells for samples, and the center of each well contains a nested set of grids to allow for flexibility in counting schemes. Because of the complexity of the grids in hemocytometers, we have found it useful to project an image of the hemocytometer grids to the class to go over guidelines for counting as a group before turning students loose to collect data.

In other versions of this microcosm experiment, we have restricted the counting to the 1-by-1 mm central grid. This consistency in area counted would have allowed not only for differences in relative abundances of species within microcosms (our primary goal), but also for differences in densities of individuals among microcosms with different nutrient levels (a secondary goal). However, there were extreme differences in absolute densities among microcosms, such that the central grid covered only a few cells in lowest-nutrient treatment, while each row of the central grid tended to be packed with hundreds of cells in the highest-nutrient treatment. To save time, for the low-nutrient samples, students were allowed to count cells that appeared anywhere in the well, rather than just within the central grid. For the higher-nutrient samples, students were allowed to limit their counts to just two rows of the central grid. The target was to end up with at least 100 individuals per nutrient treatment in order to obtain reliable estimates of diversity. Because the total volumes of the samples differed among microcosms, we had to abandon our secondary goal of quantitatively comparing densities within species across nutrient treatments. However, the differences in abundance among nutrient levels were qualitatively obvious, both from the dispersion of cells in the hemocytometers, and from the obvious variation in the greenness of the microcosms. Thus, it was qualitatively obvious that overall productivity of the microcosms increased with increasing nutrient levels.

Reaching the target of 100 sampled cells per microcosm for the lower-nutrient treatments generally required more samples than the two wells of each slide permitted. Between samples, students cleaned and dried the wells of the hemocytometers using a plastic squeeze bottle of water and a can of compressed air. Not all student groups were able to count 100 individuals in the lowest-nutrient treatment during the two-hour class period, and only two of the five student groups were able to make counts for both replicates of each nutrient treatment. However, each group obtained counts of at least one replicate per treatment by the end of the class period. Students analyzed only the data collected by their group, but the instructors analyzed all of the class data together, and the analyses reported in this paper are from all five groups combined.

Data Display and Analysis

Students focused on three response variables: species richness, biodiversity, and evenness. The species richness (S) of a microcosm is the number of different species found in the samples of the microcosm. For quantifying biodiversity, we used the Simpson's reciprocal index (1/D). An attractive feature of this index is that it does not involve logarithms, which tend to be non-intuitive to students. The Simpson's reciprocal index is calculated from the relative abundances (p_i) of all the species using the following formula:

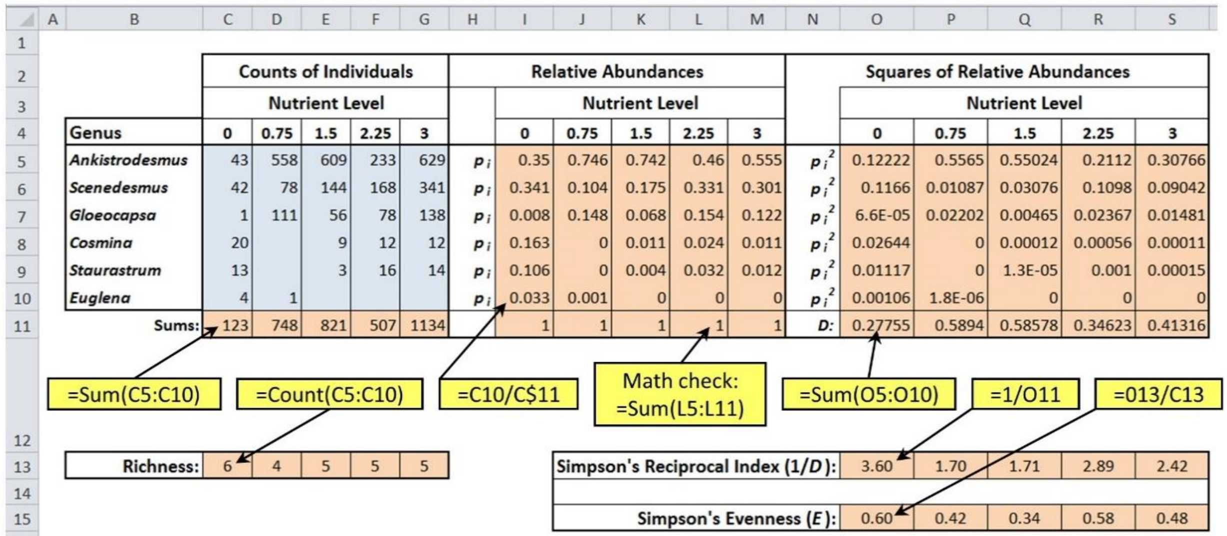
$$1/D = 1 \div \sum_{i=1}^{S} (p_i^2)$$

where Σ indicates the sum across all species, and i = 1 through S. The larger the value of 1/D, the greater the diversity of the community, with a maximum value of S occurring if p_i is equal for all species. Evenness has to do with the equitability of the abundances among species. Evenness can be seen as a component of diversity that remains after factoring out species richness. To quantify the Simpson's evenness (E) of a community, one simply divides the Simpson's reciprocal index by S. If p_i is equal for all species, the evenness is maximal, and E = 1. (Figure 2 displays an annotated snapshot of an Excel spreadsheet with data from one of the student groups and formulas for the calculation of relative abundance, richness, evenness, and Simpson's reciprocal index.)

Students generated graphs using Excel to display how the biodiversity index, richness, and evenness varied across the five nutrient treatments. They used simple linear regressions to assess whether nutrient level affected diversity index, richness, or evenness in a linear fashion. To assess whether there was a significant curvilinear relationship (i.e., either hump-shaped or U-shaped), students were instructed to perform a multiple regression that included both a linear and a squared term as independent variables (i.e., nutrient level and the square of the nutrient level). A significant positive coefficient for the squared term would indicate a concave upward (U-shaped) relationship, while a significant negative coefficient would indicate a concave downward (hump-shaped) relationship. (To create a quadratic regression line in an Excel scatterplot, check the "Polynomial" Trendline Option in the Format Trendline menu, and choose Order "2.") Students also made graphs ("charts") using Excel to compare the community compositions of the algae among the different nutrient treatments. Some students made pie charts, while most used bar ("column") charts. Some students made five separate bar charts, while others were able to display results for all five nutrient treatments on one bar chart. The diversity of displays

Figure 2

Sample spreadsheet used for calculating diversity-related metrics in the microcosm experiment



Genus	Counts of Individuals, Nutrient Level 0	0.75	1.5	2.25	3		Relative Abundances, Nutrient Level 0	0.75	1.5	2.25	3		Squares of Relative Abundances, Nutrient Level 0	0.75	1.5	2.25	3
Ankistrodesmus	43	558	609	233	629	p_i	0.35	0.746	0.742	0.46	0.555	p_i^2	0.12222	0.5565	0.55024	0.2112	0.30766
Scenedesmus	42	78	144	168	341	p_i	0.341	0.104	0.175	0.331	0.301	p_i^2	0.1166	0.01087	0.03076	0.1098	0.09042
Gloeocapsa	1	111	56	78	138	p_i	0.008	0.148	0.068	0.154	0.122	p_i^2	6.6E-05	0.02202	0.00465	0.02367	0.01481
Cosmina	20		9	12	12	p_i	0.163	0	0.011	0.024	0.011	p_i^2	0.02644	0	0.00012	0.00056	0.00011
Staurastrum	13		3	16	14	p_i	0.106	0	0.004	0.032	0.012	p_i^2	0.01117	0	1.3E-05	0.001	0.00015
Euglena	4	1				p_i	0.033	0.001	0	0	0	p_i^2	0.00106	1.8E-06	0	0	0
Sums:	123	748	821	507	1134		1	1	1	1	1	D:	0.27755	0.5894	0.58578	0.34623	0.41316
Richness:	6	4	5	5	5												
Simpson's Reciprocal Index (1/*D*):													3.60	1.70	1.71	2.89	2.42
Simpson's Evenness (*E*):													0.60	0.42	0.34	0.58	0.48

The individual count data are entered into the blue-shaded cells, and the values shown in pink-shaded cells are calculated from formulas once the count data are entered. The yellow callouts indicate formulas typed into the orange cells. (Analogous formulas are found in adjacent cells.) Note that if the "Math check" cells do not equal 1, then there were errors in data or the formulas typed into the cells. This table shows data collected by one of the five student groups participating in the experiment.

enabled class-wide discussion of the relative merits of different types of graphs during the poster session that served as the main assessment metric for this project.

Students used only the data collected by their group for their analyses, rather than the combined class data. In addition to simplicity, this strategy had the benefit of motivating each group to collect a complete, high-quality set of data. In addition, having different sets of data for each poster made the presentation session more interesting and interactive. For the results presented in this paper, we combined the data for all five student groups. In the analyses of the effect of nutrient level, we include a "block" term to represent the variation that can be attributed to differences in algal communities (or student observational skills) among the student groups. These analyses are thus not strictly regressions, as they include student group as categorical variable, which was treated as a random-effects factor. The analyses reported here were performed using JMP-in 4.0.4 (SAS Institute, Cary, NC, USA). The effect of student group was not always significant, but leaving this blocking factor in each of the models serves to illustrate how much the data differed among student groups. A finding of little or no differences among student groups would serve as evidence of the robustness of the results.

Results

The regression models indicated that the level of nutrients did not have a simple linear effect on any of the three diversity-related metrics (Table 2: $P > 0.05$ for the nutrient factor). However, the quadratic models indicated that the relationship between nutrient level and Simpson's reciprocal index was significantly curvilinear (Table 2A: $P = 0.02$ for the nutrient^2 factor). The greatest biodiversity occurred at the lowest nutrient level (Fig. 3A). As nutrient level increased, there was first a sharp decrease in biodiversity, then a gradual increase, resulting in a U-shaped pattern. This U- shaped pattern was also largely reflected in the values for species richness (Fig. 3B) and evenness (Fig. 3C), but the quadratic coefficients were not statistically significant for either of these metrics (Table 2B and 2C). The mean richness did not vary much (4.0-5.0) across nutrient treatments. The mean evenness was more variable (0.42-0.66), and evenness appeared to drive the U-shaped pattern in the Simpson's reciprocal index more strongly than did species richness.

Table 2

Summary of results of statistical models testing for linear and quadratic effects of nutrient level on: A) biodiversity index, B) species richness, and C) evenness. A significant nutrients² factor (i.e., the square of nutrient level) indicates curvature in the relationship. Student group was treated as a random-effects factor.

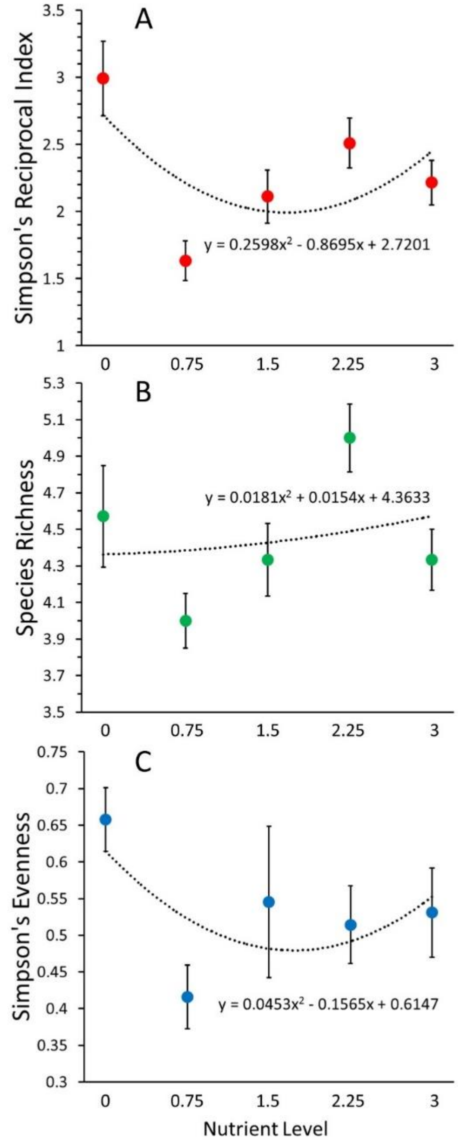
Source of variation	df	Mean square	F-ratio	P-value
A. Simpson's Reciprocal Index (Linear Model)				
Student group	4	0.36970	0.7767	0.55
Nutrients	1	0.28698	0.6029	0.44
Error	26	0.47602		
Simpson's Reciprocal Index (Quadratic Model)				
Student group	4	0.36001	0.8848	0.49
Nutrients	1	2.48329	6.1032	0.02
$Nutrients^2$	1	2.20429	5.4174	0.03
Error	25	0.40689		
B. Species Richness (Linear Model)				
Student group	4	2.29946	4.1210	0.01
Nutrients	1	0.39238	0.7032	0.41
Error	26	0.55799		
Species Richness (Quadratic Model)				
Student group	4	2.29529	3.9598	0.01
Nutrients	1	0.00321	0.0055	0.94
$Nutrients^2$	1	0.01627	0.0281	0.87
Error	25	0.57965		
C. Simpson's Evenness (Linear Model)				
Student group	4	0.06691	2.9260	0.04
Nutrients	1	0.02250	0.9840	0.33
Error	26	0.02287		
Simpson's Evenness (Quadratic Model)				
Student group	4	0.06754	3.2225	0.03
Nutrients	1	0.08842	4.2186	0.05
$Nutrients^2$	1	0.07053	3.3651	0.08
Error	25	0.02092		

The effect of student group was statistically significant for richness and evenness, but not for the Simpson's reciprocal index. Even when they were statistically significant, differences in values among student groups accounted for a relatively small percentage of the total variation (e.g., 32% and 26% for richness and evenness, respectively, in the quadratic models). Importantly, none of the inferences would have been different had the student-group factors been omitted from the models.

The community composition of the microcosms varied substantially across nutrient levels (Fig. 4). Students tended to be more comfortable first interpreting the values in the arithmetic scale (Fig. 4A). However, the fact that one can see the values for the less-abundant species much better on the logarithmic axis provides a good opportunity to persuade students of the value of using logarithms for some types of data (Fig. 4B).

Figure 3.

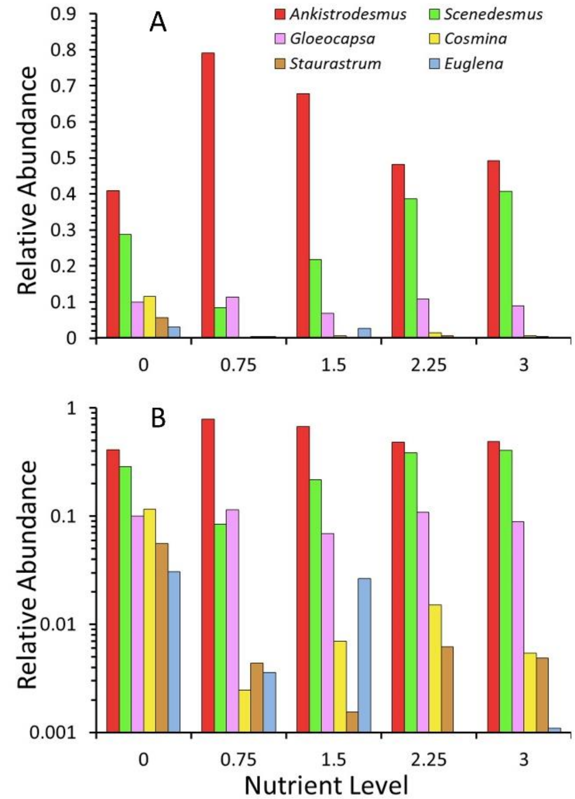
Relationship between nutrient level and biodiversity in the microcosm experiment



Points and bars represent means + SE for five student groups: n=7 microcosms each for nutrient levels 0 and 0.75, and n=6 for nutrient levels 1.5, 2.25, and 3 tubes of AlgaGro per liter of aqueous medium. The dotted lines and equations represent the results of quadratic regressions of: A) Simpson's reciprocal index, B) species richness, and C) Simpson's evenness on nutrient level.

Figure 4.

Algal community structure at five nutrient levels in the microcosm experiment



Nutrient levels indicate number of tubes of AlgaGro per liter of aqueous medium. From left to right, the bars represent the relative abundances of *Ankistrodesmus, Scenedesmus, Gloeocapsa, Cosmina, Straurastrum,* and *Euglena* in: A) arithmetic, and B) logarithmic scales.

The two chlorophyte species (*Ankistrodesmus* and *Scenedesmus*) dominated the communities at all nutrient levels; however, they were at their least dominant in the lowest-nutrient treatment (Fig. 4). The non-chlorophyte species constituted 30% of the individuals in the lowest-nutrient treatment, but only 10-13% in the other four treatments. As a result, a much more even (and thus diverse) distribution of relative abundances can be seen in the lowest-nutrient treatment. *Gloeocapsa* remained steady at approximately 10% across all nutrient levels. The other three species (*Cosmina*, *Staurastrum*, and *Euglena*) were always less common, but they all attained their highest relative abundances in the microcosm with the lowest nutrient level.

Discussion

The availability of nutrients had a substantial, but not particularly straightforward, effect on the diversity of the phytoplankton communities in this microcosm experiment. It was qualitatively obvious that increasing the nutrient level greatly increased the growth and reproduction of the algae. Therefore, higher nutrients led to greater productivity over the short term for the community as a whole. However, the effect of nutrient levels was not the same on all species: Some species benefited at the expense of others. The overall result was that diversity was greatest at the lowest nutrient level, least at intermediate nutrient levels, and intermediate at the highest nutrient level. That is, the nutrient-biodiversity relationship was significantly nonlinear, and the concave-upward curve made the relationship approximately U-shaped.

Previous studies across a diversity of ecosystems have found a variety of relationships between nutrient level and diversity. Some studies have found a linear increase in diversity with increasing nutrients, others have found a linear decrease, and many have found a hump-shaped relationship, such that diversity is maximized at intermediate levels (Wilson & Tilman, 1991; Guo & Berry, 1998; Mittelbach et al., 2001; Cardinale et al., 2009a; Fraser et al., 2015; Groendahl & Fink, 2017). Our results were a bit unusual in having the lowest diversity at the intermediate levels of nutrients (cf., Huston, 1980; Waide et al., 1999; Mittelbach et al., 2001; Wang, 2017). Nevertheless, this pattern was consistent among the five student groups, and we have obtained similar results in other years with similar experiments. The fact that this U-shaped pattern was not anticipated by the students made the experiment and the poster presentation all the more interesting.

Examination of the details of the community composition provides insight into how increases in nutrient levels led the patterns of biodiversity of the communities in this experiment. At the lowest nutrient level (without an addition of AlgaGro), it is likely that the population growth of all six species was kept in check by limiting resources. No one species was able to grow to the extent that it completely dominated the others. *Ankistrodesmus* seemed to be the most sensitive to additional nutrients. In particular, with the addition of just 0.75 tubes of AlgaGro per liter, *Ankistrodesmus* took over, making up 79% of the entire phytoplankton community. This dominance by one species in the intermediate-nutrient environments led to overall low evenness and low biodiversity. With higher and higher levels of nutrients, *Scenedesmus* became a stronger and stronger competitor, nearly drawing even with *Ankistrodesmus* at the highest nutrient level. This led to greater evenness in the highest nutrient level, but not as great as in the lowest level. It seems that competition between these two chlorophytes largely drove the pattern of diversity across the range of nutrient levels.

It is important to point out that the vast majority of the studies available in the literature analyzed the effects of nutrient levels on species richness (i.e., strictly the number of different species), rather than a diversity index that also considered evenness (but see: Wilson & Tilman, 1991; Laird et al., 2003; Groendahl & Fink, 2017). Because our microcosm experiment was designed to be performed in a class setting, it was constrained to be smaller and shorter than most published studies on the topic. Specifically, because we had a pool of only six species growing over a period of two weeks, it is not surprising that we did not see a statistically significant effect on species richness. Nevertheless, the pattern that we found for species richness was consistent with our diversity-index pattern. Moreover, the fact that we used small communities in well-controlled environments enabled us to incorporate measures of community evenness, as well as to calculate a more comprehensive biodiversity index. Therefore, our results are probably more sensitive (and powerful) in terms of examining the subtle effects that nutrient levels can have on the diversity of biological communities.

A microcosm experiment such as this one cannot fully address the scale and complexity of what happens to natural aquatic communities when fertilizers and wastewater flow into lakes and estuaries (Smith & Schindler, 2009). However, this experiment did provide insight into one of the more subtle negative effects of eutrophication. The increase in nutrients in our experiment spurred an increase in overall productivity, which by itself might seem like a positive outcome. However, nutrient addition created winners and losers, with the overall effect of decreasing the diversity of the community. Such a depleted community is likely to be less able to provide vital ecosystem services to other organisms, including to humans (Loreau et al., 2001; Balvanera et al., 2006; Duffy, 2009; Perrings et al., 2011; Hooper et al., 2012; Pereira et al., 2012; Chislock et al., 2013; Ansari & Gill, 2014; Jacobs et al., 2014).

The overall results may vary from experiment to experiment, and all student groups may not obtain the same outcome. While such variation can lead to frustration in canned experiments, there is no outcome to this experiment that is uninteresting or inexplicable. Such variation in outcomes can be an important lesson in and of itself. Allowing students to interpret and present their own group's results, then showing and discussing the combined results collated by the instructor, also teaches the lesson of the importance of replication in supporting scientific conclusions. As long as instructors take steps to ensure students set up the experiment correctly and collect data assiduously, this experiment should provide interpretable and satisfying results.

One source of variation that is not completely under control of the instructor is the speed at which students are able to count their algae using hemocytometers. Allowing time to practice using the microscopes and identifying the algae species prior to the experiment helps. Checking each group's interpretation of the hemocytometer grid during the counting is also important for consistency. Even with incorporating these measures, variation in students' acumen and enthusiasm tend to cause large differences in how quickly they collect their cell-count data. In the version of the experiment described in this paper, each group was instructed to collect two replicates of data at each nutrient level during the lab period. However, analyses of the data could still be performed with a single replicate, so it was fine if a group did not complete both replicates. In other iterations of this experiment, very slow-counting groups were required to come in after lab to finish their counting.

A second potential complication is that some species of algae replicate much faster than others. Therefore, it is important for the instructors to sample their stock cultures prior to the students' setting up their experiments to make sure each species is at a reasonable density. In particular, we have often found it useful to dilute the *Ankistrodesmus* stock cultures (and sometimes *Scenedesmus* as well) because they tend to reproduce much more quickly than the other species in the environmental conditions of our microcosms.

Conclusion

The experiment described in this paper provided students a hands-on opportunity to use original, authentic data to address an interesting experimental question using structured inquiry and the scientific method. Students hypothesized potential outcomes to the question of how nutrient addition might influence the biodiversity of an ecosystem. They performed an experiment to test their hypotheses, used their data to calculate biodiversity indices, and analyzed these data statistically to make inferences about the effect of nutrients on biodiversity. Because the answers to the experimental questions were not obvious prior to performing the study, students felt a greater sense of ownership of their investigations, which made the presentations of their results to the class especially engaging.

One of the greatest pedagogical assets of the phytoplankton microcosm employed in this study is its flexibility. For instance, we have had our classes look at the complementary question of how the biodiversity of algal communities affects the productivity of the ecosystems in microcosm experiments (Wise and Collins, this issue). We have added to the complexity of the system in BIOL 180 and in upper-level ecology courses by including such factors as competition, herbivory, disturbance, assembly order, and invasibility. This study system has also been employed by students for independent research projects in the senior seminar course for biology majors.

Acknowledgments

We thank the students of Roanoke College who participated in collecting data, the RC Biology Department for logistical support, two anonymous reviewers for constructive comments on the manuscript, S.E. Wise for carefully editing the manuscript, and F. E. Bosch for the illustrations in Figure 1.

References

Ansari, A.A., & Gill, S.S. (2014). Eutrophication: Causes, Consequences and Control. Springer, Dordrecht. 260p.

Balvanera, P., Pfisterer, A.B., Buchmann, N, He, J.S., Nakashizuka, T., et al.(2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters, 9, 1146-1156.

Cardinale, B.J., Bennett, D.M., Nelson, C.E., & Gross, K. (2009a). Does productivity drive diversity or vice versa? A test of the multivariate productivity-diversity hypothesis in streams. Ecology, 90(5), 1227-1241.

Cardinale, B.J., Hillebrand, H., Harpole, W.S., Gross, K, & Ptacnik, R. (2009b). Separating the influence of resource 'availability' from resource 'imbalance' on productivity-diversity relationships. Ecology Letters, 12, 475-487.

Chislock, M.F., Doster,E., Zitomer, R.A., & Wilson, A.E. (2013). Eutrophication: causes, consequences, and controls in aquatic ecosystems. Nature Education Knowledge, 4(4), 10.

Dodson, S.I., Arnott, S.E., & K.L. Cottingham, K.L. (2000). The relationship in lake communities between primary productivity and species richness. Ecology, 81(10), 2662-2679.

Duffy, J.E. (2009). Why biodiversity is important to the functioning of real-world ecosystems. Frontiers in Ecology and the Environment, 7(8), 437-444.

Fraser, L.H., Pither, J., Jentsch, A., Sternberg, Zobel, M., et al. (2015). Worldwide evidence of a unimodal relationship between productivity and plant species richness. Science, 349(6245), 302-305.

Grace, J.B., Anderson, T.M., Seabloom, E.W., Borer, E.t., Adler, P.B., et al. (2016). Integrative modelling reveals mechanisms linking productivity and plant species richness. Nature, 529, 390-393.

Groendahl, S., & Fink, P. (2017). Consumer species richness and nutrients interact in determining producer diversity. Scientific Reports, 7, 44869.

Guo, Q., & Berry, W.L. (1998). Species richness and biomass: dissection of the hump-shaped relationships. Ecology, 79(7), 2555-2559.

Hooper, D.U., Adair, E.C., Cardinale, B.J., Byrnes, J.E.K., Hungate, B.A., et al. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature, 486, 105-109.

Huston, M. (1980). Soil nutrients and tree species richness in Costa Rica. Journal of Biogeography, 7, 147-157.

Jacobs, S., Haest, B., De Bie, T., Deliège, G., Schneiders, A., et al. (2014). Biodiversity and ecosystem services. In: Keune, H., Dendoncker, N., & Jacobs, S. Ecosystem Services: Global Issues, Local Practices. Elsevier, p. 29-40.

Laird, R.A., J. Pither, J., & L.W. Aarssen. (2003). Species evenness, not richness, has a consistent relationship with productivuty in old-field vegetation. Community Ecology, 4(1), 21-28.

Loreau, M., Naeem, S., InchaustI, P., Bengtsson, Grime, J.P., et al. 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. Science, 294, 804-808.

Mittelbach, G.G., Steiner, C.F., Scheiner, S.M., Gross, K.L., Reynolds, H.L. et al. (2001). What is the observed relationship between species richness and productivity? Ecology, 82(9), 2378-2396.

Passy, S.I. (2008). Continental diatom biodiversity in stream benthos declines as more nutrients become limiting. Proceedings of the National Academy of Sciences, USA, 105(28), 9663-9667.

Pereira, H.M., Navarro, L.M., & Martins, I.S. (2012). Global biodiversity change: the bad, the good, and the unknown. Annual Review of Environment and Resources, 37, 25-50.

Perrings, C., Naeem, S., Ahrestani, F.S., Bunker, D.E., Burkill, P. et al. (2011). Ecosystem services, targets, and indicators for the conservation and sustainable use of biodiversity. Frontiers in Ecology and the Environment 9(9): 512-520.

Smith, V.H., & Schindler, D.W. (2009). Eutrophication science: where do we go from here? Trends in Ecology and Evolution, 24(4), 201-207.

Srivastava, D.S., & Lawton, J.H. ()1998). Why more productive sites have more species: and experimental test of theory using tree-hole communities. American Naturalist, 152(4), 510-529.

Stevens, M.H.H., & Carson, W.P. (2002). Resource quantity, not resource heterogeneity, maintains plant diversity. Ecology Letters, 5, 420-426.

Waide, R.B., Willig, M.R., Steiner, C.F., Mittelbach, G., GOUGH, L., et al. (1999). The relationship between productivity and species richness. Annual Review of Ecology and Systematics, 30, 257-300.

Wang, Z. (2017). Process strengths determine the forms of the relationship between plant species richness and primary productivity. PLoS ONE, 12(11), e0185884.

Wilson, S.D., & D. Tilman. (1991). Interactive effects of fertilization and disturbance on community structure and resource availability in an old-field plant community. Oecologia 88: 61-71.

Worm, B., Lotze, H.K., Hillebrand, H., & Sommer, U. (2002). Consumer versus resource control of species diversity and ecosystem functioning. Nature, 417, 848-851.

Using algal microcosms in introductory biology lab.
II: The influence of biodiversity on ecosystem productivity

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Abstract

Because the escalating loss of species is one of the most serious environmental crises we face, it is vital that students of biology comprehend and can communicate the roles that biodiversity plays in the functioning of ecosystems. Here, we report on a laboratory experiment that has been highly successful in our introductory biology courses at demonstrating the role of biodiversity in the productivity of ecosystems. Students created microcosms consisting of six species of phytoplankton grown separately (monocultures) and in mixtures (polycultures) in 50-mL beakers. On average, monocultures were less productive than three-species polycultures, which in turn were less productive than six-species polycultures. However, the productivity of the polycultures was generally no greater than the productivity of the most productive monocultures—a result that suggests a lack of positive ecological interactions (e.g., facilitation or niche complementarity). In contrast, there was some evidence of negative interactions among species (e.g., predation and allelopathy) that caused some polycultures to be less productive than monocultures of their constituent species. Performing this structured-inquiry experiment provided students with an opportunity to apply aspects of the scientific method in a non-trivial manner to address issues of relevance to both basic ecology principles and applied disciplines with economic significance.

Keywords: biodiversity, microcosms, niche complementarity, phytoplankton, productivity, species richness, structured inquiry, transgressive overyielding.

Introduction

The number of species present in an ecosystem (i.e., its species "richness") is important from both a basic science and an applied perspective. Specifically, species richness can influence the stability and productivity of an ecosystem, which in turn affect the goods and services that ecosystems provide to benefit humans (Balvanera et al., 2006; Cardinale, 2011; Cardinale et al., 2011; Hooper et al., 2012; Gross et al., 2014; Liu, 2016). A basic question is whether ecosystems composed of many species tend to be more productive than ecosystems composed of fewer species (Duffy, 2009; Willig, 2011; Stockenreiter et al., 2012; Yuan et al., 2015). For managed ecosystems, a common question is which combinations of species should be propagated in order to maximize biomass production for food or fuel.

The alteration of species richness can have a range of effects on the productivity of an ecosystem, depending on the niche requirements of the species and how the species interact. If two species in an environment use the same resources in the same manner, then their combined productivity when grown together (in a polyculture) is likely to be the average of their productivities when grown separately (in monocultures). However, biological interactions may lead to a phenomenon called "complementarity," such that the total productivity in a polyculture is greater than the productivities of any of the component species in monoculture (Cardinale et al., 2007; Nalley et al., 2014; Brooker et al., 2015; Wendling et al., 2017). For instance, if the two species do not use the same resources in the same manner, then the two species in a polyculture may use of the resources in an ecosystem more completely—a phenomenon known as "niche complementarity." In addition, if one species is able to acquire a resource in abundance that the other species cannot (e.g., one species can fix nitrogen) or otherwise improves the habitat for another species, then the productivity of the polyculture is also likely greater than either monoculture—a phenomenon called "facilitation" (Brooker et al., 2015).

Other interspecific interactions can lead a polyculture to be less productive than the component monocultures. For instance, species may interfere with each other's ability to obtain resources—either physically or through the release of toxic or inhibitory chemicals (i.e., allelopathy)—more strongly than they compete with individuals of their own species. Thus, the productivity of a polyculture can be lower than the mean productivity of the component species in monocultures (Nalley et al., 2014; Newby et al., 2016).

In addition to biological interactions, stochasticity involved in "choosing" which species will make up a community in an ecosystem can affect how richness relates to productivity. Specifically, a polyculture that happens to include a particularly productive species is likely to be more productive than the average monoculture. In contrast, a polyculture that is dominated by species of low productivity will tend to be less productive than the average monoculture. These phenomena are often called "sampling" (or "selection") effects to emphasize the fact that they result from the vagaries of community assembly in nature or in the design of an experiment (Tilman et al., 2001; Fridley, 2002; Fox, 2005; Stockenreiter et al., 2012; Nalley et al., 2014; Weis, 2016).

One can gain insight as to whether a relationship between species richness and productivity is driven by complementarity or by sampling effects by inspecting the productivity patterns in monocultures and polycultures (Schmid et al., 2008; Wang et al., 2013). In particular, if the productivity of a polyculture is greater than the productivity of every monoculture (a pattern called "transgressive overyielding"), then complementarity is most likely involved (Hector et al., 1999; Shurin et al., 2013). In contrast, if the productivity of a polyculture is lower than every monoculture (i.e., "transgressive underyielding"), then substantial inhibition or interference among the species is likely to be the cause. Sampling effects can lead to overyielding or underyielding relative to the mean productivity of the monocultures, but sampling effects alone would not cause the pattern to be transgressive. Sophisticated experimental designs and statistical analyses can be used partition the influence of sampling and complementarity effects (Loreau & Hector, 2001; Fox, 2005; Yuan et al., 2015). However, a basic appreciation of the biological interactions at play can be obtained by a simple assessment of whether patterns of overyielding or underyielding are transgressive (Hector et al., 1999; Tilman et al., 2001; Shurin et al., 2013).

Some of the most comprehensive work on the diversity-productivity relationship has been performed in grassland ecosystems (Tilman et al., 1997; Hector et al., 1999; Dukes, 2001; Tilman et al., 2001; Balvanera et al., 2006; Grace et al., 2007). For example, in a seminal paper summarizing the results of many years of study, Tilman et al. (2012) reported that the positive effect of species richness on the productivity of grassland ecosystems was greater in magnitude than the effects of nitrogen levels, drought, carbon dioxide levels, herbivores, and fire. In recent years, more attention has been focused on investigating the effect of species richness on productivity of phytoplankton communities (i.e., floating aquatic, photosynthetic micro-organisms, or "algae") (Weis et al., 2008; Striebel et al., 2009; Weis, 2016). Phytoplankton are appealing to researchers because their communities can be experimentally manipulated in laboratory microcosms that allow a large degree of replication. In addition, the potential for phytoplankton to serve as a source of biofuels is making such studies more valuable from an applied perspective (Smith et al., 2009; Stockenreiter et al., 2012; Shurin et al., 2013; Shurin et al., 2014; Liu, 2016; Newby et al., 2016; Jackrel et al., 2018).

This paper reports on a laboratory experiment conducted by an introductory majors' biology course in which students created microcosms of phytoplankton to investigate the effect of species richness on ecosystem productivity. Prior to the experiment, students read and discussed two scientific journal articles related to biodiversity and productivity—one on grassland ecosystems (Tilman et al., 2012) and the other on phytoplankton (Weis, 2016). After a lecture on productivity and a brief overview of the use of algal microcosms, students met with their lab groups (3-4 students each) to formulate research questions, generate hypotheses, and brainstorm possible experimental designs. Then through a whole-class discussion, the instructors guided students to an agreed-upon set of questions and experimental protocols to address the questions. Specifically, students constructed glass-beaker microcosms in which phytoplankton were grown as monocultures, three-species polycultures (3-SP's), and six-species polycultures (6-SP's), and the productivity of the microcosms was measured after two weeks of growth. Students addressed three main experimental questions: 1) Did the species differ from each other in productivity when grown in monocultures? 2) Did the 3-SP's or 6-SP's differ in productivity from each other or from the monocultures of the component species? and 3) Was there any evidence of transgressive overyielding or underyielding, suggesting the agency of complementarity or inhibition, respectively?

The intended learning outcomes for this project were that students should be able to do the following: 1) communicate the importance of species richness to the productivity of an ecosystem; 2) employ aspects of the scientific method in a structured-inquiry experiment to address an important ecological question; 3) use Excel to perform statistical analyses and construct professional-quality graphs; and 4) interpret and communicate the results and their broader implications. Their achievement of these learning outcomes was assessed through a formal lab report, written in the format of an article for an ecological journal.

Materials and Methods

Course overview

The microcosm experiments described here (and in a companion paper: Wise & Collins, this issue) are the principal laboratory activities of the introductory biology course BIOL 180 (Exploring Biological Diversity) at Roanoke College, a selective liberal arts institution of ~2,000 students in Salem, VA, USA. BIOL 180 is one of a sequence of three introductory courses for Biology majors, but it is also taken by some non-majors for whom this is their only biology course. Versions of these microcosm experiments have been used in 16 sections of BIOL 180 since 2015. This course meets for three two-hour periods per week, and the class is capped at 24 students. The design and data reported in this paper are from a version of the experiment used in the fall semester of 2018 in a section with 14 students.

Phytoplankton Species

Six freshwater phytoplankton species across six different genera were chosen for inclusion in the microcosm experiment (Table 1). All of these species grow well in laboratory conditions and are commercially available (Carolina Biological Supply Company, Burlington, NC, USA). This set of species included four green algae, two of which are charophytes of the family Desmidaceae, and two of which are chlorophytes of two different families. The set also included one diatom and one euglenozoan. Each species was maintained in a separate 250-mL beaker containing 200 mL of growth medium, which consisted of a 1:1 ratio of autoclaved tap water to deionized water with one 20-mL tube of AlgaGro® Concentrated Medium (Carolina Biological Supply Company) per liter of water. These stock-culture beakers were covered with cellophane wrap with five small ventilation holes (made with dissecting needles) and were maintained on a light rack of constant fluorescent light for one week prior to the initiation of the microcosm experiment. The light was provided by four wide-spectrum tubes (F40 PL/AQ-ECO bulbs, General Electric) mounted ~40 cm above the shelf.

Microcosms

The class was split into six groups of students, and each group was assigned to prepare a set of 10-11 microcosms in 50-mL glass beakers with 30 mL of growth medium (for a class-wide total of 62 microcosms). Each set comprised six monocultures (one for each species), one polyculture of all six species (6-SP), and three or four polycultures of three species (3-SP's). In total, the experiment consisted of 36 monocultures, six 6-SP's, and 20 3-SP's (one for each of the 20 different three-species combinations). Using graduated cylinders, students added 30 mL of growth medium to each beaker. Then using 10-mL graduated pipettes, they added 6 mL of culture from a single species into each monoculture beaker, 1 mL of culture from each of the six species into their 6-SP beaker, and 2 mL of cultures from each of three designated species into their 3-SP beakers (Appendix 1.) Each stock solution was designated a single pipette, conspicuously labeled with the genus name. To prevent cross-contamination, students were instructed to double-check to make sure they only used the pipette whose label matched the label on

Table 1.

Taxonomic information for the six phytoplankton species included in this study

Genus	Superkindom[1]	Phylum/Division	Family
Ankistrodesmus	Archaeplastida	Chlorophyta	Selenastraceae
Cosmarium	Archaeplastida	Charophyta	Desmidaceae
Euglena	Excavata	Euglenozoa	Euglenaceae
Navicula	Stramenopila	Ochrophyta	Naviculaceae
Scenedesmus	Archaeplastida	Chlorophyta	Scenedesmaceae
Staurastrum	Archaeplastida	Charophyta	Desmidaceae

[1] Eukaryotic superkingdoms are as designated in Morris et al. (2016).

the stock culture before they drew samples.

Students covered their microcosms with cellophane wrap to prevent evaporation, secured the wrap with a rubber band, and punched three small ventilation holes in the wrap using dissecting needles. The microcosm beakers were placed on a tray on the light rack and housed in the same conditions as the stock cultures were for 14 days. The beakers were gently shaken daily to prevent permanent settling of cells on the bottom.

Productivity Measurements

The (net) productivity of a trophic level can be defined as the amount of new organic material produced for all the organisms of that trophic level per unit area (or volume), per unit time. In this experiment, all microcosms were the same total volume, and all had been growing for the same duration. Therefore, to compare the relative productivity of our microcosms, we can factor out volume and time and simply compare the amounts of organic material produced. We used spectrophotometry as a quick and precise method to estimate relative productivity of our microcosms because the denser the cells are in a microcosm (due to greater numbers or sizes of cells), the more light will be absorbed by a sample from the microcosm.

Prior to measuring absorbance for a microcosm, students used a plastic dropper to mix and evenly suspend the phytoplankton cells in the beaker. They then quickly filled the sample tube and put it into their spectrophotometer to take a measurement before the cells settled. The spectrophotometers (Genesys 20; ThermoFisher Scientific, Waltham, MA, USA) were set to a wavelength of 750 nm (Rodrigues et al., 2011; Shurin et al., 2014). The spectrophotometers were blanked prior to each absorbance measurement using a tube with growth medium (no phytoplankton). (Absorbance data for the 62 samples are in the Appendix.)

Data Analysis

We addressed the question of whether productivity differed among the six species in two steps. We first performed a two-way analysis of variance (ANOVA) with absorbance of the monocultures as the response variable and species as one predictor variable. The second predictor was a block (i.e., student group), which accounted for potential differences in absorbance due to such elements as procedural inconsistencies among student groups and differences in calibration among the spectrophotometers. Block was considered a random-effects factor, and the ANOVA was performed using Minitab 14 (Minitab, LLC, Statesville, PA, USA). We then performed pairwise comparisons between the mean productivities of the monocultures for each species—as well as the means of the 3-SP's and 6-SP's—using Tukey tests with an experiment-wise alpha of 0.05.

In addition to the Tukey tests described above, we asked whether polycultures differed in productivity from monocultures using paired t-tests of absorbance values. Paired t-tests were more appropriate than standard two-sample t-tests because pairing allowed us to take into account potential block differences in absorbance values. Moreover, pairing allowed us to compare the absorbances of each polyculture with only the monocultures of species that constituted that polyculture. For instance, the absorbance of a polyculture that contained *Ankistrodesmus*, *Cosmina*, and *Euglena* would be compared with the mean absorbances of the monocultures of these same three species (in the same block). After calculating the 20 mean-absorbance values to pair with the 20 3-SP values, students performed a paired t-test using Excel. They also performed a second paired t-test to compare the productivity of the six 6-SP's to the monocultures, pairing each 6-SP value with the mean of the monocultures from the same block.

Students were given guidance to examine the patterns of overyielding and underyielding more closely using graphical and mathematical methods (e.g., Cardinale et al., 2007; Weis et al., 2008; Gamfeldt et al., 2014; Shurin et al., 2014; Weis, 2016). Here, we present log-response ratios, modelled after Gamfeldt et al. (2014) and Shurin et al. (2014), that allow discrimination between simple and transgressive overyielding. For each of the 26 polycultures, we calculated both a net biodiversity effect (NBE) and an overyielding (OY) metric, which respectively were log_{10} ratios of polyculture absorbance (P) to the average monoculture absorbance (M_{ave}) or the maximum monoculture absorbance (M_{max}) for the species constituting the polyculture:

$$NBE = log\left(\frac{P}{M_{ave}}\right) \qquad OY = log\left(\frac{P}{M_{max}}\right)$$

A value of NBE > 0 would indicate that the polyculture was more productive than the average of the monocultures of the species that constituted the polyculture, and if OY > 0, then the overyielding was transgressive.

Results

The productivities of the six phytoplankton species differed significantly, as determined by the ANOVA of absorbance values (Table 2) and the Tukey tests (Fig. 1). Student group (i.e., block) also had a significant influence on the absorbance measurements. However, the amount of variation explained by student-group differences was small (< 4% as much as that explained by the identity of the phytoplankton species).

The productivities of the polycultures tended to be greater than the average productivities of the monocultures. Specifically, the mean absorbance of the 6-SP's was roughly twice as great as the mean for monocultures, and the mean absorbance for the 3-SP's was 1.4 times as great as the monoculture mean (Fig. 1). In addition, the paired t-tests indicated that the productivities of both the 6-SP's (t_5 = 9.59, P = 0.0002) and the 3-SP's (t_{19} = 3.49, P = 0.002) were significantly greater than the mean productivities of the monocultures.

The net biodiversity effects tell a similar story regarding the relative productivities of polycultures and monocultures (Fig. 2A). Specifically, all of the 6-SP's and 70% of the 3-SP's had a positive NBE value. Notably, six of the 3-SP's had a negative NBE, with two of these polycultures showing substantially lower productivity than the means of the monocultures of the same species.

Table 2.

Summary of ANOVA results for differences in light absorbance (productivity) among genera of phytoplankton. Student group was considered a random-effects factor.

Source of variation	df	Mean square	F-ratio	P-value
Student group	5	0.002617	5.74	0.001
Genus	5	0.073053	160.16	<0.001
Error	25	0.000456		

There was very little indication of transgressive overyielding by polycultures in this experiment. Note that monocultures of *Ankistrodesmus* were just as productive as the average 6-SP, and were significantly more productive than the average 3-SP (Fig. 1). On a finer level, only four of the 3-SP's and one of the 6-SP's had a positive OY value, and these magnitudes were quite close to zero (Fig. 2B). One microcosm showed transgressive underyielding—the 3-SP containing *Euglena*, *Navicula*, and *Staurastrum*.

Discussion

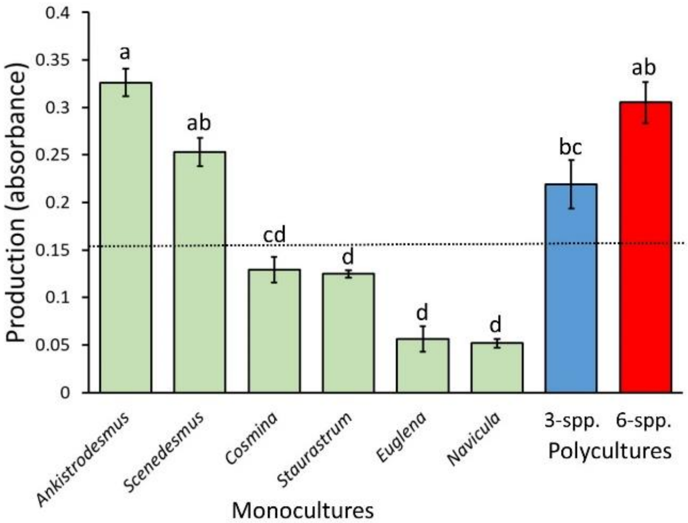
Interpretation of Experimental Results

There was a substantial range of variation in productivities of the phytoplankton species in monocultures, and taxonomic affinity seems to explain some of this variation. In particular, the two chlorophytes had the greatest productivity, with *Ankistrodesmus* being significantly more productive than all species besides *Scenedesmus*. The two charophytes (*Cosmina* and *Staurastrum*) were significantly less productive than the chlorophytes. The two least-productive species were the diatom (*Navicula*) and *Euglena*. If one were interested in cultivating one of these species for biofuel production, these results suggest that *Ankistrodesmus* holds the most promise strictly from the standpoint of productivity. The more interesting question addressed by this study is whether the productivity of the system can be increased by using different combinations of species, rather than just a monoculture.

This study produced solid evidence that polycultures of phytoplankton are more productive, on average, than monocultures. Moreover, the results suggest that the greater the species richness, the greater the average productivity is likely to be. This laboratory result is likely to hold in natural ecosystems as well, if only for the fact that the more species are present in a community, the more likely it is that the community will contain one or more highly productive species. This is the essence of a positive sampling (i.e., selection) effect. The next question is whether the positive richness-productivity relationship observed in this study is due only to a sampling effect, or whether there is evidence of complementarity, which would suggest the action of more interesting biological phenomena.

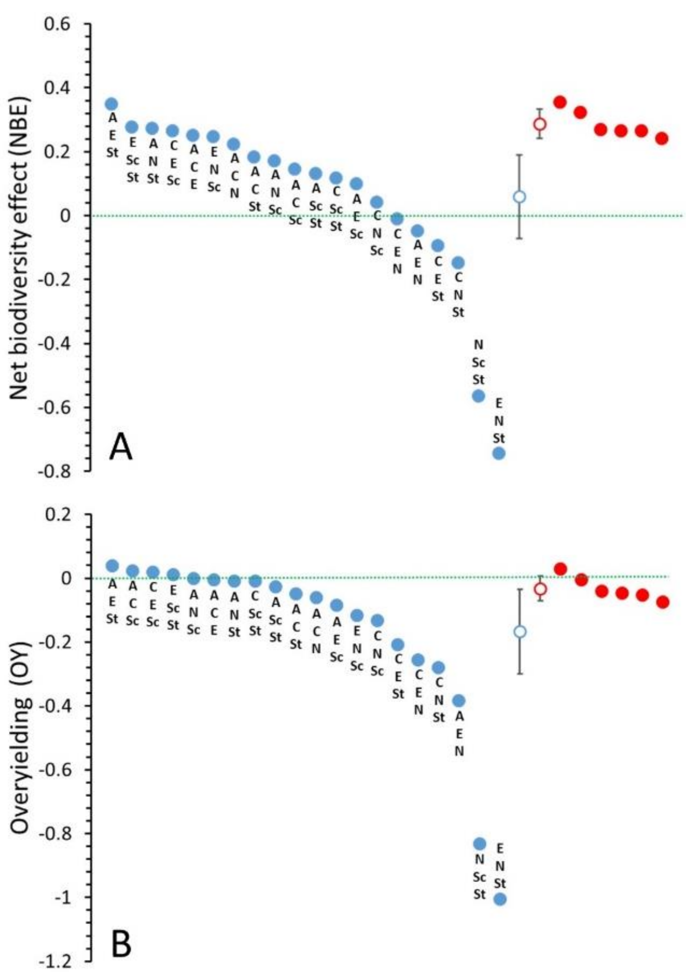
Although there was good evidence of polycultures being more productive than the means of the monocultures, the productivity of the polycultures did not exceed the productivity of every one of the species in monoculture. In other words, there was evidence of overyielding in the polycultures, but this overyielding was not of the transgressive variety. Therefore, it would appear that sampling effects alone can explain why the polycultures were more productive than the average monocultures.

Figure 1.



Relative productivity of six genera of phytoplankton, measured by light absorbance at 750 nm. Columns and bars represent means +/- one standard error. The horizontal dashed line indicates the overall mean absorbance for the monocultures. There were six replicates per monoculture (green bars), 20 replicates for all possible combinations of 3-species polycultures (blue bar) and six replicates of 6-species polycultures (red bar). Genera that share lower case leters above the bars did not differ significantly from each other in relative productivity, based on Tukey tests with experiment-wise rate of 0.05.

Figure 2.



Comparisons of productivities of polycultures and monocultures. A. A positive NBE value indicates that the productivity of the polyculture was greater than the mean of the productivities of the monocultures of the genera that constituted the polyculture. B. A positive OY value indicates that the productivity of the poly culture was greater than the productivities of each of the monocultures of the genera that constituted the polyculture (i.e., the overyielding was transgressive). Filled blue and red circles represent values for 3-species and 6-species polycultures, respectively. Letters above and below the blue circles are abbreviations for the genera that composed the polycultures. The blue and red open circles represent the mean values for the 20 3-species polycultures and the six 6-species polycultures, respectively, and the bars indicate the 95% confidence intervals for the means.

The overall picture that emerged was that there was little compelling evidence of niche complementarity or evidence that any of the species improved the production of any of the other species. However, there was evidence that the productivities of some species were actually reduced by the presence of other species. Specifically, six of the 3-SP's had negative NBE values, and two had highly negative OY values. These patterns suggest antagonistic interactions beyond simple resource competition.

In our microcosms, the 3-SP's containing *Euglena* tended to have especially low NBE and OY values—unless either *Ankistrodesmus* or *Scenedesmus* was also present. The most likely explanation for these low values is the fact that *Euglena* is not strictly autotrophic. In particular, *Euglena* is known to consume individuals of some species of diatoms and green algae. Thus, the 3-SP's that contained *Euglena* and some combination of the diatom *Navicula* and the two charophyte algae (*Cosmina* and *Staurastrum*) could have been less productive than the mean monocultures simply because *Euglena* was consuming some of the biomass produced by these species. It would seem that the chlorophyte algae were less suitable as food items for *Euglena*—perhaps simply due to their spiny bodies.

The 3-SP's that contained *Navicula* were even less likely to display a positive NBE or OY value than were the 3-SP's containing *Euglena*. While diatoms like *Navicula* are not heterotrophic, they are known to produce allelopathic chemicals that poison not only herbivores, but other phytoplankton sharing an environment with the diatoms (Ianora & Miralto, 2010; Pichierri et al., 2017). In our experiment, polycultures with *Navicula* may have had lower productivity than expected because *Navicula* produced toxins that poisoned individuals of the other species in polyculture. While these interpretations of the results involving *Navicula* and *Euglena* are speculative, potential heterotrophy and allelopathy, combined with their low productivity in monocultures, would seem to eliminate these species as candidates for biofuel production.

Pedagogical Considerations

The main caveat regarding the experimental questions is that they may have seemed a bit too esoteric for students in an introductory biology course. In particular, the distinction between sampling effects and complementarity, or the significance of the difference between simple overyielding and transgressive overyielding were a bit nuanced for some students to appreciate. To prepare students for the more esoteric concepts, we spent the greater part of two class meetings discussing these concepts from required readings prior to the experiment (Tilman et al., 2012; Weis, 2016). We spent another class period discussing the students' results in terms of these concepts. In past iterations of this experiment, we have left out these more advanced concepts and simply examined overall relative productivity differences between monocultures and polycultures. Both strategies have their advantages.

The flexibility in terms of the target level of sophistication is one of the valuable features of this experiment. For instance, instructors can have just as successful experiences with this experiment if they choose to leave out the statistical tests and focus on qualitative differences in productivity if that strategy better matches the experience level of their students.

Conclusion

The experiment provided a hands-on opportunity for introductory biology students to investigate a set of questions that are significant from both a basic ecology and applied science perspective. The broad interest in issues of biodiversity and productivity provided ample opportunities for students to engage with relevant scientific literature. Importantly, the study was hypothesis driven, and because the results were not obvious to the students prior to the experiment, the study provided an authentic application of several steps of the scientific method. The data generated in the experiment allowed opportunities for graphing and statistical analyses of a range of sophistication. Finally, we have found the results to be highly consistent and repeatable across years and sections of the course.

Acknowledgments

We thank the students of Roanoke College who participated in collecting data, the RC Biology Department for logistical support, an anonymous reviewer for helpful comments on the manuscript, and S.E. Wise for carefully editing the manuscript.

Appendix 1.

Contents of microcosms and absorbance data after two weeks of growth.
The Blocks represent student groups. Each group was responsible for six monocultures, one 6-species polyculture, and three or four 3-species polycultures.

Beaker No.	Block	Genera per Microcosm	Volumes of Stock Solutions per Genus	Abs.
1	A	one	6 mL *Ank.*	0.366
2	A	one	6 mL *Cos.*	0.154
3	A	one	6 mL *Eug.*	0.088
4	A	one	6 mL *Nav.*	0.052
5	A	one	6 mL *Sce.*	0.310
6	A	one	6 mL *Sta.*	0.143
7	A	six	1 mL each genus	0.391
8	A	three	2 mL *Ank., Cos.,* & *Eug.*	0.362
9	A	three	2 mL *Ank., Cos.,* & *Nav.*	0.319
10	A	three	2 mL *Ank., Cos.,* & *Sce.*	0.387
11	B	one	6 mL *Ank.*	0.370
12	B	one	6 mL *Cos.*	0.154
13	B	one	6 mL *Eug.*	0.084
14	B	one	6 mL *Nav.*	0.058
15	B	one	6 mL *Sce.*	0.273
16	B	one	6 mL *Sta.*	0.127
17	B	six	1 mL each genus	0.327
18	B	three	2 mL *Ank., Cos.,* & *Sta.*	0.332
19	B	three	2 mL *Ank., Eug.,* & *Nav.*	0.153
20	B	three	2 mL *Ank., Eug.,* & *Sce.*	0.305
21	C	one	6 mL *Ank.*	0.286
22	C	one	6 mL *Cos.*	0.120
23	C	one	6 mL *Eug.*	0.013
24	C	one	6 mL *Nav.*	0.042
25	C	one	6 mL *Sce.*	0.248
26	C	one	6 mL *Sta.*	0.121
27	C	six	1 mL each genus	0.257
28	C	three	2 mL *Ank., Eug.,* & *Sta.*	0.314
29	C	three	2 mL *Ank., Nav.,* & *Sce.*	0.286
30	C	three	2 mL *Ank., Nav.,* & *Sta.*	0.281

Beaker No.	Block	Genera per Microcosm	Volumes of Stock Solutions per Genus	Abs.
31	D	one	6 mL *Ank.*	0.300
32	D	one	6 mL *Cos.*	0.117
33	D	one	6 mL *Eug.*	0.030
34	D	one	6 mL *Nav.*	0.052
35	D	one	6 mL *Sce.*	0.208
36	D	one	6 mL *Sta.*	0.116
37	D	six	1 mL each genus	0.253
38	D	three	2 mL *Ank., Sce.,* & *Sta.*	0.283
39	D	three	2 mL *Cos., Eug.* & *Nav.*	0.065
40	D	three	2 mL *Cos., Eug.* & *Sce.*	0.218
41	E	one	6 mL *Ank.*	0.307
42	E	one	6 mL *Cos.*	0.156
43	E	one	6 mL *Eug.*	0.084
44	E	one	6 mL *Nav.*	0.069
45	E	one	6 mL *Sce.*	0.223
46	E	one	6 mL *Sta.*	0.120
47	E	six	1 mL each genus	0.279
48	E	three	2 mL *Cos., Eug.* & *Sta.*	0.097
49	E	three	2 mL *Cos., Nav.* & *Sce.*	0.165
50	E	three	2 mL *Cos., Nav.* & *Sta.*	0.082
51	E	three	2 mL *Cos., Sce.* & *Sta.*	0.219
52	F	one	6 mL *Ank.*	0.328
53	F	one	6 mL *Cos.*	0.074
54	F	one	6 mL *Eug.*	0.004
55	F	one	6 mL *Nav.*	0.038
56	F	one	6 mL *Sce.*	0.258
57	F	one	6 mL *Sta.*	0.121
58	F	six	1 mL each genus	0.325
59	F	three	2 mL *Eug., Nav.* & *Sce.*	0.198
60	F	three	2 mL *Eug., Nav.* & *Sta.*	0.012
61	F	three	2 mL *Eug., Sce.* & *Sta.*	0.265
62	F	three	2 mL *Nav., Sce.* & *Sta.*	0.038

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References

Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J.S., Nakashizuka, T. et al. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecology Letters, 9, 1146-1156.

Brooker, R.W., Bennett, A.E., Cong, W.F., Daniell, T.J., George, T.S. et al. 2015. Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology. New Phytologist, (206), 107-117.

Cardinale, B.J. (2011). Biodiversity improves water quality through niche partitioning. Nature, 472, 86-91.

Cardinale, B.J., Matulich, K.L., Hooper, D.U., Byrnes, J.E., Duffy, E., et al. (2011). The functional role of producer diversity in ecosystems. American Journal of Botany, 98(3), 572-598.

Cardinale, B.J., Wright, J.P., Cadotte, M.W., Carroll, I.T., Hector, A., et al. (2007). Impacts of plant diversity on biomass production increase through time because of species complementarity. Proceedings of the National Academy of Sciences, USA, 104(46), 18123-18128.

Duffy, J.E. (2009). Why biodiversity is important to the functioning of real-world ecosystems. Frontiers in Ecology and the Environment, 7(8), 437-444.

Dukes, J.S. (2001). Productivity and complementarity in grassland microcosms of varying diversity. Oikos, 94, 468-480.

Fox, J.W. (2005). Interpreting the 'selection effect' of biodiversity on ecosystem function. Ecology Letters, 8, 846-856.

Fridley, J.D. (2002). Resource availability dominates and alters the relationship between species diversity and ecosystem productivity in experimental plant communities. Oecologia, 132, 271-277.

Gamfeldt, L., Lefcheck, J.S., Byrnes, J.E.K., Cardinale, B.J., Duffy, J.E., et al. (2014). Marine biodiversity and ecosystem functioning: what's known and what's next? Oikos 124: 252-265.

Grace, J.B., Anderson, T. M., Smith, M.D., Seabloom, E., Andelman, S.J., et al. (2007). Does species diversity limit productivity in natural grassland communities? Ecology Letters, 10, 680-689.

Gross, K., Cardinale, B.J., Fox, J.W., Gonzalez, A., Loreau, M., et al. (2014). Species richness and the temporal stability of biomass production: a new analysis of recent biodiversity experiments. American Naturalist, 183(1), 1-12.

Hector, A., Schmid, B., Beierkuhnlein, C., Caldeira, M.C., Diemer, M., et al. (1999). Plant diversity and productivity experiments in European grasslands. Science, 286, 1123-1127.

Hooper, D.U., Adair, E.C., Cardinale, B.J., Byrnes, J.E.K., Hungate, B.A., et al. (2012). A global synthesis reveals biodiversity loss as a major driver of ecosystem change. Nature, 486, 105-109.

Ianora, A., & MIRALTO, A. (2010). Toxigenic effects of diatoms on grazers, phytoplankton and other microbes: a review. Ecotoxicology, 19(3), 493-511.

Jackrel, S.L., Narwani, A.,Bentlage, B., Levine, R.B., Hietala, D.C., et al. (2018). Ecological engineering helps maximize function in algal oil production. Applied and Environmental Microbiology, 84(15), 1-16.

Liu, J. (2016). Interspecific biodiversity enhances biomass and lipid productivity of microalgae as biofuel feedstock. Journal of Applied Phycology, 28, 25-33.

Loreau, M., & Hector, A. (2001). Partitioning selection and complementarity in biodiversity experiments. Nature, 412, 72-76.

Nalley, J.O., Stockenreiter, M., & Litchman,E. (2014). Community ecology of algal biofuels: complementarity and trait-based approaches. Industrial Biotechnology, 10(3), 191-201.

Newby, D.T., Mathews, T.J., Pate, R.C., Huesemann, M.H., Lane, T.W., et al. (2016). Assessing the potential of polyculture to accelerate algal biofuel production. Algal Research 19: 264-277.

Pichierri, S., Accoroni, S., Pezzolesi, L., Guerrini, F., Romagnoli, T., et al. (2017). Allelopathic effects of diatom filtrates on the toxic benthic dinoflagellate Ostreopsis cf. ovata. Marine Environmental Research, 131, 116-122.

Rodrigues, L.H.R., Arenzon, A., Raya-rodriguez, M.T., & Fontoura, N.F. (2011). Algal density assessed by spectrophotometry: A calibration curve for the unicelluar algae Pseudokirchneriella subcapitata. Journal of Environmental Chemistry and Ecotoxicology, 3(8), 225-228.

Schmid, B., Hector, A., Saha, P., & Loreau, M. (2008). Biodiversity effects and transgressive overyielding. Journal of Plant Ecology, 1(2), 95-102.Shurin, J., Mandal, S., & Abbott, R. L. (2014.) Trait diversity enhances yield in algal biofuel. Journal of Applied Ecology, 51, 603-611.

Shurin, J.B., Abbott, R.L., DeaL, M.S., Kwan, G.T., Litchman, E., et al. 2013. Industrial-strength ecology: trade-offs and opportunities in algal biofuel production. Ecology Letters,16(11), 1393-1404.

Smith, V.H., Sturm, B. S. M., Denoyelles, F. J., & Billings, S.A. (2009). The ecology of algal biodiesel production. Trends in Ecology and Evolution, 25(5), 301-309.

StockenreiteR, M., GrabeR, A.K., Haupt, F., & Stibor, H. (2012). The effect of species diversity on lipid production by micro-algal communities. Journal of Applied Phycology, 24, 45-54.

Striebel, M., Behl, S., Diehl, S., & Stibor, H. (2009). Spectral niche complementarity and carbon dynamics in pelagic ecosystems. American Naturalist, 174(1), 141-147.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M., et al. (1997). The influence of functional diversity and composition on ecosystem processes. Science 277: 1300-1302.

Tilman, D., Reich, P.B., & Isbell, F. (2012). Biodiversity impacts ecosystem productivity as much as resources, disturbance, or herbivory. Proceedings of the National Academy of Sciences, USA, 109(26), 10394-10397.

Tilman, D., Reich, P.B., Knops, J., Wedin, D., Mielke, T., et al. (2001). Diversity and productivity in a long-term grassland experiment. Science, 294, 843-845.

Wang, J., Zhang, C., Chen, T., & Li, W. H. (2013). From selection to complementarity: the shift along the abiotic stress gradient in a controlled biodiversity experiment. Oecologia, 171, 227-235.

Weis, J.J. (2016). Effect of phytoplankton richness on phytoplankton biomass is weak where the distribution of herbivores is patchy. PLoS ONE, 11(5), e0156057.

Weis, J.J., MadrigaL, D. S., & Cardinale, B. J.. (2008). Effects of algal diversity on the production of biomass in homogeneous and heterogeneous nutrient environments: a microcosm experiment. PLoS ONE, 3(7), e2825.

Wendling, M., Büchi, L., Amossé, C., Jeangros, B., Walter, A., et al. (2017). Species interactions leading to transgressive overyielding in cover crop mixtures. Agriculture, Ecosystems and Environment, 241, 88-99.

Willig, M.(201)1. Biodiversity and productivity. Science, 333(6050), 1709-1710.

Yuan, Z., Yu, K., Epstein, H., Stefanova, K., & Zhang, R. (2015). Plant species richness is not consistently associated with productivity in experimental subalpine meadow plant communities. Folia Geobotanica, 50, 207-217.

Abstracts by Category

20-Minute Presentations

10:50-11:10 Saturday October 24th

Use of a short, in-class, open-ended free response activity to assess student understanding of the cell membrane in an undergraduate physiology course

Kristen LW Walton, Missouri Western State University

Students in an upper division, stand-alone physiology course at Missouri Western State University are required to have completed a freshman-level introductory cell biology course and a sophomore-level genetics course as prerequisites. These prerequisite courses include discussion of the eukaryotic cell membrane and basic properties and functions of the membrane. However, many students remember the basic information about membrane structure but have difficulty relating that structure to membrane function and related topics in our physiology course, including vesicular transport, primary and secondary active transport, osmosis, and current flow across the membrane. To gain a better understanding of what students recall about the cell membrane before beginning in-class discussion about membrane structure and function, students were given an open-ended prompt, "What do you know about the structure and function of the animal cell membrane?" The students were allowed to work in small groups or alone if they preferred, and could generate their response as drawings, written statements, or both. They were given 10 minutes to construct a response. These student responses were analyzed using the conceptual framework for the "cell membrane" core concept recently published by Michael and Modell (Adv Physiol Educ 2019). 100% (19 out of 19) submissions included a drawing or description of the cell membrane as a phospholipid bilayer, and 84% of submissions included integral and peripheral membrane proteins. However, other components of the "cell membrane" conceptual framework were included much less frequently or not at all. While 58% of the responses listed diffusion or osmosis, only 32% listed active transport, and less than 10% mentioned vesicular transport, cell-cell or cell-matrix junctions, maintenance of solute concentration inside versus outside the cell, or cell-to-cell communication. No responses explicitly included simple diffusion of lipid-soluble molecules, membrane receptors, ion channels, or physical separation/compartmentalization of the cell. Several responses had errors, such as incorrect labeled of the fatty acid tails of phospholipids as hydrophilic. This quick activity provides valuable information about what students recall from prior coursework and what concepts need to be revisited before moving into more detailed discussion of cell membrane function.

***Important things to know on how to publish successfully in Bioscene*.**

Robert Yost, Bioscene editor

Robert Yost, current editor for Bioscene, will discuss how to prepare a manuscript for Bioscene, submission dates, publication dates, and the review process. Join us for this interactive discussion.

Maintaining Active Learning with Collaborative Group Work in Online Learning Environments

Jamie Dyer and Ryan Elsenpeter, Rockhurst University

Due to the coronavirus pandemic, many of our courses have had to move into the virtual teaching landscape. This switch in delivery mode has resulted in dramatic changes in the class environment. Learning to navigate this new educational medium in a short period of time has presented many challenges, including trying to maintain an active learning environment that includes high impact teaching practices, including collaborative group assignments. Incorporating such practices into freshman-level biology courses with numerous students presents additional problems, as incoming student knowledge varies widely and more reluctance to working in groups and contributing ideas is observed in this population. During this session, we will provide examples that we have been using to promote active learning and collaborative group problem solving in a general biology course, as well as open a discussion to allow for sharing of additional tools, methods, and experiences for enhancing learning in biology courses and development of interpersonal skills through online learning environments.

3:00-3:20 Saturday October 24th

Beachcomber Shell Ecology Goes Online

Kathleen A Nolan, St. Francis College, and Jill E. Callahan, St. Peter's University

Collections of seashells were used to simulate real populations. Two collections of seashells were ordered online, (Sanibel Island, Florida, and Pacific Northwest) and one was collected on a beach in St. Augustine, Florida. From pictures taken, students were asked to determine: 1. Species richness and 2. Species diversity using the Simpson's Reciprocal Index using these collections.

Comparisons were made of all three populations, and students generated hypotheses that might explain differences in species diversity among all three areas. Additional exercises that could be conducted by students include rank-order abundance curves and species accumulation curves.

During our presentation, we will share our handout with pictures with the participants. The answer keys will also be provided. We will go through how we determined species richness and demonstrate how to calculate Simpson's Reciprocal Index of diversity. We will also show how to calculate a rank abundance curve and species accumulation curve. We will share geographical information about each of the three areas, and show how this information can help the students to analyze their data as to why one area might be more/less species rich/diverse than another area. We will also provide information about additional references that might help the participants conduct additional online ecology labs/exercises with their students.

What criteria do students use to form research groups and how do these criteria relate to students' learning and attitude towards group work?

Mitra Asgari, Arizona State University, Amy E. Cardace and Mark A Sarvary, Cornell University

This research project explores how self-selected student groups are formed and how group composition relates to student attitudes about group work. Previous research has shown benefits of both self-selected and teacher-selected student groups, and we aim to uncover more detail about how self-selected groups function in practice. We utilize a matched pre-post design to examine how student group work attitudes change over a semester. We analyzed survey data to study the criteria students use to form groups, the demographic composition of the resulting groups, and how student attitudes towards group work vary. Students were also asked about content knowledge, demographics, and how they formed their research group. The data was collected in a large-enrollment biology laboratory course over two semesters (n=600) at an R1 research university over two semesters. Preliminary descriptive analyses showed that "students sitting next to me" (57%) was the most common factor in forming research groups. We also studied instances of demographic isolation within groups, and find the isolation of female, underrepresented minority, and first-generation in 20%, 29%, and 28% of groups formed, respectively. These percentages fall within the range we found among a simulation of randomly assigned groups as well. Finally, we will utilize a multi-level linear regression to account for group clustering when estimating the effects of demographic variables on students' group work attitudes scores. This study can provide valuable information about the criteria students use when forming groups, how demographics are concentrated in these groups, and how these group concentrations relate to student outcomes.

Academic Advising in a Pandemic: Lessons Learned

Laura Salem and Annie Lee, Rockhurst University

Academic and pre-professional advising involves making personal connections with students. The pandemic provided some challenges to the regular process of working with students as academic advisors. During this presentation we will share our lessons learned with working with large populations of students interested in health care careers. We will share challenges, resources, and student feedback.

9:00-9:20 Sunday October 25th

A simple risk assessment of raw milk consumption in a college Microbiology course

Jose de Ondarza, Plattsburgh State University of New York

Microbiology is a requirement of several degree programs that allows students to investigate topics such as food production, preservation and safety. One topic that garners attention in journals, on-line blogs and popular media is the sale and consumption of raw milk. This is particularly pertinent in light of the growing movements of "localvores", organic food proponents, and additive-free eating. Yet, few students seem to have more than a basic understanding of the risks associated with raw milk consumption. A lab-based Microbiology course offers a unique and effective tool to address this subject in a hands-on setting.

Goals and Objectives: This lab-based activity is designed to have students complete a risk assessment of the human consumption of raw (unpasteurized) milk. At the end of this activity, students will be able to draw conclusions about the safety of raw milk based on their own lab evaluation of raw and pasteurized milk samples.

Methods: Milk samples are obtained from local dairy farm as well as pasteurized milk purchased in a local store and assayed in a blind study to obtain a total heterotrophic count as well as a coliform count. Each student group performs this assay on each milk sample without knowing the sample source. Following incubation for 48h at 35C, colony counts on TSA and VRBA were done and data shared.

Results: While total bacteria vary greatly (depending on the age of the milk sample), pasteurized milk samples never tested positive for coliforms in over 20 years of repeating this experiment. In contrast, raw milk samples contained between 1 – 50 coliform bacteria per ml each time, with only one exception: a raw milk sample that was collected from a single cow, with no coliforms observed.

Conclusions: While raw milk may be safe for human consumption, repeated testing of raw milk samples obtained from milk tanks on local farms demonstrably show the presence of coliforms, providing a powerful argument for the pasteurization of milk and milk products which may otherwise not catch on among young adults whose source of information includes many unsupported claims about the benefits of raw milk via the internet.

Using 3D printing to model the light reactions of photosynthesis

Barbara Hass Jacobus, Jordan McQueen, Karen Smiar, and James Mendez, Indiana University-Purdue University Columbus

The future of 3D printing provides endless possibilities to innovate, create, and modify how learning can take place in a classroom. Models are particularly useful in helping students picture complex events that occur at molecular level that are not easily observed first-hand. We have designed a 3D-printed model that allows students to "split" water and follow the movement of the released electrons (ball bearings) through the light reactions of photosynthesis. Students use a 3D-printed sun with an embedded magnet to pass the electrons through Photosystem II, down an electron transport pathway where ATP is generated, as visualized by an LED that lights up when the electrons pass through the tunnel, into Photosystem I, and finally down a second electron transport pathway where the electrons are captured to form NADPH. Based on student input, an illustrative overlay guide was designed to complement the textbook in use in the classroom and direct students in guiding their electrons through the model. We are integrating this technology into introductory biology courses and assess its utility in increasing students' understanding of the complex light reaction pathway.

The Genomics Education Partnership: a nationwide collaborative CURE that offers online-based research opportunities for students and faculty at diverse institutions

Judith Leatherman, University of Northern Colorado, Nighat Kokan, Cardinal Stritch University, Evan Merkhofer, Mount Saint Mary College, David Lopatto, Grinnell College, Wilson Leung, Washington University in St. Louis, Laura K. Reed, University of Alabama and The GEP Faculty Community

The Genomics Education Partnership (GEP; https://thegep.org) is a growing collaborative community of practice that provides authentic Course-based Undergraduate Research Experiences (CUREs) in genomics. Our members include faculty from over one hundred and fifty institutions, including community colleges, primarily undergraduate institutions, minority-serving institutions, and research-intensive universities. We have created curriculum which provide beginning and advanced undergraduate students the opportunity to investigate and discover what eukaryotic genes look like in their genomic context, and to become more sophisticated users of bioinformatics tools. For example, the "Understanding Eukaryotic Genes" curriculum modules (https://doi.org/10.24918/cs.2017.13) are focused on beginning students and stress gene structure, while "A Hands-on Introduction to Hidden Markov Models" (https://doi.org/10.24918/cs.2016.8) introduces advanced students to the use of machine learning in computational gene predictions. GEP students learn how to utilize multiple lines of evidence (e.g., sequence alignments, gene predictions, RNA-Seq data) to construct gene models that contribute to our shared comparative genomics projects on the evolution of Drosophila Pathways, the Drosophila Muller F element, and venom proteins in parasitoid wasps. Students who contribute gene annotations to these projects can be eligible for authorship on our research publications. The GEP is leveraging the relative low cost, ease of scalability, and portability of our projects to continue providing students with research opportunities in online settings during the COVID-19 pandemic.

The large consortium of faculty implementing a GEP CURE in a variety of ways has also provided opportunities for educational investigations. Through the use of faculty logs, assessment of student learning gains, and responses to surveys and focus groups, we have examined actions that impact student learning. Recent findings show that our students experience "formative frustration", where initial failure, followed by exploration, re-evaluation, adjustment, and re-analysis becomes a beneficial learning experience. The low-cost, low-stakes structure of genomics investigations encourage faculty to let their students experience this formative process.

We are currently recruiting new faculty members, and we have developed online faculty training. Please contact us at https://thegep.org/contact/. Supported by NSF IUSE-1915544 and NIH IPERT-1R25GM130517-01 to LKR.

10:20-10:40 Saturday October 25th

Utilizing loop-mediated isothermal amplification to detect the presence of Escherichia coli: an inquiry driven undergraduate laboratory module

Courtney Lappas, Lebanon Valley College, Brandon Roy, Cornell University, Eric Ryndock, Millersville University

The amplification of nucleic acids is a fundamental tool utilized in various scientific disciplines, including Molecular Biology, Immunology, Microbiology and Genetics. A working knowledge of the techniques utilized to amplify nucleic acids is therefore arguably one of the most valuable tools imparted to undergraduate students. However, due to the time and technology required for traditional PCR and its derivatives, it is not always possible to include such methodologies in undergraduate laboratory curricula. Loop-mediated isothermal amplification (LAMP), a technology that has become increasingly utilized in a variety of laboratory and field settings during the past two decades, is an alternate method of nucleic acid amplification that is rapid, sensitive and performed under isothermal conditions. We will describe an adaptable, inquiry-driven laboratory module that is focused on the detection of Escherichia coli DNA via LAMP amplification. The main objectives of the exercise are: to introduce students to LAMP, to help students develop the ability to apply the scientific method to scientific questions, to guide students as they develop the ability to identify the most appropriate methodology to use in the investigation of scientific questions, and to train students to critically evaluate scientific data. This laboratory module has been successfully completed by undergraduate students in an upper level Molecular Biology course.

Data-driven Research Projects for Undergraduates – CODE Program

Michele C. Morris - HudsonAlpha Institute for Biotechnology

The opportunity for an undergraduate student to participate in an authentic research project can be invaluable to their learning, self-confidence, and graduate school acceptance. But research projects can be expensive and limited to the few students a lab can effectively mentor. The Characterizing Our DNA Exceptions (CODE) program introduces an alternative option using computational biology and protein modeling tools to conduct genetic research. The HudsonAlpha Institute for Biotechnology initially developed the CODE project for Alabama schools and is now to expanding its reach. HudsonAlpha is a non-profit genomics research institute with an Educational Outreach team that leverages the science and business activities on campus to design innovative experiences, products, and digital applications that educate society and prepare the future workforce.

CODE is creating a network of faculty from smaller universities who share an interest in computational biology, protein modeling, and STEM education reform. The project works to introduce bioinformatics, research skills, active learning, and research-driven coursework at these small institutions. Facilitators are trained (virtually or in-person) in the methods and tools needed to lead their students through a computational exploration of DNA variants of uncertain significance. Working with HudsonAlpha researchers and educators, students use computational analyses to determine the biological relevance of variants from patient samples, as well as explore other topics of interest. Variants of uncertain significance are often identified by genomic sequencing. CODE students research the available literature on the genes containing these variants, build three-dimensional computer models of the proteins, run molecular dynamics simulations to predict variant impact on protein behavior, and then analyze their data and share their results with the scientific community. Other student projects include collaborative approaches to characterize all the VUSs in a single gene and provide that data for future studies. Findings that indicate a potential pathological impact by a variant can be further studied with biological assays by additional collaborators. We believe that participating in a data-driven bioinformatics research project such as CODE will increase student awareness and interest in computational biology, as well as their self-efficacy, achievement, and persistence in science fields.

Top reasons that science majors cite for withdrawing from STEM gateway courses

Latanya Hammonds-Odie, Charmita Burch, Allison D'Costa, Clay Runck, David Pursell, Tirza Leader, and Judy Awong-TayloGeorgia Gwinnett College

At Georgia Gwinnett College (GGC), an open access, four-year state college, 30-40% of students who were enrolled in the introductory science courses for majors did not complete that course. A significant question that needed to be answered was how educational institutions, and more specifically how GGC, can meet the demands for greater numbers of STEM graduates to fill the technologically advanced jobs of the future. The specific aim of this project was to better understand why students withdraw from gateway (introductory) courses in their major in spring and fall 2019 and spring 2020. This research project was a quantitative methods study employing questionnaires to collect data. We solicited the participation of approximately 850 undergraduate students who withdrew from one or more gateway course(s) in spring 2019, fall 2019, or spring 2020. The questionnaire covered reasons for and timing of the withdrawal decision. Additionally, students were questioned about their use of on-campus and online resources. We will present our analysis of the responses from 65 students. This work is funded and supported by a grant from the National Science Foundation under NSF Award No. 1623779. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

10:50-11:10 Sunday October 25th

An Apple for all! Implementing 21st century technology to achieve improved outcomes for students in General Biology.

Kristin Picardo and Katie Sabourin, St. John Fisher College

During the 2019-2020 academic year, St. John Fisher College piloted an Apple iPad 1:1 initiative. Major goals of the initiative, now in year 2, are to achieve a level of equity by providing the exact same tools in the hands of every student, improved communication and collaboration between students and faculty, reducing paper use in support of sustainability goals on campus, and to focus on critical thinking using the SAMR model to enhance and transform the educational experience.

In this session, we will provide an overview of our pilot experience to include results from student and faculty surveys, student performance in General Biology, challenges encountered, and Ah ha! moments. We will also briefly review the specific apps and methods used to fully integrate the iPads into the classroom and will share student-created videos of how they used the technology. Participants need not be in a similar situation with Apple technology to appreciate what we share, as we aim to generalize our findings to the use of technology broadly in the classroom.

Providing common technology in the hands of students and a General Biology instructor in a pilot study revealed promise for moving students out of academic difficulty. The instructor for the General Biology course for majors taught using the Apple iPad, Apple pencil, and Bluetooth keyboard. All students in one of the two sections taught by this same instructor had the exact same technology for their use during the entire semester. After performing the worst of all sections of the course (6 among 3 instructors) on exam 1, the section using a common technology in class had a higher average exam score in the course by the end of the semester. While the student performance data collected in the pilot are difficult to tease away from other variables for this specific cohort of students, their satisfaction and perceptions on the experience were overwhelmingly positive. Based on this and findings from other courses that were part of the larger campus pilot, the institution will be moving forward with a 1:1 initiative.

Teaching a microbiology laboratory course online immediately

James F. Graves, University of Detroit Mercy

With the development of the coronavirus pandemic and the closure of the campus, it became necessary to teach microbiology laboratory for nursing and science students online. Several companies leased impressive learning management systems and others sold kits so that a student could do experiments at home. To deal with the situation quickly, an online course was constructed by using Blackboard Inc. course management software, email and the cell phone. Outlines in PowerPoint with recorded talks, scanned handouts for experiments that included the results, internet links to videos, and photographs served as material to students for asynchronous study. For virtual stain unknowns, virtual streak plates for a grade and lab reports the students could use handouts, books and internet, but were required to perform the exercises by themselves synchronously. Virtual stain unknowns existed in the form of a photograph of bacteria, instructions and short questions. For virtual steak plates, students drew sketches of an agar plate inoculated by the quadrant technique, before and after incubation, answered short questions, and submitted a photograph. Students wrote reports for selected experiments because the writing of laboratory reports was an important educational activity. Reports required Purpose, Materials and Methods, Results and Discussion in a Word document. Quizzes consisted of multiple choice questions delivered online with use of the Respondus LockDown Browser and Monitor automated proctoring system. Questions were presented one at a time, without backtracking and quizzes submitted automatically. Instead of a culture unknown (which requires several weeks of bench work), the students, in pairs, made library research posters with PowerPoint on identification of infection-causing microorganisms. Interestingly, on the virtual stain unknown and streak plate exercises students would make the same mistakes as those done in the real laboratory. Internet disconnection for students during online quizzes was a problem. Some students felt that the amount of work for the online course was excessive. An online microbiology laboratory course does have educational value, but hands-on laboratory skills still need to be developed to fulfill objectives.

Using Group Exams to Improve Student Learning

Scott M. Shreve, Lewis and Clark Community College

Lecture exams and mid-terms are commonly used to assess student learning in the classroom. I have made several efforts to make exams part of the learning process for students, without clear results. Collaborative learning has been linked to increased student achievement, and I decided to see if the benefits of collaborative learning could be obtained from traditionally summative exams. I examined the effect of group lecture exams on individual final exam and pre-post assessment scores in an upper-level evolution course during spring 2020. Exam and assessment performances were compared to students taking all individual exams in spring 2019. Scores on the lecture exams were significantly higher when taken as group exams in 2020 than as individual exams in 2019. This is expected as the stronger students are positively influencing the grades of the other students. Individual final exams, however, did not differ between 2019 and 2020 (78.8% vs. 77.5%, p=0.78). Post-semester assessment scores were slightly higher in spring 2020, but this was not statistically significant (79.0% vs. 87.3%, p=0.0897). The changes in the course format, especially in regard to exam delivery, necessitated by the coronavirus pandemic make it difficult to draw any conclusions about individual vs. group exams. However, there is no strong evidence that group lecture exams negatively impart performance on an individual final exam.

1:00-1:20 Sunday October 25th

Why students do not turn on their video cameras during online classes and an equitable and inclusive plan to encourage them to do so

Frank R. Castelli and Mark A, Sarvary, Cornell University

After transitioning to emergency remote instruction in response to the COVID-19 pandemic, our introductory biology course shifted all in-person laboratory sections into synchronous class meetings held via the Zoom teleconferencing program. Out of consideration for students, we established a policy that video camera use during class was optional, but encouraged. However, by the end of the semester, several of our instructors and students suggested that a lack of student camera use diminished their educational experience. We surveyed students to better understand why they did not turn on their cameras. We discovered several reasons including, being concerned about personal appearance and other people being seen in the background, having a weak internet connection, and it being the social norm, as well as others. This information was used to develop strategies to encourage –without requiring– camera usage while promoting equity and inclusion. Broadly, these strategies are to not require camera use, explicitly encourage usage while establishing norms, address potential distractions, engage students with active learning, and understand your students' challenges through surveys. While the demographics and needs of students vary by course and institution, our recommended strategies will likely be directly helpful to many instructors and also serve as a model for gathering data to develop strategies more tailored for other student populations.

The Culturally Responsive Science Teaching Practices of Undergraduate Biology Teaching Assistants

Hillary A. Barron and Sehoya Cotner, University of Minnesota

Utilizing pedagogies of empowerment such as culturally responsive science teaching (CRST) in undergraduate classrooms can mitigate the gatekeeping phenomenon often seen in science. Teaching assistants (TAs) engage in more one-on-one time with students than most faculty in undergraduate biology education, yet minimal pedagogical training is offered to them. Therefore, training for improved pedagogical knowledge is important for TAs, but training for culturally responsive science teaching is critical as TAs have broad and lasting impacts on students. Using constructivist grounded theory methods, this study explores the ways training for culturally responsive science teaching impacted undergraduate biology teaching assistants. This study applied grounded theory methodology to develop a theoretical understanding of the TA's experiences. Four major themes describing the ways in which TAs enacted CRST emerged from these data: Funds of Knowledge, Differentiated Instruction, Reducing Student Anxiety, and Intentional Scaffolding. Additionally, two major themes describing the things that impacted TAs' abilities to enact CRST emerged: Targeted Supports in CRST and TA Relationships with Students. Collectively, these themes have broad and important implications for the ways in which undergraduate science education can be reimagined to be more inclusive and culturally responsive.

"Is this bulls**t?" – creating an interdisciplinary learning community to increase information literacy for non-STEM majors

Elizabeth Harrison, Kennesaw State University, Tom Lilly and David Minchew, Georgia Gwinnett College, Adrienne Button, Emory University Oxford College

Today more than ever, the ability to acquire, evaluate, and use information is essential for our students not only because of the overwhelming amount of information they are exposed to in their classes and in their lives, but also because acquiring and using information is a fundamental part of life in the 21st century. Unfortunately, our students frequently demonstrate that they are not gaining the information literacy competencies needed to thrive in the 21st century. They often have limited understanding of what information is and how it is produced and valued, nor do they have the tools and strategies to effectively find and evaluate information and use it to effectively solve problems. Without these literacy knowledge practices and dispositions, our students will not be adequately prepared to meet the demands that are going to remain a central feature of their lives and careers. Learning communities are a high impact pedagogical practice that help students form relationships with other learners, learn how concepts can be applied across disciplines, and enhance student engagement and success. We used the learning community model to improve information literacy skills in our non-major biology students. Professors across three disciplines developed a learning community that was first implemented in Fall 2019 for students enrolled in Biological Sciences II (for non-STEM majors), English Composition I, and Introduction to 21st Century Information. The overarching goal of this learning community was to teach our students information literacy by explaining how to detect and deal with bulls**t in scientific and public discourse. We developed interdisciplinary assignments, communicated regularly about student progress, and evaluated students' communication skills, information literacy, and intercultural awareness. By the end of the semester, students were able to differentiate between different sources of information, research information from various perspectives, and effectively communicate about scientific topics.

3:00-3:20 Sunday October 25th

Development of the Community College Research in Education and Scholarly Teaching (CCREST) Program

Heather Seitz and Jean Ann Vickers, Johnson County Community College

The CCREST program is an NSF funded project (IUSE #1711693) to support community college STEM faculty in the Kansas City metro region engage in work on the Scholarship of Teaching and Learning (SoTL). The overarching goals of the CCREST program are to create an opportunity for faculty to be trained in the practices of SoTL and be supported for their research work. We are further interested in how this support increases community college faculty engagement in publishing and presenting their educational research findings.

The CCREST program includes training in scientific teaching practices and scholarly research design in the classroom. Following this initial training, the faculty participants are supported throughout the school year with a faculty learning community. The final component of the program is a capstone training to help faculty analyze their data, discuss the appropriate use of statistical analysis in educational data, and prepare their results for publication or presentation.

Through implementation of the program we have collected baseline teaching practices data using the COPUS method as well as the ATI instrument. In addition to teaching practices evaluation, we have analyzed data supporting faculty participation and evaluation of the training workshops. Finally, lessons learned from faculty and program directors highlight the challenges faculty face in implementing SoTL in the community classroom environment.

Student Perceptions of Scientific Reading and Writing Ability in a Comparative Physiology Course

Christina Wills, Rockhurst University

After the completion of curriculum reform in 2016 to more align with Vision and Change, Rockhurst University's General Physiology course was transformed from a test centered mammalian (primarily human) physiology course into a writing intensive comparative physiology course taught in the Fall odd years. Students were assigned: a weekly writing task that focused on writing to diverse audiences, three literature reviews (on plants, fungi, and animals), and a final poster presentation on a topic not covered in the course. A survey on student perceptions of reading scientific literature and scientific writing skills was administered on the first and last days of class. In response to a semester of a writing intensive course, students indicated that they perceived an overall increase in their comfort level writing to different audiences, their ability to read and understand scientific literature, and their ability to write scientifically. Students also perceived that their overall writing skill levels increased over the semester.

40-Minute Oral Presentations

11:20-12:00 Saturday October 24th

Course-Based Undergraduate Research During and Beyond COVID-19

Alita Burmeister, Melanie Bauer and Mark Graham, Yale University

Course-based Undergraduate Research Experiences (CUREs) address the limited number of early, authentic research opportunities available and retain more college students in STEM. With the outbreak of the COVID-19 pandemic, the national CURE education landscape changed quickly and dramatically with limited time for planning new curricula. This situation presented a unique window to explore how CUREs change in newly-online environments and whether activities from such courses can be used to enrich research-based learning more generally. To do this, we used a qualitative approach through focus group interviews of CURE instructors to capture and analyze instructors' options on translating into online formats. We asked participants to focus on the knowledge, attitudes, and skills -- apart from those directly requiring in-person experimentation -- that would be important for students to develop as professional research scientists. Across all focus groups, instructors identified 51 research-enriching learning objectives and constructed 17 course activities using the backwards design method. In this 40-minute talk, we will present these activities and instructors' insights for possible, immediate use during the 2020-2021 academic year as universities continue to face sudden shifts back to online instruction. We will also discuss the potential for many of these learning objectives to be useful beyond COVID-19 to enrich students' experiences in both research-based and traditional laboratories.

New Kits to Teach CRISPR: Both Hands-on and Online Resources Available

Ian Harwood and Delquin Gong, Bio-Rad Laboratories

CRISPR is revolutionizing science, but reliably and affordably teaching CRISPR-Cas9 gene editing in course laboratories has been difficult. In this talk, how students can learn the science, math, and ethics of CRISPR gene editing and genotyping using hands-on experiments, mechanistic and mathematical modeling, and bioinformatics will be introduced.

Bio-Rad's new award-winning Out of the Blue CRISPR and Genotyping Extension kits includes laboratory activities that use CRISPR-Cas9 to change bacteria colonies from blue to white, PCR and gel electrophoresis to confirm gene editing, and free on-line resources including modeling the molecular mechanism and designing CRISPR therapies for diseases using bioinformatics.

A prize will be raffled: attendees need to attend to be eligible to win. For more information visit http://www.bio-rad.com/outoftheblue and http://www.bio-rad.com/teachcrispr

Knerdy innovations in biology courseware

The Wiley Team

Wiley is proud to debut Concepts of Biology for non-majors courses at ACUBE. Alta is Knewton's fully integrated, adaptive learning courseware. A complete course solution, Alta is designed to optimize the way students study and learn while completing assignments. All of Alta's content — including instructional text and video, examples and assessments — is organized by learning objective and served up at the precise moment a student needs it. Alta helps students achieve mastery in your course. If a student struggles on an assignment, Alta recognizes their knowledge gap immediately and provides just-in-time remediation — even when it requires reaching back to prerequisite concepts. Alta is $39.95 and provides students with everything they need to complete their course. Registered attendees will receive a Knewton Alta Knerd t-shirt.

2:10-2:50 Saturday October 24th

Roundtable Discussion: Teaching CRISPR, COVID and More

Ian Harwood, Delquin Gong and George Chenaux, Bio-Rad Laboratories

In this roundtable facilitated by scientists and staff of the Bio-Rad Explorer education program, attendees are invited to participate in discussions on teaching CRISPR gene editing and emerging CRISPR technologies, advanced diagnostics techniques including multiplex PCR, quantitative PCR (qPCR), and droplet digital PCR (ddPCR), and skills in-demand by employers including product development, manufacturing, and quality control/quality assurance.

A prize will be raffled: attendees need to attend to be eligible to win.

From CRISPR to COVID, Bio-Rad's R&D scientists are developing and using cutting-edge technologies for use in undergraduate courses, academic research, and industrial and diagnostics applications.

For more information about the Bio-Rad Explorer education program, visit http://www.explorer.bio-rad.com

Doctor in the house: Improving undergraduate critical thinking skills through diagnosing medical case studies

Robin Forbes-Lorman, Ripon College and Julia A Lily

Students in undergraduate anatomy and physiology courses are not often exposed to clinical examples of homeostatic imbalances, particularly ones that provide an opportunity for the diagnosis of a medical case. Last spring, a senior undergraduate student and I designed a set of medical cases that required students to integrate their content knowledge of multiple organ systems, practice critical thinking related to diagnostic processes, and communicate effectively. Students were given a patient's symptoms and medical record, and are asked to determine the patient's illness, its cause, and a treatment approach. Over several weeks, students used deductive reasoning to diagnose the primary and underlying condition of their patient and prepare a formal report on their patient's condition and their recommended treatment. In addition to requiring students to apply their prior knowledge, this lesson introduced homeostatic imbalances in a unique way and also has the potential to be revised to ask students to consider common cognitive biases that occur during medical diagnosis. I will present an overview of the lesson and then ask for feedback and facilitate a discussion about similar activities that others have done. Particularly, I am interested in discussing other ways that instructors incorporate similar (or perhaps better) activities and reflection on these activities.

Can evolution misconceptions be corrected?

Lynn Swafford, Wayne Community College

Most biology students have preconceived ideas about what evolution is and how it works. So in my general biology for non-majors courses, I use pre-tests to help determine what these initial misconceptions are. Then after covering evidence and mechanisms for evolution, my students complete a group activity in which they work together to research and correct common misconceptions about evolution. At the end of the semester, I also give a post-test to figure out what evolution concepts my students are still struggling with. Come learn about these three activities, find out which evolution misconceptions are the most difficult to overcome, and contribute your own suggestions to a discussion on how to correct evolution misconceptions.

9:30-10:10 AM Sunday October 25th

A model for a hyflex majors-level high enrollment Principles of Biology laboratory

V. Christine Minor and Lauren E. Stoczynski, Clemson University

Fall 2020 presents a unique and difficult challenge to many of us who are trying to provide students with in-person but safe experiences in the face of COVID-19. As Fall approaches, instructional targets continue to shift; therefore, laboratories, as well as other classes, must be flexible, for both online and in-person access. At our institution, students have a choice regarding HOW they attend classes and this choice may flex from week to week. The ability to choose makes laboratory instruction especially challenging. Our approach includes deconstructing traditional in-person labs into their constituent components of tactile skills, experimentation/inquiry, and data analysis skills. Content related experimentation/inquiry and data analysis skills were tested for online delivery during the summer using the LMS with instructor support available. Tactile skills are being delivered in a hyflex in-person mode. In this presentation we will illustrate how we "deconstructed" each lab, how we approached all of our learning outcomes through this model, how we flex as needed, and how we manage logistics of moving large numbers of students (approximately 600 students and 12 TAs) through the process. We will also address lessons we have learned from preparing for this approach that can be applied to biology laboratory curriculum construction no matter what situation we find ourselves teaching in the future.

Resilient Classrooms Mitigate Student Resistance

Neil Haave, University of Alberta, Augustana Campus

We know that active learning promotes student learning outcomes (Freeman et al, 2014). Despite our best intentions, however, some students continue to resist our implementation of active learning (Tolman & Kremling, 2017). Two important issues are critical to mitigating student resistance to learning. One is that instructors must carefully consider how they facilitate active learning with their students (Finelli et al, 2018). The other is that although many consider resilience to be a quality developed within students, recent research suggests that resilience is a product of our environment (Ungar, 2019) suggesting that how we construct our classrooms can have a large impact on our students' resilience for learning. This presentation invites participants to discuss how instructors may best respond to students' resistance to learning by better facilitating the learning activities we implement in our classes and designing our courses for resilience.

Citations

Finelli, C. J., Nguyen, K., DeMonbrun, M., Borrego, M., Prince, M., Husman, J., Henderson, C., Shekhar, P., & Waters, C. K. (2018). Reducing student resistance to active learning: Strategies for instructors. Journal of College Science Teaching, 47(5), 80–91.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences of the United States of America, 111(23), 8410–8415.

Tolman, A. O., & Kremling, J. (Eds.). (2017). Why students resist learning: A practical model for understanding and helping students. Stylus Publishing, LLC.

Ungar, M. (2019). Change your world: The science of resilience and the true path to success. Sutherland House.

Interdisciplinary teaching and active learning approaches for an energy conservation theme in biology, physics, and chemistry courses

Joanna Cielocha, Nancy Donaldson, Lisa Felzien, and Michael Marvin, Rockhurst University

Interdisciplinary teaching initiatives across science disciplines are an effective way to tie together curricula for both students and faculty. Designing meaningful and engaging activities that span science disciplines is challenging and forces faculty to grapple with their own misunderstandings and knowledge gaps, allowing a better grasp of the student experience. We have formed a collaborative faculty group representing the disciplines of physics, physics of medicine, molecular biology, ecology and organismal biology, biochemistry, and chemistry. We have focused on the topic of energy and taken the approach that connecting the concept of energy conservation with energy transferin our disciplines may be achieved through a shared set of tangible energy transfer examples from physics; big picture, ecological concepts from biology; energy conversions in photosynthesis and cellular respiration in biology and biochemistry; and chemical reactions in biochemistry and chemistry. We have also developed diagrams and graphical models to help students see connections among our classes and to assist with their construction of knowledge about big-picture, conceptual ideas that are woven through our disciplines. Our approaches build on active learning models developed in our Physics of Medicine program at Rockhurst University. In this presentation, we will share our common examples, diagrams and graphical models as well as the iterative process of developing pre and post assessments methods to examine student learning and attitudes. Initial results from our most recent assessment approach include General Biology I (cellular and molecular topics), General Biology II (energy transfer in an ecosystem), General Biochemistry I (energy transfer during metabolism), and Physics of Medical Imaging (full course integration of energy topics).

80-Minute Workshops/Roundtables

9:20-10:40 AM Saturday October 24th

Build-a-Course Workshop

Rebecca S. Burton, Alverno College

A step-by-step workshop starting with valid outcomes and working through authentic assessments, clear criteria, and effective rubrics. Bring your ideas for a new class and leave with a plan.

How science works: teaching the personal and dynamic nature of science

Rosie Bolen, Mount St. Mary's University, and Kathryn S. Jones, Howard Community College

Numerous studies have shown that material presented in activities that students find emotionally engaging and personally relevant contributes to student success. This workshop will introduce participants to two free, ready-to-use resources designed to increase student engagement. The resource Scientist Role Models from Howard Hughes Medical Institute's (HHMI) BioInteractive allows students to explore profiles of diverse field and laboratory scientists and choose one researcher study in depth. In this activity, which is appropriate for both majors and non-majors, students are guided by a worksheet to investigate the scientist's research and write about what they learned. An advanced version of the handout, in which students read primary literature authored by the scientist, is available for upper-level students. Instructors can supplement the HHMI BioInteractive profiles with information from the Scientist Spotlights Initiative web resource. This activity personalizes the process of science by learning about the lives and work of diverse scientists, helps students feel like they belong in science and promotes inclusion in the classroom. The AAAS Science in the Classroom resources introduces students to the authentic, dynamic nature of science by making primary literature accessible to a broad audience. This site provides undergraduate students (and their professors) scaffolding of journal articles by providing extensive annotations and supplementary materials, including embedded videos and data-driven activities. The articles reflect a variety of topics that are relevant to students' lives. Participants in this workshop will experience both of these resources from the perspective of the student and will get implementation suggestions from facilitators who have used these resources in their classrooms. Participants will also have the opportunity to explore different activities available for these two resources and reflect on how they could use them in their classrooms.

Cell Collective: Computational modeling and simulation designed with the classroom in mind

Ehren Whigham, University of Nebraska-Lincoln, Dane Bowder, Doane University

Cell Collective (https://cellcollective.org) is a free, web-based, research-grade modeling platform adapted to engage students in creating and simulating dynamic models of biological processes. The ability to use modeling and simulation is identified as a Core Competency by Vision and Change. The use of modeling and simulation emphasizes higher-order cognitive skills, positioning students to be critical and reflective thinkers proficient in problem-solving and effective communication.

In this workshop, participants will experience, as a student, how to build a model of a biological system. That model will then be used to simulate the behaviors of the system. Comparing the behavior of the system under varied conditions helps students gain insight into the mechanism of the phenomenon. When used in a classroom, students will make and test predictions and faculty can highlight elements of experimental design.

Participants will gain confidence and experience in computational modeling which can be leveraged in their courses through self-contained, guided exercises. Cell Collective laboratories are suitable for introductory through upper-level classes and are readily completed in either an in-class or remote setting. We will end with descriptions of the varied ways Cell Collective has been leveraged in courses.

3:30-4:50 PM Saturday October 24th

Hands-on Molecular Biology Labs at Home. Teach DNA Structure, Gene Expression, and Enzyme Kinetics Remotely

Ally Huang, miniPCR bio

We invite you to participate in a hands-on session of our BioBits Central Dogma Lab. You will visualize the flow of genetic information and monitor transcription and translation in real-time through fluorescent readouts. Because the labs uses cell-free freeze-dried technology, minimal equipment is required and the protocol is quick and straightforward - perfect for learning about the central dogma of molecular biology right in your own home. We will also discuss how other core concepts such as DNA structure and enzyme activity, and practical applications like micropipetting and serial dilutions, DNA amplification and the fundamentals of fluorescence can be explored using the P51 Molecular Viewer platform.

You will receive a P51 molecular view and all the reagents needed to perform the experiment. Limited to 15 participants.

Improving visual literacy using PyMOL, augmented reality and LEGO bricks®

Swati Agrawal, University of Mary Washington, and Shane Austin, The University of the West Indies

Students pursuing biochemistry and cell biology courses encounter several examples of proteins and nucleic acids in classes. These examples vary in complexity and the level of detail they are required to study, often the textbook or learning resource will contain cartoon images of the protein. Each image encodes lots of information and relies on several discipline specific norms; including, use of color, shapes, patterns and illustrations that the students have only previously seen as drawings. This makes obtaining information from these illustrations difficult for some students.

We have developed a series of active learning strategies to enhance visual literacy of our students. Replacing traditional lecture-based instruction with hands on engaged learning has significantly improved student perception of complex 3 dimensional architecture of proteins and Nucleic acids and their interactions. This is mainly because this teaching method provides a tactile way to interact with structures that are usually only shown in 2D using pictures. During the proposed workshop, participants will take part in two guided activities based on themes in glycolysis and Krebs cycle and learn how to incorporate active learning strategies using protein databank (PDB) and the molecular visualization tool PyMOL and Augmented reality. We will share step by step lesson modules prepared to ease student familiarity in navigating and exploring information found on Protein Data base. Participants will learn how to use pymol in classes to teach key concepts in macromolecule structure and function. Relation of the structural features of proteins to their function is one of the underpinning themes in the study of proteins in both biochemistry and cell biology. Therefore, being able to predict how proteins will be affected by mutation or modification is important. Using LEGO® bricks as metaphors, instructors will build models to explain this, and also learn how to guide students to generate suitable models that represent the various facets of proteins' functions and processes. Finally we will guide them through a series of easy to use protocol to prepare renderings of proteins and nucleic acids in order to visualize it using Augmented reality.

Do We Really Want Our Students to be Scientists?

Brittney N. Wyatt, Utah Valley University

As the college population becomes increasingly diverse, there is an important need to create inclusive, welcoming STEM environments for all students to succeed in science. This success might come in the form of a student who transforms into a scientist, science person, science learner, or someone who feels connected to the scientific community at the end of their educational experience. Students that identify with science are more likely to persist in their STEM courses and continue on to STEM-related careers. However, how this identification has been defined and measured varies between studies. As educators and researchers, what does science identity mean to us and what does it mean to our students? Do we want our students to identify as a scientist or as a science learner? Based on preliminary data, entry-level students describe scientists through classic stereotypes (intelligent, analytical, curious), while students who have either been exposed to an intervention or are at the end of their undergraduate career, describe scientists as learners. Students who stereotypically describe scientists do so because of how their previous science courses have influenced them. Through analysis of introductory biology textbooks, scientists are mentioned in terms of their actions (classify, determine) and by historical references of primarily white men. All of which could prevent students from identifying with science. In this workshop, participants will review science identity theories and assess preliminary results on how high school, introductory biology, and senior-level biology students view scientists. Possible interventions such as research projects, scientists spotlights, and growth mindset assessments to promote student science identity will be discussed. The workshop will also include time to network with fellow educators and researchers on the importance of assessing science identity that benefits our students, which ultimately might mean something other than being a scientist.

1:30-2:50 PM Sunday October 25th

Teaching Like a Pro in Your First Years

Rebecca S. Burton, Alverno College, Conrad Toepfer, Brescia University, Jason Wiles, Syracuse University

Which educational innovations have been validated by peer-reviewed studies and which have been debunked or never tested? How can you maximize the cooperation of students, peers, and administrators as you implement the best in innovative pedagogy? What effective and efficient strategies will allow you to focus your time and attention on what matters most? Where can you find excellent "turn-key" activities? Master teachers will facilitate a discussion on pedagogy, logistics, and careers for new and aspiring biology educators. Experienced educators are also welcome.

A moment can change your mind: mindfulness and mindset interventions to increase success and persistence in STEM

Melissa Goodwin, Sara Goodman, Noveera Ahmed, Michelle Erklenz-Watts, and Kristin Picardo, St. John Fisher College

This workshop will demonstrate class-based mindfulness and mindset interventions and activities that can be infused throughout a STEM curriculum and students' college experience. Activities include a 'mindful minute', reflective journaling, and cognitive reframing and strategizing practices regarding content as well as lived experience.

Our NSF funded research demonstrates the effectiveness of an academic experience infused with mindfulness (a practice known to lead to structural and functional changes in the brain) and mindset exercises (a practice known to lead to differential responses to challenge and difficulty) on increased persistence and success in biology and chemistry for academically talented, economically challenged students. By coupling strategic mindset selection training with mindfulness practice, students and educators alike can learn to take advantage of a momentary pause in order to make a metacognitively appropriate shift in motivational framing of a task or challenge. Early findings indicate 100% retention and academic success of NSF S-STEM supported students in the program, even in the midst of the disruption throughout the ongoing global pandemic.

One activity we will share is the 'mindful minute'. In a seminar course for first-year S-STEM scholars, students were first introduced to the concepts of mindfulness and mindset. They were then asked to regularly apply the practice of mindfulness to specific situations they encountered along their first year in their STEM classes and transition to college life. To do so, the group decided on a particular challenge they had in common. They then explored what a growth mindset response might be, a fixed mindset response, and how to harness the power of the 'pause' to make a decision about the best way to move forward.

In this workshop, we will describe the literature behind the neuroscientific basis for applying mindfulness and mindset practices to student learning which will become the content we use in our activity together. We will model how educators can use these practices in their classrooms as well as in their own professional development. To do so, we will invite participants to create concept maps and apply the reflective practice strategies we use when teaching content with our own students.

This material is based upon work supported by the National Science Foundation under Grant No.1833904. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Fostering Inclusive Learning Environments in STEM

Natalia Caporale, Michael Moore, Jana Marcette, iEMBER

Despite increases in the diversity of students who enroll in undergraduate STEM majors, this diversity is still not present in the American STEM workforce. This disparity is largely due to the disproportionate attrition of STEM of students of color, women, and students with disabilities due to a variety of systemic, institutional barriers. [RC1] Sense of belonging and the feeling of being included in the science community have been shown to play key roles in promoting retention of students in STEM. Classrooms are the first formal introduction of most students to STEM disciplines, and as such, they can be considered as micro-ecosystems of STEM. Creating inclusive environments in STEM classrooms can increase students sense of belonging and has the potential to promote student retention. In this workshop, participants will engage with each other to examine their own perspectives of the meaning of inclusion and how these perspectives shape their goals and classroom practices. This discussion will be followed by the presentation of several tools and strategies for creating inclusive and supportive classrooms including: (1) ways to gently encourage active participation of all students in the classroom; (2) reflection prompts to examine their own biases and how those biases may impact their teaching; (3) discussion of the importance of non-content related instructor talk in framing activities and classrooms. Subsequently, participants will engage with each other to discuss these tools as well as the barriers that they may encounter when trying to apply them as well as potential strategies to address those barriers. This workshop is aimed at everyone interested in learning more about inclusion and how to foster inclusive environments. This workshop is organized by members of the iEMBER (inclusive environments and metrics in biology education research) network. This network focuses on promoting inclusive learning environments in STEM by fostering discussions and research collaborations among professionals from STEM, science education and social sciences.

Poster Presentations

Special place assignments: connecting ecological concepts to each student's unique locale through scaffolded portfolio assignments

Anne CS McIntosh and Jody Rintoul, Augustana Campus, University of Alberta

Many biology courses include standard forms of assessment such as midterm exam(s) and a final exam in the lecture portion of the course, and a series of lab assignments that students complete over the semester. In addition to active learning activities in the lecture portions of biology courses, we think it is important to provide alternative forms of assessment that can help to reinforce concepts that students learn about in both lecture and lab. In introductory ecology courses and those that build on them, a central learning objective is for students to be able to describe and explain how abiotic and biotic environmental factors interact to contribute to the ecological properties (structure) and processes (function) that are observed from the scale of an individual organism up to a biome. In this poster we will introduce two 'special place' assignments that provide undergraduate biology students with opportunities throughout the semester to make linkages between course topics and a physical place that has unique value for them. In our introductory ecology course students respond to a series of questions for each topic, and in our more advanced community ecology course, students must additionally reference journal articles related to each of the ecological concepts we are focused on in class, and formulate research questions related to their special place. In both special place assignments, these scaffolded learning opportunities culminate in creation of a final portfolio document that applies the ecological concepts that students have learned to interactions within each of their special places. Our goal with these assignments is that by anchoring concepts and ideas to a special physical place, our students can more meaningful comprehend the importance and relevance of the information they learn about. This will in turn open the door to new ecological ideas and questions that will further student learning beyond the classroom.

Student Designed Study Resources for Human Anatomy and Physiology Cat Dissections

J.T. Cornelius

As an undergraduate honors project in human anatomy and physiology at Rockhurst University, I developed a supplemental resource to assist students through a cat dissection as such activities provide an excellent hands-on opportunity to study anatomy. The goal of my project was to compile and create various sources to aid in the dissection of a cat for an undergraduate human anatomy and physiology course. This turned into a lab manual/study guide resource to direct students through the dissection process and emphasize conceptual learning. This dissection guide was created with the intent to support students learning and to guide them through the detailed process of dissections. The guide I created is composed of checklists, color coding activities, practice quizzes, supplemental YouTube videos, and application/recall exercises to facilitate the study of human anatomy and physiology. Through this project I was able to understand and expand on the importance of proper adaptations of learning materials to aid in the further expansion of anatomical concepts as well as increasing my own understanding of the material.

The influence of habitat complexity on crayfish foraging behavior

Randi (Ruth) Darling, Westfield State University

I teach an animal behavior course where students conduct independent research projects; however using live animals for research is challenging at a small university. Often, students choose to conduct a laboratory project over a field project believing that it will be easier to observe animals and control variables, but it can be difficult and expensive to acquire and maintain animals. If students work with vertebrates, there are added complications such as obtaining Institutional Animal Care and Use Committee (IACUC) approval and training. Additionally, following IACUC regulations often involves resources that we do not have. Because of these complications, I suggest to students that they consider an invertebrate species for their projects. In particular, crayfish are a species that are easy to obtain and care for, have low mortality, and exhibit interesting behavior that can be observed over several weeks. This article describes an inquiry-based research activity examining the influence of habitat complexity on crayfish foraging. This activity is well suited for students in ecology, animal behavior or invertebrate biology classes and gives students flexibility in the hypothesis they test and the methods they use, while providing a framework that lets them successfully complete a behavior project.

Foundations of STEM success: Using a cohort model with mentoring and supplemental instruction to enhance STEM student success

Katie Burgess, Alicia Murillo, William Moran, and Darrin Smith, Avila University

Avila University's Advancing Cohorts of Excellence in STEM (ACES) NSF Program is designed to improve retention, graduation, and overall academic success of its scholars. S-STEM scholars are low-income, academically talented students majoring in Biology, Biochemistry and Molecular Biology, Computer Science, or Software Engineering. The ACES Program has implemented support services that include a cohort model, common coursework with course-specific supplemental instruction, STEM seminars, STEM resource center, and faculty, peer, and professional mentorships. The program is working to improve data analytics by creating a STEM Student Success Dashboard, which will facilitate monitoring and analysis of on-track indicators by discipline, student subgroup, and dosage of support services. Furthermore, a qualitative analysis of the lived experiences of S-STEM scholars is being conducted to determine how the student support resources and activities aid in meeting the grant objectives. Preliminary findings demonstrate that S-STEM scholars had increased first year retention compared to non-S-STEM students and analysis of second-year retention and graduation rates is ongoing. (NSF Award #1643549)

Virtual science camp: maintaining community connections during the COVID-19 pandemic

Daniel Kiernan and Pearl Fernandes, The University of South Carolina

Campus connections with local schools continue to be an important part of the mission of many institutions of higher education. For many years now, our division of science, mathematics and engineering has functioned in a general support role for many local schools. For example, we play a unique role aiding STEM-focused programming in both the public and private sectors. As we do this, we also work to build bridges with young people in the hope that our institution will be on their mind when they someday make decisions about collegiate education. One way our university has supported STEM in our local area has been to offer a summer STEM-based camp for the last 10 years. This camp offering has drawn out local students to campus each summer to experience STEM under the direction of various professors in the lab setting. This past summer because of the COVID-19 crisis, many programs that reach the community including programs of higher education were canceled. This presentation focuses on the success of our virtual STEM camp to continue to reach young people and build connections between our institution and our local community. Initial data indicates that this virtual venue functioned as a viable option for colleges and universities to continue to support local schools and STEM education. All who want to build deeper connections between your science department/division and your local community are encouraged to attend.

Faculty responses to COVID-19 emergency remote teaching transition better with experience or training

Lisa L. Walsh, Sandra Arango-Caro, and Kristine L Callis-Duehl, Donald Danforth Plant Science Center

Beginning in early March, U.S. higher education institutions moved classes online in response to the coronavirus disease 2019 (COVID-19) pandemic. Developing an online course often takes months of planning, and quickly transitioning a course online may not provide instructors with enough time to do so effectively. The support provided to faculty to transition their classes online varied nationwide (Crawford et al. 2020). We surveyed over 100 biology faculty across the country to gauge their preparation for and experiences with emergency remote teaching to better understand faculty experiences during times of crisis. Each participant revealed if they had taught online before COVID-19 and if they received formal training for online teaching during or after the COVID-19 transition. Faculty described the difficulties and benefits they encountered teaching online, along with a memorable moment from teaching during the COVID-19 pandemic. Their responses were read multiple times to identify emerging themes, independently coded by two researchers and reviewed for consensus. We used decision tree forests to identify the most polarizing themes for experienced vs. inexperienced online teachers and instructors who did vs. did not receive training. More than 65% of faculty surveyed had never taught online before COVID-19 and those inexperienced faculty were three times more likely to struggle with engaging students online. Experienced online teachers were almost four times more likely to have a memorable moment associated with kindness. By August, 41% of faculty surveyed had not received formal training in online teaching. Faculty who did not receive formal training were twice as likely to describe a negative memorable moment, while faculty who received formal training were less likely to struggle with fostering a sense of community in their virtual classroom. The most common academic difficulty faculty encountered was student engagement, followed by transitioning to a virtual class. Our results demonstrate the positive impacts that experience and formal training had on faculty and students and underline that training for online teaching should prioritize how to engage students online and virtual activities that foster community. Finally, it highlights the importance of rapid re-training of faculty during an educational emergency so they are better prepared.

Face-Face to Online: Reflections during the COVID-19 Pandemic

Pearl Fernandes and Daniel Kiernan, University of the South Carolina

Face-face teaching has been the traditional method of learning for students. A face-face class provides a structured learning environment where students attend the lecture in a classroom setting at a set time and interact with their peers and the instructor. The COVID-19 pandemic caused an abrupt shift from face-face to an online learning environment.

A reflection study was conducted on biology majors who had to switch class to an online format on goals, challenges, and skill sets from the online class. Students were asked if they had achieved their goals at the end of the semester. The majority of the students felt that they achieved their goals but had to work more in an online class. Students who did not feel they achieved their goals reported that the lack of a structured environment and lack of good time management skills affected their goals.

Students reported that they learned better when they were around their peers or had in-class discussions. Challenges that all students faced in an online class were self-motivation and staying focused. Nearly all the students said they missed the full experience of being and learning in a classroom setting.

The biggest skill that students took away from the online class and the pandemic was flexibility. They feel that adapting to change is vital to success. Other skill sets that they learned were self-motivation, organization and strategies to become an independent learner. Students relieved their stress with online learning and the pandemic by interacting with their peers through social media and taking breaks between learning by exercising. Overall, students felt that they learned more about themselves and how to enhance self-care so they could achieve success as independent learners.

Competency-based testing improves class performance in a large-enrollment introductory biology class

Joseph Ankrom and Michelle Withers, Binghamton University

Unlike formative assessments which happen during the learning cycle and provide immediate feedback on learning that allows both the teaching and student to make necessary corrections, summative assessments tend to occur at the end of a unit when finding out that a student has failed does not provide opportunity for improvement. Although we often tell students that failure is part of the learning process, we do not assess our classes as if this is true. If students fail an examination early in the semester but attain competency on the material by the end of class, the early failure is typically calculated as part of their final grade for the course. Why do we care if a student learns the material immediately or if it takes multiple tries as long as they attain an acceptable level of proficiency by the end of the course? Competency-based testing allows educators to drive learning with summative assessments in much the way formative assessments work. This approach provides a trial-and-error format for students to test, learn what they know and do not know, correct misunderstandings, fill in knowledge gaps, and/or practice necessary skills, and re-test. We replaced a traditional testing paradigm with competency-based testing in a large-enrollment (>200), introductory biology class at a research university. Students were primarily first-semester freshmen roughly equally split between male and female. The class was taught using evidence-based teaching strategies where students spent roughly 70% of their time engaged in active, collaborative work answering polling questions, solving problems or case scenarios, and/or engaging in model-based reasoning exercises. In the traditional testing format, students took four midterms and one final examination composed of multiple-choice, matching, True/False, fill-in-the-black and short answer questions. In the competency-based format, students took two midterms and a final examination similar to the traditional examinations, however, they also took online examinations every two weeks that were composed of isomorphic questions that allowed them the opportunity to test and correct their understanding. Student performances increased in courses using the competency-based testing approach.

A Peer Observation Rubric for Integrating Cultural Awareness into our Classrooms

Tara Prestholdt, The University of Portland, Heather Dillon, The University of Washington, and Stephanie Bartlett, The University of Calgary

This poster highlights a peer observation rubric that can help answer questions such as what new knowledge and tools we need about different cultures and pedagogies and how might our classroom activities create dialog and deeper knowledge of people and places.

Nipped in the Bud: COVID-19 Reveals the Malleability of STEM Student Self-Efficacy

Kirkwood M. Land, University of the Pacific, Eileen K. Camfield, University of California, Merced and NaTasha Schiller, Wingate University

When a global pandemic hits in the midst of a longitudinal study of biology student success, researchers can unearth rich information about student resilience. By sharing case studies from two demographically different mid-sized 4-year institutions, this article illustrates the aspects of student academic efficacy that were undercut by the shift to emergency remote instruction (ERI) in introductory biology courses in spring 2020: agency and belonging. By assessing student predictions of exam performance and analyzing themes from 276 student narrative efficacy surveys, the authors highlight the power of a careful balance between cognitive and social interventions to help students recover. Students in this study showed a 50% loss of efficacy after ERI (mid-semester) but were able to improve to at least 75% above starting efficacy after instructor mediated responses. Thus, the authors also show how academic efficacy highly is malleable. In turn, they demonstrate a new assessment model that uses student narrative writing to reveal "invisible" threats to students' perceptions of their capacity to succeed. Finally, they generalize from their findings to provide recommendations for effective strategies for supporting those students for whom every semester

The Mobile Summer Institutes: Addressing institutional barriers to teaching reform

Michelle Withers, Robert Bills, Elias Miller, and Joseph Ankrom, Binghamton University

While research has demonstrated the benefits of active learning on student performance, the majority of post-secondary STEM educators still rely heavily on passive lecture formats. This disconnect results from many factors, including lack of training and institutional support and incentive structures for improving teaching. Pedagogical training addresses the first issue but, alone, cannot overcome institutional barriers to teaching reform. The Mobile Summer Institutes on Scientific Teaching (MoSI) is a place-based adaptation of the successful National Academies Summer Institutes (SI) intended to address both individual and institutional barriers to change. Two workshops, one for administrators and one focused on strategic planning, were added to the original SI format, based on Henderson's 4 Categories of Change Strategies. During the facilitated strategic planning session, MoSI participants identify aspects of a campus that would make it ideal for student learning, then determine where their campus falls short of the ideal. They then develop strategic plans to address one or more of the shortcomings. Notably, nearly every institution has identified teaching evaluation as a barrier to implementing active learning strategies. This issue was incorporated into the strategic plans of every pilot MoSI. The program has expanded to serve over 30 post-secondary institutions representing a variety of types, and while strategic plan topics have become more diverse, teaching evaluation continues to be a common focus. In this study, we are using grounded theory thematic analysis to determine the relationship between a variety of factors such as institution type, participant demographics, level of administrative support, etc., and the types of barriers identified and incorporated into strategic plans.

Redesigning the Undergraduate Human Anatomy and Physiology Course to Align with Vision and Change

Amy K. Hebert, Merrilee F. Guenther, and Corey Shaffer, Elmhurst University

Much work has been done to incorporate the guidance of Vision and Change (AAAS 2011) into the undergraduate biology curriculum, however little has been done for human anatomy and physiology courses. At Elmhurst University, we set out to redesign our course to better align with Vision and Change and incorporate more student-centered learning. Course learning objectives derived from the Human Anatomy and Physiology Society (HAPS) were mapped to core concepts (also referred to in class as the "Big Ideas of Biology": evolution; structure and function; information flow, exchange, and storage; pathways and transformations of energy and matter; and systems) and homework was designed to guide students through objectives. Course meetings consist of infrequent small lectures on the big ideas with the majority of class time dedicated to small group review of objective homework, case-studies, and other application-based activities. An assessment was designed and will be administered as a pre- and post-test to measure student ability to relate the core concepts/Big Ideas to the learning outcomes of the course. The goal of this work is to enhance student understanding of the relationship of Anatomy and Physiology to the core concepts of biology, while also improving overall student performance and critical thinking skills.

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, should not use any hidden from view editing tools, should not use footnotes, and should not use a reference manager to develop the reference list. All references should be entered individually and follow the current APA latest edition Publication Manual. The text font for the entire document should be Calibri 10 point. All weights and measures must be given in the SI (metric) system.

C. In text citations:

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).

D. 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.

It is important to note the formatting. Articles with incorrectly formatted reference lists may be returned to the authors for corrections. Note that only the initials and the first letter of the full name of an author are capitalized.

The following information and examples for referencing and constructing tables, and figures were taken from the ***Publication Manual of the American Psychological Association: The Official Guide to APA Style***, 7th ed.

(1) Articles

Articles without a DOI

(a) Single author

Anderson, M. (2018). Getting consistent with consequences. Educational Leadership, 76(1), 26-33.

(b) Two authors

McCauley, S.M., & Christiansen, M.H. (2019). Language learning as language use: A cross-linguistic model of child language development. Physiological Review, 126(1), 1-51.

(c) 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.

(d) Mutli-authored more than seven authors

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

Articles with a DOI

(e) McCauley, S.M., & Christiansen, M.H. (2019). Language learning as language use: A cross-linguistic model of child language development. Physiological Review, 126(1), 1-51. https://doi.org/10.1037/rev0000126

(2) Chapter in an edited book

Book without a DOI, from most academic research data bases or print version

(e) Weinstock, R., Leong, G.B., & Silva, J.A. (2003) Defining forensic psychiatry: Roles and responsibilities. In R. Rosner (Ed.), *Principles and practice of forensic psychiatry* (2nd ed., pp 7-13). CRC Press.

Book with a DOI

(f) Balsam, K.F., Martell, C.R., Jones, K.P. & Safren, S.A. (2019). Affirmative cognitive behavior therapy with sexual and gender minority people. In G. Y. Iwamasa & P. A. Hays (Eds.),*Culturally responsive cognitive behavior therapy: Practice and supervision* (2nd ed., pp 287-314). American Psychological Association. https://doi.org/10.1037/0000119-012

(4) Web sites

Webpage on a website with a group author

(g) Centers for Disease Control and Prevention. (2018, January 23). *People at high risk of developing flu-related complications*. https://www.cdc.gov/flu/about/disease/high_risk.htm

Webpage on website with an individual author

(h) Martin Lillie, C.M. (2016, December29). *Be kind to yourself: How self-compassion can improve your resiliency*. Mayo Clinic. https://www.mayoclinic.org/health-lifestyle/adult-health/in-depth/self-compassion-can-improve-your-resiliency/art-20267193

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 on a separate page and in a Word editable format. Figures should not be constructed using the cut-and-paste technique nor be a snapshot of a table. Tables that are not editable may result in the return of the manuscript to the author. The figure legend should be as a Word document on a separate page. The legend should be brief but descriptive

Tables will appear in the final text as follows:

Table 1.

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

F. Figures

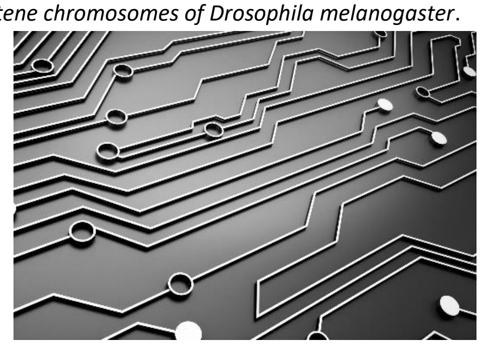
Figures should be submitted as **high resolution** (≥ 300dpi) individual electronic files, either TIFF or JPEG. Placement of figures should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. Figures only include graphs and/or images. Figures consisting entirely of text will not be accepted and must be submitted as tables instead.

All figures must be on a separate page and in a Word editable format. Figures should not be constructed using the cut-and-paste technique nor be a snapshot of a figure. Figures that are not editable may result in the return of the manuscript to the author. The figure legend should be as a Word document on a separate page. The legend should be brief but descriptive.

Figures will appear in the final text as follows:

Figure 1.

Polytene chromosomes of Drosophila melanogaster.



NOTE: Colored figures may be converted to gray scale for publication in the printed version but will appear in color in the online version of the journal.

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 as noted above.
C. Make sure that recommended changes have been made or a clear explanation as to why they were not.
D. Figures and legends formatted appropriately and submitted on separate pages. The desired placement in the manuscript should be clearly indicated.

VIII. Editorial Policy and Copyright

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