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ARTICLES

Infusing Bioinformatics and Research-Like Experience into a Molecular Biology Laboratory Course

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Abstract: A nine-week laboratory project designed for a sophomore level molecular biology course is described. Small groups of students (3-4 per group) choose a tumor suppressor gene (TSG) or an oncogene for this project. Each group researches the role of their TSG/oncogene from primary literature articles and uses bioinformatics engines to find the gene and promoter sequence of their TSG/oncogene. Based on the promoter sequences, students design appropriate primers for the PCR amplification and cloning of the promoter of the gene of interest and perform a diagnostic digest to confirm the results. Finally, each student writes an individual report about his or her findings and results and each group presents the results to the class. This laboratory sequence teaches students how to read primary literature, use common bioinformatics engines, clone a DNA sequence, and present the results in an oral and written format.

Key words: project-based learning, molecular biology laboratory, bioinformatics, molecular cloning

INTRODUCTION

Traditional molecular biology and biochemistry laboratory courses are composed of individual and very prescriptive exercises. Those exercises teach students techniques but they do not show the scientific process or excite the students to continue doing research (Burnette & Wessler, 2003). Students performing those laboratory exercises do not design experiments or develop the critical thinking skills so crucial in undergraduate education (Glidon and Rosengren, 2012; Knutson et al, 2010; Coil et al, 2010). Evidence suggests that research-focused instruction is more effective for developing those skills (Vision and Change in Undergraduate Biology Education, 2011; Anderson et al, 2005; Treacy et al, 2011). In addition to implementing active learning and problem solving approaches into the biology and biochemistry curriculum, it is also important to integrate modern computational skills and bioinformatics (Badotti et al, 2014; Honts, 2003; Voet, 2003; Voet, 2004). Numerous institutions are introducing bioinformatics into existing biology and biochemistry curricula at multiple levels (Wightam and Hark, 2012; Hydorn et al, 2005; Furge et al, 2009).

In an effort to engage students in an authentic research experience and to bring a sophomore level molecular biology laboratory curriculum into the 21st century, a nine-week laboratory project was developed. Students enrolled in the course meet once a week for three hours and are simultaneously taking a molecular biology lecture (3 hours per week for 16 weeks). Students taking molecular biology – lecture

and laboratory - have already completed two semesters of general biology and general chemistry courses. The total number of students taking the laboratory course varied between 30 and 50 people. During the nine-week project students examine primary literature, mine bioinformatics engines for gene and promoter sequences, and clone promoter sequences into vectors. Additionally, students present the results to the class and write individual laboratory reports about the project. The goal of this student-centered adventure is to combine computational skills, bioinformatics, and molecular cloning techniques into one cohesive whole. It also gives students the freedom to choose a gene and its promoter, learn about it from primary literature and then present the findings in an oral and written format.

METHODS

The project begins with a short introduction to bioinformatics and the structure of a typical gene and its promoter. During the first session students complete an activity that familiarizes them with different search engines (Bioinformatics Resource Portal ExPASy, National Center for Biotechnology Information – NCBI, Google Scholar) and tests their understanding of the presented material on bioinformatics and gene structure. Students are placed in groups of 3-4 and given an assignment for the project. Each group chooses a tumor suppressor gene (TSG) or oncogene and conducts research about its role in normal cells and in cancer. Students are asked to research the gene, protein and promoter for the TSG/oncogene. In the second week, students

complete a micropipetting exercise that reinforces proper technique while introducing them to basic computational skills using Excel. In week 3, students are introduced to mammalian tissue culture techniques where each group isolates genomic DNA from HeLa cells and calculates the concentration of that genomic DNA. Weeks 2 and 3 provide time for students to address their concerns about the project and ask questions about the assignment. Learning about gene and promoter sequences that can cause cell transformation is very interesting and exciting to the students but it also creates a level of uncertainty regarding how to complete the assignment using search engines that are new to them. In week 4, students present literature findings about the TSG or oncogene to the rest of the class and design primers to clone the gene promoters. In the following weeks students perform molecular cloning techniques – they design PCR conditions, run PCR reactions and agarose gels, ligate, transform the DNA products, and finally perform diagnostic restriction digests to see the results of the cloning. During the last week of the project, each group presents and interprets its results in front of the class. This session gives the member of each group an opportunity to talk about their results before the individual laboratory report is due.

Course schedule and experimental details

The overall agenda for the nine-week project is presented in Table 1. Each session is accompanied by a 30 minute lecture from the instructor and a 10 minute quiz to gauge student understanding of the material from the previous week. All course materials – power point lectures and detailed protocols - can be obtained by contacting the author.

Table 1. Weekly agenda for the nine-week project.

Week	Title
Week 1	Introduction to bioinformatics and explanation of the project
Week 2	Micropipetting and serial dilution exercise
Week 3	Genomic DNA isolation
Week 4	Presentations and primer design
Week 5	PCR and restriction digest exercise
Week 6	Agarose gel electrophoresis and gel purification
Week 7	Ligation and transformation
Week 8	Mini-prep and diagnostic restriction digest
Week 9	Interpretation of results in preparation for a formal laboratory report

Week 1: Introduction to bioinformatics and explanation of the project.

During this 3 hour session students learn: (1) what bioinformatics is; (2) how to read a DNA sequence; (3) the differences between prokaryotic and eukaryotic sequences; (4) how to search for prokaryotic and eukaryotic gene and promoter sequences using search engines such as ExpASY and

NCBI; (5) how to compare multiple sequences to each other. After a short presentation from the instructor, students are placed in groups (3-4 people per group) and complete an activity. The goals of the activity are to give students hands-on experience with the search engines and to check their understanding of the previous material. Each group is required to: (1) find the gene and protein sequence of human Rb; (2) indicate the start, stop, and length of the Rb coding sequence and protein sequence; (3) using BLAST, compare the Rb protein to other proteins in the database.

At the end of the session, students are given the following assignment:

1. Define a tumor suppressor gene and an oncogene.
2. Give an example of each.
3. Define a gene promoter.
4. A. If you are in a Monday laboratory, choose one tumor suppressor gene (one per group)
B. If you are in a Tuesday laboratory, choose one oncogene (one per group)
5. Find one research article describing the promoter of your chosen tumor suppressor/oncogene.
 - a. find the promoter sequence (using any resource you learned about during the first week)
 - b. where is the promoter located?
 - c. how long is it?
 - d. what is the minimum length of the promoter for the gene to be transcribed?
6. Find one review article describing the tumor suppressor gene/oncogene that you chose.
 - a. why is this gene important?
 - b. what happens when the gene is not expressed/overexpressed/mutated?
7. Find a gene sequence of your tumor suppressor/oncogene (using any resource you learned about during the first week).
 - a. can you see the start and the stop of the gene?
 - b. how long is the sequence?

Please provide a list of references at the end.

8. Prepare a 10 minute presentation showing your results to the rest of the class.
Equipment list week 1: access to computers.
Week 2: Micropipetting and serial dilution exercise.
During this session students practice micropipetting, make serial dilutions using colored solutions, and practice using a spectrophotometer. They also use Excel for calculating averages, calculating standard deviations, and graphing. Most importantly, this session also gives students an opportunity for students to ask questions about the assignment.

Students use small (P-20 and P-200) and large (P-1000) pipettes to measure and combine colored solutions. Then, using an appropriate micropipette, they check their accuracy in pipetting. All students are asked to practice this portion of the exercise until they become proficient and accurate.

In the second part of the meeting students dilute a yellow stock solution by combining 150 μL of stock solution and 850 μL of water (dilution #1). Then, they take 150 μL of dilution #1 and mix it with 850 μL of water (dilution #2). They are asked to perform this task in triplicate, to measure the absorbance of each solution in a spectrophotometer using a 570 nm wavelength and to calculate the dilution factor. Students input the serial dilution data into an Excel spreadsheet, calculate averages and standard deviations when appropriate and plot the data using a bar graph.

Finally, this is the time for students to ask for help with the assignment and for instructors to provide support finding sequences and appropriate articles.

Equipment list week 2: food coloring, micropipettes, spectrophotometer, access to computers.

Week 3: Genomic DNA isolation.

Each group is given a confluent plate of HeLa cells. Students scrape the cells off of the plate and isolate genomic DNA using Wizard Genomic DNA purification Kit (Promega). At the end of the protocol, DNA is rehydrated with 40 μl of rehydration solution provided in the kit. To verify successful DNA isolation students calculate the concentration and purity of the sample based on the absorbance values at A260 and A280 using a spectrophotometer.

Equipment list week 3: HeLa cells, tissue culture incubator, tissue culture hood, cell scrapers, Wizard Genomic DNA Purification Kit (Promega), heat block, quartz cuvettes, spectrophotometer, computers

Week 4: Presentations and primer design.

Each group presents the background information on the chosen tumor suppressor gene or oncogene; shows the sequences; and addresses assignment questions 5-7 (listed in the description of week 1 above) in detail. The presentations allow students to learn about the various genes investigated by other groups. The presentations also allow the instructor to verify the quality and accuracy of the findings before the students begin the molecular cloning portion of the project.

Based on the presented findings, each group designs primers necessary for cloning a tumor suppressor gene promoter or an oncogene promoter. Primers are submitted to the instructor at the end of the session and sent to Eurofins MWG Operon for synthesis. The primers are typically received within 48 hours.

Equipment list week 4: computers

Week 5: PCR and restriction digest exercise.

Students dilute the PCR primers to a final concentration of 0.1 $\mu\text{g}/\mu\text{l}$ in water and calculate the volume of genomic DNA needed for the PCR reaction. Thermal cycler conditions appropriate for

Table 2. Ingredients for the PCR Reaction.

Ingredient	Volume Added
Deionized Sterile H ₂ O	to 50 μL
Genomic DNA	(50 ng) x μL
10x buffer solution	5 μL
0.1 $\mu\text{g}/\mu\text{l}$ forward primer	2 μL
0.1 $\mu\text{g}/\mu\text{l}$ reverse primer	2 μL
10 mM dNTP	2 μL
Taq polymerase	1 μL

amplifying the promoter sequence are used. The PCR reaction components and the thermal cycler conditions are listed in Table 2 and Table 3. After the PCR is complete, the reactions are stored at -20°C until the next week.

While the PCR is under way, students complete the virtual restriction digest activity provided below:

- Find the sequence for a circular plasmid called pET24c. Please download the sequence.
 - How many places on this vector do EcoRI and NdeI cut? (use NEB Cutter)
 - When a double digest of the vector is performed with EcoRI and NdeI, two linear fragments are released. What are the sizes of the two fragments? (Digest #1)
 - When the vector is digested with EcoRI alone, what DNA fragments would you expect on the gel? (Digest #2)
 - When the vector is double digested with EcoRI and EcoRV, what fragments are released? What are the fragment sizes? (Digest #3)
 - Draw a picture of a gel and position a ladder next to it (you may use 1kb ladder from NEB); draw the DNA bands for each of the digests on the gel.
- EcoRI and NdeI restriction enzymes produce “sticky ends” when they cut DNA.
 - What sequences do EcoRI and NdeI recognize? (use NEB website)
 - What do the “sticky ends” look like after being cut by EcoRI and NdeI?
 - Why might restriction enzymes that produce “sticky ends” be better when ligating DNA than enzymes like BsaBI which produce “blunt ends” after digestion?
- Open a file with the promoter sequence you are investigating.
 - Is Bam HI, XhoI, and EcoRI cutting the sequence? If yes, how many times?
 - Choose 1 restriction enzyme that cuts the promoter sequence only once; what fragments do you see on an agarose gel after cutting the sequence? (draw bands on the gel; digest #4)
 - Choose 1 restriction enzyme that cuts the promoter sequence twice; what fragments are on an agarose gel after cutting the sequence? (draw bands on the gel; digest #5)

Table 3. Thermal cycler conditions. “x” needs to be determined based on the designed primer’s melting temperatures.

Steps	Temperature	Time
1	95°C	2 min
2	95°C	30 seconds
3	x°C	30 seconds
4	65°C	50 seconds/kb
5	Go To Step 2. Repeat 34 times	
6	65°C	10 min
7	4°C	1 hr

Equipment list week 5: thermal cyclers, PCR reagents (New England Biolabs or Promega), primers (Eurofins MWG Operon), computers.

Week 6: Agarose gel electrophoresis and gel purification.

Students prepare a 1% agarose gel containing 126 nM ethidium bromide. The genomic DNA and the PCR reactions are resolved on a gel and visualized on a transilluminator. A 1 kb ladder from NEB is used for band size comparison. PCR bands of appropriate size are excised from the gel and purified using Wizard SV gel and PCR clean-up system (Promega). PCR bands are eluted with 20 µl of water and the concentration of purified fragment is verified using NanoDrop (Thermo Scientific).

Equipment list week 6: low melting agarose, TAE buffer, ethidium bromide solution, 6x DNA loading dye (NEB), 1 kb ladder (NEB), Wizard SV gel and PCR clean-up system (Promega), NanoDrop spectrophotometer (Thermo Scientific).

Week 7: Ligation and transformation.

Students use a Quick ligation kit (NEB) to ligate the PCR fragment (150 ng) into the pGEM-T Easy vector (50 ng) (Promega). After a 5 minute incubation at room temperature, students transform the recombinant DNA into sub-cloning efficiency DH5α chemically competent cells (Invitrogen). The transformants are spread on LB plates containing ampicillin and grow over night at 37°C. Students are asked to view the transformation plates sometime during the week in order to determine the number of colonies.

Equipment list week 7: Quick ligation kit (NEB), pGEM-T Easy vector (Promega), DH5α competent cells (Invitrogen), LB Amp plates, 37°C incubator/shaker.

Week 8: Mini-prep and diagnostic restriction digest.

The day before each lab session this week, the instructor picks 3 colonies per group from the transformation plates and starts over-night liquid

cultures. Students isolate the promoter-pGEM-T Easy plasmid from each culture using the QIAprep spin miniprep kit (Qiagen). DNA is eluted with 50 µl of water. Using the purified plasmid DNA, students perform a diagnostic restriction digest according to Table 4. The reactions are incubated for 30 minutes at 37°C, loading dye is added after the incubation, and all samples are separated on an agarose gel.

Equipment list week 8: LB media, ampicillin, QIAprep spin miniprep kit (Qiagen), EcoRI restriction endonuclease, agarose gel

Week 9: Interpretation of results.

Students collect the data and share results with the rest of the class. They explain each gel, band sizes and other results. In addition to modeling a talk that might be given at a scientific meeting, the presentations help the students prepare for writing the final lab report that is due the following week.

Equipment list week 9: computers

RESULTS AND DISCUSSION

Project-based laboratory activities should be considered as an addition to every biology and biochemistry curricula. The long-term projects involving numerous scientific assays, that may or may not successfully produce usable data, gives students an idea of what research is really like. The laboratory sequence described here began, just like any “real” research project, with an exploration of the primary literature. In the project described here, the literature search is primarily a fact-finding mission about the characteristics of a chosen TSG or oncogene and its promoter. During this literature search, students learn about a real gene that has a real impact on cells. The freedom to choose a TSG or oncogene puts students in control and gives them an opportunity to research something that interests them. Finding a gene sequence of interest tends to be the least challenging portion of the project. Finding the promoter sequence and evidence from primary literature that this is the minimum sequence necessary for transcription is typically much more challenging. Students must find not only the promoter sequence but also an article that supports their claim. That is why students were given three weeks before they presented their findings and continued with the project. Each of our groups had successfully found the gene and promoter sequences. All of our students also designed the forward primer with ease but some of them had trouble with the design of the reverse primer (4 out of 12 groups). For this reason, every group had to show both primers to the instructor before submitting the final primer sequences for ordering. The most exciting part of the project was running PCR products on an agarose gel. Students were eager to see the results. As expected, there were four possible outcomes: 1) no PCR band; 2) a PCR band that did not correspond to the expected promoter size; 3) multiple PCR

Table 4. Diagnostic Restriction Digest.

Ingredient	Volume
Plasmid DNA	17 µl
10x CutSmart buffer	2 µl
EcoRI endonuclease	1 µl

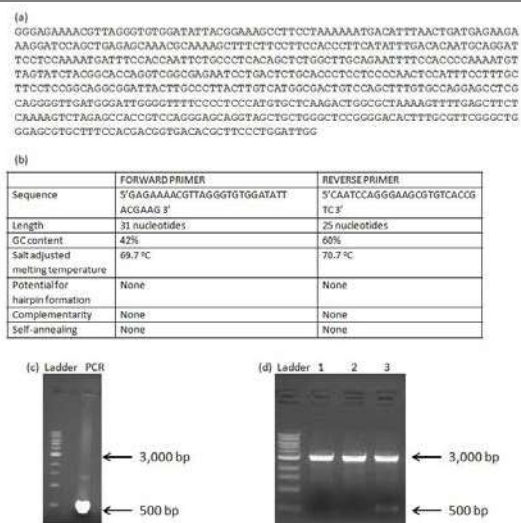


Fig.1. Representative data showing the results of the nine-week project. (a) p53 promoter sequence (GenBank accession number J0438); (b) p53 promoter-specific forward and reverse primers and their characteristics; (c) agarose gel showing a PCR amplified fragment of DNA about 500 nucleotides in length; (d) pGEM-T Easy vector without an insert (lanes 1,2) and pGEM-T Easy vector with a DNA fragment about 500 nucleotides in length inserted (lane 3).

bands; and 4) a PCR band that corresponds to the expected promoter size. Six out of twelve groups had a DNA band that corresponded to the size of their gene promoter. One group had multiple bands on the gel and five groups did not have a band at all. All groups that did not have a PCR product were given a choice of re-doing their PCR with a different polymerase (Expand High-Fidelity PCR system from Roche) or using another group's PCR products. All groups chose to redo their PCRs and four groups had a PCR band on the second try. Every group had colonies on the transformation plates and nine groups had an insert in at least one of their colonies.

Learning assessment

The assessments for the project-based based portion of the laboratory (9 out of 16 weeks) consisted of weekly quizzes, a group power point presentation, and an individual formal laboratory report. Each quiz was designed to assess understanding of the background material presented by the instructor and the experimental techniques performed the previous week. Each student was also responsible for reading and comprehending the material associated with each laboratory exercise. These quizzes represented to 25% of the students' grades for the nine-week project.

On week 4, the members of each group of students gave a power point presentation about their literature findings, gene and promoter sequences. Each presentation submitted to the instructor contained a contribution table describing each student's role in

this part of the project. The presentation represented 22% of the total grade for the nine-week project.

Upon completion of the project, each student wrote an independent laboratory report that mimicked a manuscript intended for peer review and publication. Each report consisted of an introduction containing a clear objective, materials and methods section, results, discussion, conclusion, and references. This portion of the project amounted to 43% of the total grade for the project. Representative data obtained in the project are shown in Figure 1.

At the end of week 16 of the semester, students filled out an anonymous survey. On the scale of 1-7 (one being lowest and seven being highest) students considered this course challenging (average response 6.7) but found the assessments relevant (average response 6.75) and course objectives well-chosen and appropriate (average response 6.55). When asked about the overall quality of the laboratory course, students showed enthusiasm and appreciation for the project.

Hazards

HeLa cells must be handled according to the rules of biosafety level 2. Protective gloves and clothing must be worn while handling the cells. All waste (plates, scrapers, tubes, tips) must be collected separately and properly disposed. *E. coli* DH5 α is a nonpathogenic strain of bacteria. Ethidium bromide is a mutagen and might be harmful if inhaled, ingested, or absorbed through the skin.

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“Evo in the News:” Understanding Evolution and Students’ Attitudes Toward the Relevance of Evolutionary Biology

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Abstract: This investigation evaluated the effects of exposure to the “Evo in the News” section of the *Understanding Evolution* website on students’ attitudes toward biological evolution in undergraduates in a mixed-majors introductory biology course at Syracuse University. Students’ attitudes toward evolution and changes therein were measured using the Evolutionary Attitudes and Literacy Survey. We employed a quasi-experimental design with pre-test/post-test comparison wherein an experimental group was assigned pre-laboratory work using “Evo in the News” articles while a control group was assigned similar pre-lab work without exposure to “Evo in the News.” At the conclusion of the semester, the experimental group showed significant improvement in their perceptions of the relevance of evolution to understanding real-world scientific problems and to their daily lives while the control group did not. Incorporating “Evo in the News” activities into an introductory biology course is a cost-effective and non-labor-intensive way to expose students to ongoing, practical science research based on evolutionary theory. This study supported the hypothesis that exposure to real-world applications of evolutionary theory such as those featured in “Evo in the News” is correlated with increases in students’ attitudes toward evolutionary science, particularly with regard to their perceptions of its relevance.

INTRODUCTION

Biology is a broad and complex field of study, encompassing areas as diverse as biochemistry and ecology and everything in between. There are, however, unifying principles that tie together the study of all of these seemingly independent subtopics. Among the most central of these unifying principles is biological evolution (Alles, 2001; Dobzhansky, 1972; Gould, 2001; Linhart, 1997; Wiles, 2010).

The teaching of evolution though, particularly in the United States, has been beset with difficulties that have led to poor understanding of evolution among the general public (Alters, 2005; Alters & Alters, 2001; Cobern, 1994; Demastes et al., 1995; Lawson & Worsnop, 1992; Scott, 2004; Sinclair & Pendarvis, 1998; Wiles & Ashgar, 2007; Wiles, 2010). Numerous polls of the general public have demonstrated that, compared to citizens of other industrialized nations, Americans exhibit a striking lack of understanding and acceptance of evolution and related aspects of science (Miller et al., 2006; Wiles, 2010). In addition, it appears that a substantial portion of the American public tends to eschew evidence-based scientific theories on the history and diversity of life on Earth and, instead, favors non-scientific explanations that are rooted in religious creationism, including its recent incarnation known as “intelligent design” (Alters & Alters, 2001; Nelson, 2008; Wiles, 2010).

Considering the social divide over evolution and its implications for teaching, Wilson (2005) asserted that regarding evolution there are “two walls of resistance, one denying the theory altogether and the

other denying its relevance to human affairs” (p.364). Wilson’s (2005) EVoS program was designed to overcome both of these walls; however, the program requires replacing the introductory biology courses that have become firmly entrenched at most universities with a full course centered on evolution and its applications. Herein we explore a potential means of surmounting at least the second of these walls within the context of an existing biology course with minimal curricular change. Students may find difficult concepts such as evolution more engaging and potentially easier to understand when they are able to see the relevance of the content (Hillis, 2007). The use of popular media to present real-world issues and their connection to scientific concepts has been shown to increase students’ understandings in scientific areas (Bondos & Phillips, 2008). However, implementation of these tools is often hindered when teachers are underprepared to use them, the tools are too complicated for the students to use, or the tools are too expensive to implement.

One of the pedagogical tools developed to address these concerns is the University of California Museum of Paleontology’s *Understanding Evolution* website (www.evolution.berkeley.edu). This award-winning, online resource incorporates extensive guidelines and suggestions for teachers regarding its classroom use. It is user-friendly for students and teachers and includes a host of activities organized according to grade-level appropriateness across K-16 settings. And, importantly, it is freely accessible.

Although this site was initially developed with K-12 students and teachers in mind, it has since been expanded for use in post-secondary education (Musante, 2011). Initial research has been done on

the impact of the tools found in the *Understanding Evolution* website and the site as a whole (Nadelson & Sinatra, 2009; Scotchmoor & Thanukos, 2007). However, until recently the focus has been on the uses for and perceptions of K-12 students and their teachers. One of the sections of the website is titled “Evo in the News.” This section uses popular media articles and videos to showcase current scientific inquiry into real-world problems, and it draws explicit connections between highly applicable research and its evolutionary underpinnings which can be related to classroom content. It is aimed at helping students understand the relevance of evolutionary science in the context of practical situations.

The purpose of this study was to compare changes in student attitudes about biological evolution and understandings of evolutionary concepts among students participating in the use of “Evo in the News” as a supplement to their coursework in a general biology class.

METHODS

Data were collected and analyzed according to a protocol that had been approved by the appropriate Institutional Review Board. Participants were students (n=117) enrolled in an introductory biology lecture and lab course at Syracuse University. Students at Syracuse University do not declare their academic majors until the end of their first year. As such, the Biology Department views all first-year students as potential biology majors, and there is no non-majors general biology course. The course in which the participants were enrolled serves as a foundational course for biology majors, but it is also taken by non-majors in order to fulfill a degree requirement for a science course with a lab. Course content was consistent with the range of topics typically addressed in a majors or mixed-majors biology survey course using the widely-adopted Campbell Biology text. Students represented all levels of undergraduate study from freshmen to seniors.

We employed a pre-test/post-test design for this quasi-experimental study and compared changes in student attitudes about biological evolution among students who were exposed to “Evo in the News” as a supplement to their coursework (experimental group) and those who were not exposed to “Evo in the News” (control group) in a general biology class. The research questions guiding this study were:

1. What are the initial attitudes about and knowledge of biological evolution for our sample of students?
2. Is there a significant difference in changes in student attitudes regarding evolution between the group of students participating in the biology course as traditionally presented (control group) as opposed

to those students participating in the “Evo in the News” activities (experimental group)?

There is no reason to believe that the control group differed from the experimental group in any way other than the experimental variable. Each teaching assistant (TA) in Introductory Biology is assigned to teach two sections of laboratory. Students enroll in these sections according to how they fit with their academic schedules, and we have seen no tendencies for students of any demographic to preferentially enroll in any section in particular. Each TA taught one “control” section and one “experimental” section so that potential differences between TAs would not be an issue between control and experimental groups. Furthermore, we randomized which section (the first one taught by a TA in a week versus the second one) would be control or experimental. Apart from the differential assignment of pre-lab activities described herein, other aspects of the lab experience were identical between control and experimental groups.

Both groups were given similar pre-lab assignments (online articles of equivalent length, same number of pre-lab questions, relating to same content) prior to each lab experience throughout the semester. For four of the lab experiences during the semester, the experimental group was assigned pre-lab experiences based on a section of “Evo in the News” chosen to match the content being studied in the particular lab experience with which it was paired. Four labs represented about a third of the sessions, and it was a manageable number of sessions for the researcher to coordinate during the study. They were evenly spaced throughout the semester. Assignments for the control groups were similar in structure, but materials were not drawn from “Evo in the News,” and did not make explicit connections to evolution. (See sample exercises in Appendices A and B.)

Instrumentation

In order to assess students’ understandings of evolution as well as their attitudes toward evolutionary theory, the data collection instrument used in this research was the original (long-form) Evolutionary Attitudes and Literacy Survey (EALS, Hawley et al. 2010). This instrument was developed to address concerns about other instruments’ validity and reliability as well as to comprehensively survey both attitudes and understandings with the same instrument. The long-form EALS consists of 104 statements divided into 16 constructs or areas of study. (Note: A short-form has since been constructed. See Short & Hawley [2012].) Students responded to the statements on a 7-point Likert scale in which 1 represented strongly disagree, 4 represented neither agree nor disagree, and 7 represented strongly agree. Voluntary participants were asked to respond to all statements in the EALS electronically via our online course management

system (Blackboard) both at the beginning of the semester and at the conclusion of the semester.

Students in the treatment group were also asked to answer several open-ended questions at the conclusion of their responses to the EALS. These were developed to provide feedback on the uses of and the students' perceptions of the "Evo in the News" tool as it pertained to their experiences in this lecture and laboratory course.

RESULTS AND DISCUSSION

With regard to the attitudes constructs of the EALS for the initial survey, of particular interest is the relevance construct. For the statement "Evolution is relevant to our everyday lives," 36% of the participants answered at or below the midpoint on the Likert scale. This indicates that these individuals had neutral to negative feelings regarding the relevance of the evolutionary theory to problem solving in the real world. The other statements in this category all deal with whether evolutionary theory is relevant to biology, the humanities, understanding plants, understanding animals, etc. The percentage of the respondents that had negative feelings regarding evolutionary theory's relevance ranged from a low of 17.1% for evolution's relevance to biology to a high of 46.2% for evolution's relevance to the humanities. Hence, there was certainly room for improvement among a substantial portion of the participant population prior to the intervention.

Interesting results emerged when looking at the differences in student attitudes toward biological evolution from the beginning of the course to the end. Specifically, within the attitudes constructs, we calculated overall gains between pre- and post-measurements in the "relevance" construct for each student and conducted an independent samples t-test between the experimental and control groups. Students in the experimental group who were assigned pre-lab activities involving "Evo in the News" articles from the *Understanding Evolution* website showed significant gains in their views regarding the relevance of evolutionary science over students who were not assigned to complete these activities as measured by the EALS survey (See Figure 1. $t=2.177$, $p=.041$).

Responses to open-ended questions for students in experimental group

The students in the experimental group were also given the opportunity to complete several open-ended questions regarding their experiences with the "Evo in the News" pre-labs and their attitudes regarding evolution. The response rate was extremely low, with only 15 students volunteering to fill out the questionnaire, but their comments do reveal an interesting array of reactions to the activities.

One of the questions asked whether students thought that evolutionary science was more relevant to their everyday lives after completing the "Evo in

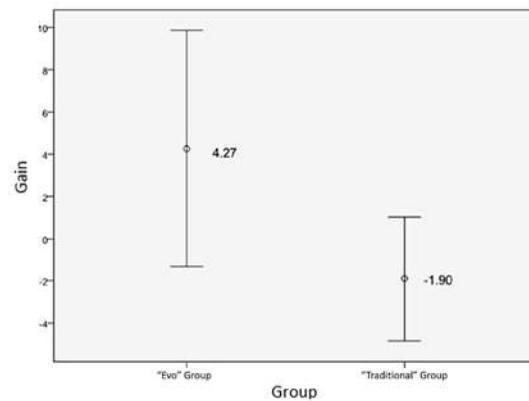


Fig. 1. Mean gains in relevance scores on the EALS for the experimental group (evo) versus the control group (traditional). Gains were calculated as the difference in the sums of the relevance scores from pre-survey to post-survey.

the News" assignments than they did before the assignments. They were asked to respond yes or no and explain. Of the 15 respondents, two did not respond to this question, six responded with a yes and seven with a no.

Almost half of the students who responded with "no," however, explained that they didn't feel differently because they already found evolution to be quite relevant prior to the course. One of the students replied, "no, I like reading the idea about evolution; comparing it to my beliefs, but reading one article is not going to change the way that I think completely." This student was not convinced about the relevance of evolutionary theory, but s/he did think that the assignments had some value. Two students did seem to have decidedly negative feelings about evolutionary science itself. One student responded, "No, we are being force fed evolution, denying our right to believe what we believe," and another with "No because I just don't see why it should affect my life."

Of the students who responded "yes," several explained that they "enjoyed" the articles and being exposed to other applications of evolution besides those introduced in class. Responses included, "they made me realize how interwoven the issue of evolution is with so many other aspects of daily life," and "because evolutionary science is found in many various current day issues." Another student replied saying, "I've gained a greater understanding of the evolution of behavior, something that I never really considered as an entity that could be acted upon by natural selection."

The other open-ended question asked students whether they thought after being exposed to "Evo in the News" that evolution could help solve real-world problems more than they might have thought before. Two did not answer, six said "yes," and seven "no." Three of the students who answered "no" explained that they already had strong positive feelings

regarding the uses of evolutionary theory. One of the more resistant students answered, “no, I just do not believe in evolution. Maybe it does occur but it is within species, there is no way that the complexity of our organisms and the amazing diversity and efficiency of other organisms happened by chance.”

Several of the students who answered “yes” explained that they had never before been exposed to the uses of evolution and found it to be much farther reaching than they had known before. Typical responses included, “I think evolutionary science provides a basis to consider who we are and where we came from and how we can best use our abilities to solve problems in the real world,” and “yes, because some ideas from evolutionary science can be applied to real-world problems.”

CONCLUSION

Students’ understandings of and attitudes toward the relevance of evolution to scientific research and discovery, as well as to their daily lives, are of great importance. Being able to connect evolutionary concepts to scientific problems is a fundamental skill for any student of biology. This is, no doubt, one of the reasons Wilson (2005) has emphasized the relevance of evolution so strongly in his very successful EvoS program and identified denial of the relevance of evolution to human affairs as one of the two walls of resistance to evolution among students and the general public.

Wilson’s efforts with the EvoS program are both ambitious and commendable, and they have been shown to be effective in generating improvements in students’ attitudes regarding the relevance of evolution. However, implementing the EvoS program in most college and university settings may require more institutional commitment and curricular overhaul than is likely to be practical in many post-secondary settings. The results of this study, which indicate that students can adopt better understandings and attitudes toward the relevance of evolution with a much less labor-intensive intervention are, therefore, quite encouraging. While our results may not be as striking as those reported by Wilson (2005), our study suggests that our incorporation of activities involving “Evo in the News” articles into existing curricula helped students who initially considered evolutionary science to be of little importance to change their minds substantially regarding their assessment of the relevance of evolution.

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Appendix A – Example of Pre-Lab “Evo in the News” Assignment

- Use the link below to access the article entitled, “Got lactase”.
http://evolution.berkeley.edu/evolibrary/news/070401_lactose
- Read the article including the sidebar.
- Answer the following questions based on the article. Your answers should be handed in at the beginning of lab and you should be prepared to discuss this assignment on that day.

Questions :

1. What is lactose intolerance?
2. What is the difference between those individuals who are lactose tolerant and those who are lactose intolerant? Why are they one or the other?
3. In what types of environments or cultures is lactose tolerance advantageous?
4. Why is milk drinking more common in modern Europe?
5. When/why did lactose tolerance become an advantageous trait among many populations in Africa?
6. In evolutionary terms, why is it surprising that many Hadza are lactose tolerant?
7. What is “selective sweep”?
8. What is convergent evolution, and how is lactose tolerance an example of this concept?

Appendix B – Example of Pre-Lab Control Group Assignment

- Use the link below to access the article entitled, “Digestive enzymes and food absorption”.
<http://www.livestrong.com/article/291983-digestive-enzymes-food-absorption/>
- Read the article.
- Use the link below to access the article entitled, “Difference between glucose and lactose”.
<http://www.livestrong.com/article/271341-difference-between-glucose-lactose/>
- Read the article.
- Answer the following questions based on the article. Your answers should be handed in at the beginning of lab and you should be prepared to discuss this assignment on that day.

Questions :

1. Carbohydrates, fats, and proteins are broken down in the human digestive system into constituent molecules that can be absorbed. Identify the smaller constituent molecules derived from carbohydrates, fats, and proteins that can be absorbed into the circulatory system.
2. Identify the major groups of digestive enzymes used in the human digestive system.
3. Where does absorption of these molecules take place in the human?
4. Why do whole grains make you feel full longer than simple sugars?
5. What are the major similarities between glucose and lactose?
6. How does the human digestive system treat glucose and lactose differently?
7. How does glucose enter the cells of the body from the bloodstream?
8. What happens in the human digestive system if an individual is lactose intolerant?

Impacts of Digital Imaging versus Drawing on Student Learning in Undergraduate Biodiversity Labs

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Abstract: We examined the effects of documenting observations with digital imaging versus hand drawing in inquiry-based college biodiversity labs. Plant biodiversity labs were divided into two treatments, digital imaging (N = 221) and hand drawing (N = 238). Graduate-student teaching assistants (N = 24) taught one class in each treatment. Assessments revealed that imaging relative to drawing had a significant negative effect on the lower order content students included in their lab reports, student perceptions of the lab overall, the time efficiency of their learning experience and perceived excitement. Documentation style had no significant influence on lower-order or higher-order learning or attitudes towards biology as a discipline. Contrary to overall trends, observations indicated that a proportion of students were excited and motivated by digital imaging. A mixed model of allowing students the choice of documenting observations with digital imaging or drawing may be the best model.

INTRODUCTION

The United Nations Decade of Education for Sustainable Development (2005-2014) recognized biodiversity education as a worldwide priority (Lindemann-Methies et al., 2009). In the United States a great opportunity for biodiversity education exists in the hands-on lab component of college introductory biology classes. Although advocates for biodiversity education emphasize a need for engaging learning experiences that are grounded in evolution and go beyond rote memorization (Lindemann-Methies et al., 2009, Basey et al., 2014), commonplace undergraduate biodiversity labs take on the form of “marches through the phyla” that emphasize declarative knowledge (see Morgan and Carter 2009, Scully & Fisher 2009). The need for information on how to transform these biodiversity labs to engaging experiences grounded in science and emphasizing evolution-based higher-order reasoning is paramount.

Basey et al. (2014) argued that commonplace biodiversity labs are particularly difficult to transform because of the theoretical nature of evolution, the relatively large quantity of novel and highly interactive terminology required for evolution-based higher-order reasoning and limitations on working memory. Studies on the effects of transformative designs for biodiversity labs are rare. Smith and Cheruvilil (2009) reported a substantial loss in content understanding by their students when they used a transformed design for their biodiversity labs. Timmerman et al. (2008) reported substantially lower effect sizes for their transformed inquiry-oriented biodiversity segment in lab + lecture (0.6) than for their non-transformed non-biodiversity segments (plant anatomy = 2.1, animal anatomy =

1.8). However, neither study analyzed the effects of their transformed design on higher-order cognition learning (i.e. application, analysis and synthesis). Basey et al. (2014) successfully promoted both lower-order and higher-order learning in a transformed biodiversity lab by reducing overall lower-order content, increasing time allocation through time-efficient hands-on pre-labs, and including written post-labs emphasizing higher-order learning by having students use documented observations as evidence for evolution-based higher-order argumentation. In this study, we extended the model for biodiversity labs of Basey et al. (2014) by analyzing whether observation documentation through digital imaging or hand drawing impacted student learning and attitudes.

Biodiversity lab educators have contended that digital imaging can enhance documentation of hands-on lab observations (Mills et al. 2001, Thomassan 2002, Withers & Wallace 2007), can improve implementation of inquiry in the lab (Leonard 2003, Withers & Wallace 2007, McIntosh & Richter 2007), and can improve student learning (Waegel 2004). In a case study approach to biodiversity, Travaille & Adams (2006) touted the use of digital imaging for an inquiry analysis of *Caenorhabditis elegans*, a model species for biology education, and Bowen & Bell (2004) hyped the use of digital cameras for the study of butterfly life cycles. Beyond biodiversity labs, Kelley et al. (2008) and Zinn et al. (2011) advocated for the incorporation of digital imaging and digital imaging analyses as an important component of the biology undergraduate curriculum because of its rising importance in the job market.

Even with all the arguments for implementation of digital imaging in biology labs, studies examining impacts of digital imaging on student learning and/or

attitudes are rare. Tatar & Robinson (2003) found no difference in content learning in a high school biology lab between a class using digital photography and a class using no digital photography, but found that student's procedural knowledge was better for the class using digital photography. Kelley et al. (2008) had students quantitatively evaluate images and found that students improved in their ability to analyze scale, quantify and interpret images and characterize imaging methods, but they did not evaluate content cognition. More studies that address impacts of digital imaging on student learning and attitudes especially in relation to biodiversity labs are clearly needed.

The goal of this study was to evaluate the hypothesis that digital photography enhances learning and attitudes of students in biology labs over the traditional method of hand drawing. We specifically examined the relative impact of visualization style (digital photography versus hand drawing) on student formative lab reports, then on student learning outcomes and attitudes (i.e. Bloom's lower-order cognition, Bloom's higher-order cognition, attitudes towards biology as a discipline, and attitudes towards the biodiversity lab).

METHODS

The research was conducted at the University of Colorado at Boulder in 2011 during introductory general biology lab. The lab class ran concurrent with a lecture covering similar content, but was a stand-alone class and approximately 75% of the students in lab took the concurrent lecture. Most of the 850 students enrolled in the class were traditional students with freshman and sophomore class standings. Students were grouped into lab sections of 18 each and were instructed by 24 different graduate-student teaching-assistants (GTAs).

The lab curriculum was comprised of inquiry-based experimental labs intermixed with several non-experimental hands-on biodiversity labs. We focused this study on the newly redesigned plant biodiversity lab that began with a 3-week pre-lab (30 min per week) followed by a focal lab (3 hours). During the engaging, hands-on, pre-lab students observed with a microscope the stages in the life cycle of the C-Fern (*Ceratopteris richardii*). They pipetted spores on a growth medium and directly observed germinating spores, gametophytes, swimming sperm and live fertilization. In the focal lab students documented the life cycles of mosses, conifers and flowering plants through observations of living specimens, preserved specimens and microscope slides. Over the following week, each student incorporated his/her documented observations into a lab report that used evidence from the lab to address the two following overarching ideas. 1) Life originated in aquatic environments and then radiated to terrestrial habitats, and 2) Evolution through natural selection with

adaptive radiation is an overarching theoretical framework that explains the current diversity of living organisms.

Classes were divided into two treatments, digital imaging (I) or hand drawing (D). Students in both treatments worked in groups of two. Twelve GTAs were randomly assigned to each treatment.

On the first day of class students chose whether or not to participate and only materials from participating students were coded and statistically evaluated. On week 2 students began a plant biodiversity pre-lab. On week 5 students worked on a 2-hour and 50 minute hands-on plant-biodiversity lab. On week 6 students took a practical assessment at the beginning of lab. On week 11 students took a multiple-choice assessment in exam for the associated lecture. On week 15 students completed attitude surveys in lab.

Imaging Equipment

Students were divided into groups of two. Each group in both treatments had one internally illuminated compound microscope with 3.6X, 10X, 40X and 100X objectives and 10X eyepieces, and one internally illuminated stereomicroscope with magnification from 0.7 to 4.5X and 10X eyepieces. For imaging, the stereomicroscopes were Meiji EMZ-8TR with a photo port separate from the stereo image. Each group of students had a Canon EOS TLi Digital Camera with a T2-9 Canon T Mount for EOS, MA 150/50 camera attachment for the Meiji EMZ-TR, and the CAEDRT11K Canon EOS Rebel T1i digital SLR camera kit. The digital cameras were easily transferred from the compound microscope to the stereomicroscope with live imaging and capture through the computer. Once an image was captured, students retained the image on the classroom computer in their own folder and sent a copy via e-mail.

Assessment

A. Lab Report: APM assessed lab reports using a comprehensive rubric/checklist designed to compare results across all treatments. Rubric scores indicated the amount and type of evidence that was included in the lab reports and was divided into "knowledge and comprehension" (LO) and "analysis and synthesis" (HO; Crowe et al. 2008). Content in the rubric was divided into categories, a point was assigned for each correctly used content category and points were summed to produce a separate LO and HO score. In a second analysis lab reports were similarly scored based only on the content that related directly to the quiz. Grading reliability was checked periodically by randomly selected re-grades, and as a result, at one point in the coding process the first 150 lab reports were re-graded.

B. Practical Quiz: The practical quiz had five stations with three stations categorized as LO and two stations as HO according to the Blooming Biology Tool (Crowe et al., 2008). LO stations had

two parts: 1) visual identification (generation style, knowledge), and 2) relating the visual identification to a representative aspect of plant life cycles (short-answer style, comprehension). Visual identification had two possible formats: 1) a microscope with adjacent slides so students had to use the microscope, and 2) a microscope image displayed on a computer. The two HO questions were categorized as a synthesis and an analysis question. For the analysis question students were provided data, were asked whether the data were consistent with evolution through natural selection and were asked to explain their answer. For the synthesis question students were provided specimens from one of the four plant divisions examined. Students were asked in a multiple-choice question which of four animal phyla was the equivalent in terms of adaptations to terrestrial life and to explain their answer. Importantly, all students had access to an on-line study guide with digital images from the lab.

Two versions of the quiz were used, both with the same analysis question and each of the remaining questions was paired between versions. One matched LO question (computer image) was excluded from the analysis because student performance varied between quiz versions. The remaining four questions -- two LO and two HO -- matched up well across quiz versions.

John M. Basey (JMB) and Anastasia P. Maines (APM) independently coded the same 30 quizzes using a common rubric. Codes were compared on

each question with a *t*-test and no significant differences in grading were present (all $P > 0.05$). The remaining quizzes were coded separately.

To determine transfer of learning from lab report to quiz, components of lab reports that directly related to quiz questions were assessed for percent completeness. Transfer from lab report to quiz was quantified by subtracting the adjusted lab report score from the % score on the quiz. The adjusted lab report score was only those items from the rubric that directly related to quiz content. (Note: lab report questions were different than quiz questions, so a relative comparison at best can only be made.)

C. Multiple-Choice Exam: Ten multiple-choice exam questions related to plant biodiversity were written at the knowledge, comprehension and analysis levels of Bloom's taxonomy according to Crowe et al. (2008). The lecture professor (who did not have knowledge of the specific lab treatments) chose several exam questions from each level of learning to include on the lecture exam (5 knowledge, 5 comprehension and 5 analysis). In addition, all multiple-choice exam questions written by the lecture professor that pertained to lab learning goals were also included. At the end the assessment was comprised of 10 knowledge, 6 comprehension and 5 analysis questions.

D. Validation of Bloom's Categorizations: Two outside experienced reviewers independently classified multiple choice exam questions into Bloom's levels. Following classification a quadratic

Table 1. Model-averaged coefficient estimates for all variables present in models with strong support ($\Delta AIC_c < 2$) related to lower and higher-order learning for the lab report, quiz and exam relative to type of visualization (drawing or imaging). SE = standard error, CI = confidence interval (95%), and Relative Import = relative importance of the model. A negative effect size indicates a negative effect. Imaging is relative to drawing.

Explanatory Variable	Effect Size	SE	Lower CI	Upper CI	Relative Import	Z value	P value
<i>Does lab visualization influence the lab reports produced by students?</i>							
<i>Lab Report Lower Order</i>							
Imaging	-0.046	0.019	-0.083	-0.009	1.00	2.455	0.014
<i>Lab Report Higher Order</i>							
Imaging	-0.017	0.009	-0.035	0.001	0.64	1.802	0.072
<i>Is the transfer/retention of information from lab report to quiz for LO and HO different for the different types of visualization?</i>							
<i>Lower Order Difference</i>							
Imaging	2.637	2.172	-1.619	6.893	0.42	1.214	0.225
<i>Higher Order Difference</i>							
Imaging	-2.082	1.474	-4.972	0.807	0.49	1.413	0.158
<i>Does type of visualization influence LO and HO scores on quiz and exam?</i>							
<i>Quiz Lower Order</i>							
Imaging	-0.052	0.028	-0.107	0.002	0.66	1.889	0.059
<i>Quiz Higher Order</i>							
Imaging	-0.044	0.023	-0.090	0.002	0.65	1.882	0.060
<i>Exam Lower Order</i>							
Imaging	-0.011	0.019	-0.048	0.027	0.30	0.573	0.567
<i>Exam Higher Order</i>							
Imaging	-0.037	0.032	-0.025	0.010	0.42	1.172	0.241

Effect sizes have been standardized on two SD following Gelman (2008). Bold denotes parameters with strong effects because the 95% CI does not overlap zero.

Table 2. Model-averaged coefficient estimates for all variables present in models with strong support ($\Delta AIC_c < 2$) related to students perceptions of lab parameters relative to type of visualization (drawing or imaging). SE = standard error, CI = confidence interval (95%), and Rel Import = relative importance of the model. A negative effect size indicates a negative effect. Imaging is relative to drawing.

Explanatory Variable	Effect Size	SE	Lower CI	Upper CI	Relative Import.	Z value	P value
<i>Overall Lab Rating</i>							
Imaging	-0.608	0.219	-1.037	-0.178	1.00	2.774	0.006
<i>Excitement</i>							
Imaging	-0.562	0.213	-0.980	0.145	1.00	2.638	0.008
<i>Time Efficiency</i>							
Imaging	-0.696	0.227	-1.142	-0.250	1.00	3.061	0.002
<i>Ease of Lab</i>							
Imaging	-0.379	0.215	-0.802	0.043	0.30	1.760	0.078
<i>Lecture Help</i>							
Imaging	-0.296	0.242	-0.770	0.179	0.43	1.220	0.222

Effect sizes have been standardized on two SD following Gelman (2008). Bold denotes parameters with strong effects because the 95% CI does not overlap zero.

weighted kappa (Cohen 1968) was estimated for each reviewer relative to the independent classification by JMB that was used in this study. Each independent reviewer rated questions as knowledge, conceptualization, application, or analysis ($N = 42$).

E. The Colorado Learning Attitudes about Science Survey (CLASS): The pre/post formatted CLASS has been well validated and widely used (Barbera et al., 2008). The CLASS surveys students' beliefs about a science discipline such as biology and how those beliefs are influenced by classroom instruction. The CLASS is founded on the idea that attitudes and beliefs of novices are different than those of experts and instruction that fosters expert-like beliefs are wanted.

F. Survey of Attitudes Towards Specific Labs: This survey evaluated students' opinions specifically about digital imaging vs. hand drawing in the plant biodiversity labs as well as their opinions about two control labs that did not vary for all students. Reliability and validity of the survey has been established (Basey et al. 2008, Basey & Francis 2011). The survey simply prompted students to rate the plant biodiversity lab on a scale of 1–10 for the following categories: overall lab rating, how easy they thought the lab was to master (ease of lab), level of excitement, time efficiency and how much the lab helped with lecture.

Analyses

We used linear mixed-effect models to determine the effect of documentation style on CLASS scores, as well as LO and HO for the lab reports, the quiz and the lecture exam. Documentation style was treated as a fixed effect and TA as a random effect. We used linear regression for student-attitude assessments. Where appropriate, response variable scores were arcsine square root transformed prior to analysis. When continuous variables were included in models with binary variables, parameters were standardized by centralizing predictor variables to a

mean of zero and a standard deviation of 0.5. All analyses were performed using the lme4 package in program R (R Development Core Team, 2012).

We evaluated support for competing candidate models with an information-theoretic approach (Burnham & Anderson, 2002) using Akaike's Information Criterion corrected for small sample sizes (AIC_c). Models were ranked by ΔAIC_c scores. Results of the full model selection are available in the online supplement. For all candidate models with $\Delta AIC_c < 2.00$ from the best model, Akaike weights (w_i) were used to calculate model-averaged coefficient estimates, unconditional standard errors (SE), 95% confidence intervals (CIs), and to weight the evidence of importance for each variable.

RESULTS

Classification of assessment questions into Bloom's levels was valid. The quadratic weighted kappa for each reviewer relative to classification used in this study was high (reviewer 1: $K_{qw} = 0.863$, $se = .035$; reviewer 2: $K_{qw} = 0.870$, $se = .006$).

Student lab reports were influenced by documentation style. Specifically, imaging relative to drawing had a small significant negative effect on the amount of LO students included in their lab reports, but did not significantly influence the amount of HO (Table 1). In addition, the transfer of LO and HO from the lab report to the quiz was not significantly influenced by documentation style (Table 1).

The combination of classroom activities and the lab report did not significantly influence learning by students in the different imaging treatments as assessed by the quiz and exam. However, it is noteworthy that imaging relative to drawing had a marginally significant ($0.05 < P < 0.10$) negative influence on quiz LO and HO scores (Table 1).

Imaging relative to drawing had a negative impact on how students rated the lab overall, time efficiency and perceived excitement; yet was not

Table 3. Model-averaged coefficient estimates for all variables present in models with strong support ($\Delta AIC_c < 2$) related to results of the CLASS. SE = standard error, CI = confidence interval (95%), and Rel Import = relative importance of the model. A negative effect size indicates a negative effect. Imaging is relative to drawing. Unfavorable is a shift away from the expert view and favorable is a shift towards the expert view.

Explanatory Variable	Effect Size	SE	Lower CI	Upper CI	Relative Import.	Z value	P value
<i>Unfavorable</i>							
Imaging	-0.489	1.318	-3.065	2.086	0.28	0.372	0.710
<i>Favorable</i>							
Imaging	-1.926	1.781	-5.417	1.565	0.39	1.081	0.280

Effect sizes have been standardized on two SD following Gelman (2008). Bold denotes parameters with strong effects because the 95% CI does not overlap zero.

perceived as significantly more or less difficult nor did it significantly help with lecture (Table 2).

Results of the CLASS indicated that there was no support for an influence of either documentation style on attitude shifts in either the favorable (more like experts) or unfavorable (less like experts) direction (i.e., null models had ΔAIC_c scores < 2.00 and no significant differences were present, Table 3).

DISCUSSION

The potential for digital imaging to enhance learning and attitudes of students in survey-style biodiversity labs is quite apparent and to our knowledge has not previously been quantitatively evaluated. This study used a quasi-experimental design because students were assigned into treatments alphabetically, but GTAs were randomly assigned to each treatment. Treatments were run concurrently, GTAs taught in both treatment styles, we factored out the GTA effect in the statistical analysis, and we had a large enough sample size for reliable results. Since we could not find a verified plant biodiversity practical assessment associated with our desired learning goals, we developed the two cognitive assessments for this study and used a post assessment design. The attitude assessments were previously verified and well supported.

The results did not support the contention that digital imaging would improve introductory college biodiversity labs. First, students who used hand drawing had a tendency to be more thorough when producing lab reports with respect to LO material than students using digital imaging. Why would this occur? Observations indicated that in the digital-imaging treatment, considerable lab time was occupied with technological issues that were not a part of the drawing treatments. Examples of issues were time spent learning the digital software, errors using the cameras (e.g. accidentally using the incorrect camera setting or not connecting the computer interface), problems using the computer to save images and problems e-mailing. In addition, students had a difficult time getting a quality image due to poor microscope skills. In order to get a good image students in the imaging treatment relative to the drawing treatment had to be more proficient in

microscope usage (i.e. light adjustment to maximize resolution, focus, centering the object in question, not looking at their neighbor's drawing, etc.), and thus likely took up more time getting a good image than making a drawing. As a very rough estimate, one group per every other class would not complete their desired photographs because they could not get a good image. In such cases, however, we allowed the students to simply find an image from another student that was saved on the computer and use that image. In support of this contention, students thought that the digital imaging treatments were less time efficient than the drawing treatments. Thus, the lack of LO information in the lab reports of students may have been due to less overall time invested in writing the lab report because time was lost while imaging or working with images, or that the students simply did not have adequate images and did not include additional associated text to make up for the absence of an image. We did not assess students' comfort and familiarity with the imaging technology. Prior to the biodiversity lab, students had only one opportunity to become familiar with the imaging technology. However, they used the imaging technology in each of the three weeks during the pre-lab leading up to the focal lab.

Although observations support the contention that digital imaging improves microscope skills, results of the quiz do not support this. One LO quiz question required students to use the microscope to analyze a slide to answer one question. No differences were present for LO questions on the quiz between treatments.

Evidence from this study indicates that the primary drawback with digital imaging is in relation to students' attitudes. Students preferred the drawing treatment to the digital imaging treatment as reflected by the overall rating. Of the four explanatory variables associated with overall rating, students thought that the digital imaging treatment was less exciting and not as time efficient, but it did not influence their lecture learning experience and it was not perceived as any easier or harder. Of the variables explaining students' attitudes towards specific labs, excitement has had the greatest influence (Basey et al. 2008, Basey & Francis 2011). Observations

indicated that certain students in the imaging treatments relative to the drawing were more excited during specific hands-on experiences. For instance when students examined the swimming sperm and took videos in the pre-lab, they appeared to be much more excited than the students in the drawing labs viewing the same thing (both groups were very excited at times though). Also, students seemed to get very excited when they were successful at getting a high-quality image on the large computer screen that was representative of the learning goal. Some students commented that they really liked the digital photography aspect of the lab. Several students wanted to use their images for their start up image on the screen of their computer. Contrary to these observations and similar contentions in the literature, the attitude survey indicated that students in general thought the digital imaging relative to drawing was less exciting.

Educational Implications

Whether or not to replace drawing in favor of digital imaging in hands-on biodiversity labs, emphasizing observations as evidence for higher-order integrated reasoning most likely depends on desired learning goals of the teacher. Results of this study fail to show that differences were present between treatments for cognitive learning of LO foundational information or HO integrated reasoning, as well as moving students to think more like experts in biology. However results of this study indicated that students overall were more excited about drawing, thought that drawing was more time efficient, and overall they rated drawing in lab as better than digital imaging. On the other hand, observations indicated that individual student variation is a potential factor to consider and allowing students the freedom to choose their preferred documentation style may be the optimal design.

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Collaborative Learning Utilizing Case-Based Problems

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Abstract: Engaging students in discussion and creating high impact teaching and learning practices are a challenge in every classroom. Small group discussion and poster presentations were used to solve case-based problems to highlight issues for the learner and to allow each student to demonstrate understanding and application of theory to real life examples through open-ended, focused questions. This study consisted of students enrolled in an Anatomy and Physiology course sequence. Assessment was based on group goal and individual accountability. Rubrics for evaluation were developed for self and peer assessment of each groups' dynamics. A poster session provided our students with an opportunity to explain their work to an audience, as well as generate active discussion and peer evaluations. This study showed a significant positive effect ($p = 0.0001-0.0025$) on students' knowledge, attitude and psychomotor skills.

Key words: collaborative learning; small group discussion

INTRODUCTION

The University of Cincinnati, Clermont College (UCCC) is an open access regional campus that focuses on undergraduate students pursuing associate and technical degrees, as well as transferring to the main campus in Clifton. We have a diverse student population of which 58% are female, 42% are part-time students, 17% are minorities, and 36% are 25 years and older.

Students who enroll in Anatomy & Physiology are, in general, seeking degrees in health care fields. The Anatomy & Physiology course sequences are rigorous in both quantity and depth of material. Although courses have a laboratory component, the majority of the time is spent in traditional lecture. Moreover, in most classroom settings, not everyone is an active learner. Only a few students raise their hands and speak, ask questions, or interact in class. Due to time constraints, there is little occasion to apply what is learned to pathologic anatomy, which discusses the changes brought on by disease, or clinical anatomy that relates to manifestations of disease. Shared learning gives students an opportunity to engage in discussion, take responsibility for their own learning, and become critical thinkers (Totten, et al., 1991). Currently, work place environments and technological advancements require workers to solve problems and make team decisions. *The Essential of Baccalaureate Education for Professional Nursing Practice* outlines nine essential outcomes expected of graduates of baccalaureate nursing programs (American Association of Colleges of Nursing, 2008). Essential VI indicates that effective communication and collaboration among health professionals is imperative to providing patient-

centered care. It also directs that the undergraduate baccalaureate program should prepare students to incorporate effective communication techniques, including negotiation and conflict resolution to produce positive professional working relationships (American Association of Colleges of Nursing, 2008). Feingold et al. (2008) demonstrated that students clearly connect the concept of working in a group to their future roles as members of health care teams. According to the American Physical Therapy Association, physical therapist assistants work as part of a team throughout their career (American Physical Therapy Association, 2013). As instructors we recognized that our course assignments were not helping our students to learn these skills. To respond to these challenges, we designed a small group discussion (SGD) project using case-based problems that relate to theory and practice.

The goal was to actively engage students by having them work collaboratively to solve case-based problems. By utilizing small group discussion, we hoped to enhance critical thinking skills, improve self-esteem, cultivate a positive attitude towards learning, increase motivation, and improve interpersonal skills. It is our belief that a positive impact in the aforementioned areas would result in higher achievement for our students.

Research Questions

1. Will there be a significant difference in achievement on test questions prior to participation in SGD utilizing case-based problems, when students are learning individually, compared to achievement on test questions after participating in SGD, when students are learning collaboratively in groups?
2. Will students find that participating in SGD has a positive impact on their knowledge, attitude,

Table 1. Sequence of events for SGD over the course of the quarter.

Week	SGD Event
1	Post SGD guidelines, rubrics and case studies to Blackboard. Assign students to read material prior to next class. Embed pre-SGD test questions within Quiz 1.
2	Discuss the SGD guidelines in class. This includes goals of the project, responsibilities of individuals and of each group, end products and due dates. Discuss both student and instructor rubrics for evaluation of the project. Assignment of students to groups (randomly selected by instructor prior to class). Once assembled in groups, discuss roles within the group with the entire class. Ask students to discuss examples of “bad” behavior in group settings within their group. Discuss examples from each group with class as a whole. Perform a team building exercise. Students will begin working in their assigned groups beginning the following week.
3, 4, 5 & 6	After lab, allow 30 minutes for group to meet. Mediate any group issues.
7	After lab, allow 30 minutes for group to meet. Mediate any group issues. Invitations to the SGD poster session sent out to all faculty and staff of Clermont College.
8	SGD paper is due to instructor at the beginning of the week. SGD poster is due to instructor at the end of the week. This includes a preliminary presentation to the instructor for evaluation and feedback.
9	SGD poster session open to the entire Clermont College community. Rubrics designed to provide feedback to the students regarding their presentations are given to members of the community who attend the poster session. Students fill out rubric evaluating self and group member performance. Students fill out survey regarding SGD experience.
10	Instructor tabulates grade for each student based upon: instructor’s evaluation of paper and poster/presentation; average for each student’s self and peer assessment score. Instructor returns these rubrics and grade, along with feedback from Clermont College presentation.
Exam	Embed post-SGD test questions in Final Exam.

and psychomotor skills when utilizing collaborative learning to solve case-based problems?

METHODS

The Science & Health Department, specifically the Biological Sciences, at UCCC, offers courses that meet general education and program education requirements for the general student population. Beginning academic year 2012-2013, the University of Cincinnati converted from a three quarters system (ten weeks plus an exam week per quarter) to a two semester system (fifteen weeks plus an exam week per semester). All courses in this study were conducted when the university was using the quarter system. The University of Cincinnati IRB did not require a protocol due to anonymity of all data acquired.

Introductory Phase

The population for this study consisted of undergraduate students, in their first or second year of education, in Anatomy and Physiology course sequences, during the academic years 2009-2010 and 2010-2011. Each lab section had a maximum of 20 students. During the second week of classes, students were randomly assigned into small groups by drawing names out of a hat. See Table 1 for a timeline of SGD events. Each small group consisted of three to five students. Due to time constraints during lab and lecture, the students were required to meet outside of class time for a minimum of 60 minutes per week. To determine if students met for

the mandatory 60 minutes per week, students were required to list the dates the group met on the form used to evaluate the performance of each member of the group (see Table 4), otherwise it was based on the honor system. The first step in the collaborative learning process was to explain the learning strategy and specify the academic task of solving case-based problems. Next, instructions were given regarding the essential elements of effective cooperative learning based on research: positive interdependence, face-to-face promotive or positive interaction, individual and group accountability, interpersonal and small-group skills, and group processing (Johnson et al., 1991, 1993, 1998). Guidelines and assessment rubrics were distributed, and were made available on Blackboard and the instructors’ websites. Both the guidelines and assessment rubrics were thoroughly explained. After the project was explained, students were placed into groups and engaged initially in a team building activity. Play-Doh™ and wooden skewers were distributed to each group. They were instructed to create an object that would symbolize that group’s teamwork. Each group was given seven minutes to complete the task. At the end of the time each group described to the class the object they had created, what it symbolized and how they felt it could contribute to a positive outcome for their SGD project. At the end of the session, it was pointed out to the students that although they were all given the same materials to work with, each group

came up with very different end products; their SGD projects would be analogous.

Instructional Phase

At the beginning of each term, the students were presented with identical structured case-based problems. See Figure 1 for an example of a Case Study. These were constructed based on organ systems covered during the course of the quarter. Each topic was chosen to provide an in-depth learning experience, to highlight issues for the learner, and to demonstrate application of theory to “real life” situations.

write a narrative of the clinical scenario. Explicit instruction was given regarding the use of the guided questions: they were not simply to be answered, but to be used as a starting point to initiate the creation of the narrative. They were also required to create a poster based upon the narrative and give an oral presentation highlighting the most important aspects of the case.

Production Phase

Although the students were required to meet outside of class, at least thirty minutes of each lab session was also allotted for the small groups to meet.

Case History:

Sam Jones, a 50 year old accountant, was brought to the emergency room because he had suddenly lost the ability to speak and within a few minutes was unable to move his right extremities. He fell from his seat and was found lying on the floor by his son. He is slightly obese with a history of hypertension and high cholesterol for which he is on medication. He has been smoking cigarettes since age 18 and consumes one and a half packs of cigarettes a day.

Upon examination by the emergency room physician, the patient was awake, could follow commands but was unable to verbalize his answers to questions. When asked to raise both arms, the right arm drifted downward. His right upper and lower extremities were paralyzed and he had a mild droop on the right lower part of his face. He also had hyperactive deep tendon reflexes (DTR) and a positive Babinski sign on the right. He had diminished pinprick, vibratory sense of tuning fork, and two-point discrimination on the right side of his head and arm as compared to the left side. His coordination was intact in his other extremities. Cranial and pelvic X - rays revealed normal findings.

Vital signs: BP = 160/102, Temperature = 98.2, Pulse = 86, Respiratory Rate = 22

Focus Questions:

1. What is a stroke? Describe the mechanisms by which strokes occur.
2. Describe the collateral blood flow of the brain and how this can affect the development of stroke.
3. Discuss the risk factors and warning signs that predispose this patient to a stroke.
4. Discuss the functional relationship of the cortical areas (Brodmann areas) to the neurological deficits of the patient. What specific areas have been affected?
5. Explain the significance of the findings of deep tendon reflexes and Babinski sign.
6. Explain how he can regain neurological function following an injury to the nervous system. What preventive measures can be helpful to this patient?

Fig. 1. Sample Case Study

After feedback from students, additional case-based problems were developed for use in the second year of the study (2010-2011). These cases were specific to each quarter’s topics, so that each group had a unique case, for a total of 4 different cases in each quarter. However, this precluded our use of pre-SGD and post-SGD test questions as the material in the cases was taught during the entire quarter instead of in a single test unit.

As a guide, the students were given a list of questions to initiate research and discussion. These included the following:

- a. Discuss the structures and functions of the organ system affected.
- b. Explain signs and symptoms pertinent to the chief complaint and other associated conditions.
- c. Describe the causes and risk factors essential to the case.
- d. What pertinent lab works will help correlate diagnosis?
- e. Correlate possible complications that might arise if not given proper care and management.
- f. Explore common preventive measures and suggestions to help patient’s recovery or limit disability.

Additional questions were added that were specific to each case. The students were required to

The instructors were available to assist with intra-group difficulties, but the students were encouraged to rely upon each other for transformation of knowledge, clarification, elaboration, synthesis, organization of learning concepts and application of solving case-based problems.

The groups were given 4-5 weeks to complete and submit their written report. A week after the written report was submitted, each group gave a 3-4 minute oral poster presentation summarizing their case. Shortly thereafter, the students again presented their posters in an open session. This session was open to the entire UCCC community. Invitations were extended to all faculty and staff; students were encouraged to invite friends and family.

Assessment Phase

In this phase several evaluations were made by the instructor, by attendees of the poster presentation, and by the students.

Instructor Evaluation

The instructor made several types of assessment regarding performance by the students. To assess the effectiveness of this learning strategy, we developed a set of pre-SGD and post-SGD test questions to measure student understanding of a particular organ system. These were designed to assess the understanding of the material differentiating between

students learning individually (prior to the implementation of the SGD protocol) and students learning collaboratively (after completion of the SGD protocol) utilizing case-based problems in SGD. The number of students given the pre-SGD and post-SGD test questions differs from the number of students who completed the SGD project because after student feedback, in the second year of the study (2010-2011), we changed our case-based studies from being identical among all groups to assigning different case studies to each individual group. An instructor's evaluation rubric of the group's written report was formulated to set a standard for how it would be graded (Table 2); this was worth 40 of the 90 possible points of the written report. The poster with the accompanying presentation was evaluated separately, again utilizing an assessment rubric. Immediate feedback was provided to the students at the end of the poster presentation; this allowed the students a chance to improve and refine their presentation prior to the campus-wide session. The grade for the poster was determined entirely by the instructor.

participation of each member; this was worth 50 of the 90 possible points of the written report. The points awarded to each individual member by all members of the group (self-evaluation included) were tallied and averaged to determine point value. After each group submitted their written report, a 10-question survey tool was administered, using 5-point grading scale, to assess if the goals of the project were met in terms of student's knowledge, attitude, and psychomotor skills (Table 5).

Statistical Analysis

We used descriptive statistics, including means and medians, to summarize the data. Comparisons between the SGD and non-SGD groups were made using the Chi-square test and Student's t-test where appropriate. SAS version 9.2 (Cary, NC) was used for all analyses.

RESULTS

Pre-SGD and Post-SGD Questions

Of the 110 students who completed the pre-SGD and post-SGD test questions during the first year of the study (2009-2010), the pre-SGD test questions

Table 2: Instructor evaluation rubric of the group's written report.

Criteria	Unsatisfactory 1 – 2	Minimal 3 – 4	Effective 5 – 7	Exemplary 8 – 10	Score
Identification of the main Issues/problems	Identifies & understands few of the issues in the case study	Identifies and understands some of the issues in the case study	Identifies and understands most of the main issues in the case study	Identifies and understands all of the main issues in case study	
Analysis of the Issues	Incomplete analysis of the issues	Superficial analysis of some of the issues in the case	Thorough analysis of most of the issues	Insightful and thorough analysis of all the issues	
Comments on effective solutions/strategies	Little or no action suggested, and/or inappropriate solutions to all of the issues in the case study	Superficial and/or inappropriate solutions to some of the issues in the case study	Appropriate, well thought out comments about solutions, or proposals for solutions, to most of the issues in the case study	Well documented, reasoned and pedagogically appropriate comments on solutions, or proposals for solutions, to all issues in the case study	
Encourages participation	Incomplete research and links to any readings	Limited research and documented links to any readings	Good research and documented links to the material read	Excellent research into the issues with clearly documented links to class (and/or outside) readings	

Poster Presentation Attendees Evaluation

After the oral presentation, involved students, faculty members, and college staff members evaluated presentations using a session evaluation form. The feedback was given to each group. The rubric for evaluating the poster presentation can be found in Table 3.

Student Evaluation

We developed rubrics for both self- and peer-assessment of the groups' dynamics to ensure participation of each member (Table 4). Each student was asked to evaluate his or her own performance within the group, as well as asked to evaluate the

were answered correctly 56% (61 out of 110) of the time; the post-SGD test questions were answered correctly 69% (76 out of 110) (see Figure 2). This difference was significant ($p = 0.0004$), demonstrating the students had better understanding of subject matter after engaging in the collaborative learning strategy. We did not administer pre-SGD and post-SGD test questions during the second year of the study (2010-2011) because during that time, each group had unique case-based studies ($n = 189$); the material in these studies was covered during the entire quarter instead of in a single test unit as was done during the first year of the study.

Table 3: Poster presentation grading rubric.

Criteria	Unsatisfactory 1	Minimal 2	Effective 3	Exemplary 4-5	Score
Creativity					
Visuals	No graphics; inappropriate graphics	Some graphics; appropriate to case; no additional info compared to text	Many graphics; relevant to case; added some additional info to text	Interesting graphics; very relevant to case; added significantly to info in text	
Criteria	Unsatisfactory 1-5	Minimal 6-10	Effective 11-15	Exemplary 16-20	Score
Content	Incomplete: Introduction, discussion, recommendations, conclusion, literature cited	Superficial: Introduction, discussion, recommendations, conclusion, literature cited	Thorough: Introduction, discussion, recommendations, conclusion, literature cited	Insightful & thorough: Introduction, discussion, recommendations, conclusion, literature cited	
Oral presentation	Literature not referenced; read directly from poster; could not answer questions; disorganized presentation; no eye contact	Mentioned some literature sources; little additional info; spoke hesitantly-only from cue cards/poster; answered some questions; little eye contact	Mentioned most literature sources; gave adequate additional info; spoke very well; answered most questions; some eye contact	Presented in a logical and clear fashion; extensive discussion of literature sources; superior additional information; spoke extremely well; answered questions thoroughly; good eye contact	

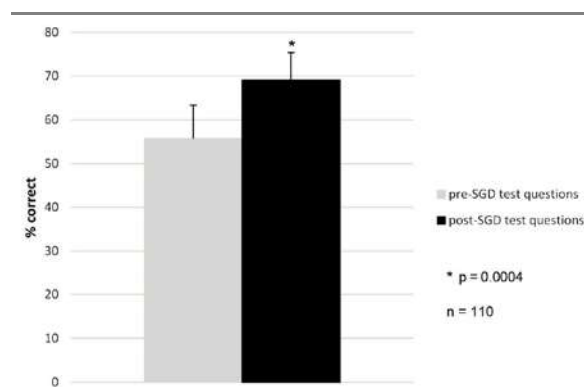


Fig. 2. The results of pre-small group discussion and post-small group discussion test questions (2009 – 2010).

Survey Responses

The 10-question survey tool (Table 5) answered by each student at the conclusion of the SGD project showed a positive significant impact ($p < 0.0001$ to $p < 0.0025$) on the students' knowledge, attitude, and psychomotor skills. In total, 299 students participated in answering the survey questionnaire during the first and second years of the study. The knowledge assessment showed that an average of 62.8% ($p < 0.0001$) of students strongly agreed that they: a) were provided with an effective learning experience using concepts presented in lecture and reading materials; b) were encouraged to use critical

thinking skills to understand the subject matter; and c) had the opportunity to apply concepts learned about theory to solve problems in "real life" scenarios (see Figure 3).

The attitude assessment showed that an average of 60.4% students ($p < 0.0001$ to $p < 0.0025$) strongly agreed that they: a) were able to express their own knowledge; b) provided group motivation; c) influenced the generation of ideas; and d) had a

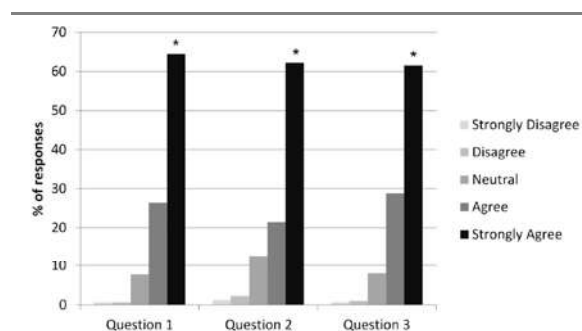


Fig. 3. Percentage of students' responses on the assessment of knowledge, $n = 299$, $*p > 0.0001$.

Question 1. Did I provide an effective learning experience using concepts presented in lecture and reading materials?

Question 2. Did the use of small group discussion encourage me to think more deeply and understand the subject matter?

Question 3. Did I provide the opportunity for the application of the presented concepts to solve problems in real life examples?

Table 4. Self and peer assessment rubric of small group discussion.

After your work is complete, evaluate your own work and that of your group mates using this rubric.
 Circle one in parenthesis. Course: A & P (1, 2, 3) Section (001/ 002) Group # (1, 2, 3, 4)
 Name: _____
 Group Members: _____
 Topic: _____
 Dates the group met: _____

Criteria	Unsatisfactory 1 – 2	Minimal 3 – 4	Effective 5 – 7	Exemplary 8 – 10	Score
Understanding of the problems	Identifies and understands few of the issues in case study	Identifies and understands some of the issues in the case study	Identifies and understands most of the main issues in the case study	Identifies & understands all of the main issues in the case study	
Analysis of the Issues	Incomplete analysis of the issues	Superficial analysis of some of the issues in the case	Thorough analysis of most of the issues	Insightful and thorough analysis of all the issues	
Preparation for the discussion	Do not collect any information relating to the topic	Collect very little information- some relates to the topic	Collect some basic information- most relates to the topic	Collect great deal of information- all relates to the topic	
Listens and cooperates with group mates	Always talking and usually argue with group mates	Usually do most of the talking and sometimes argue	Listen but sometimes talk too much and rarely argue	Listen and speak in fair amount and never argue with group mates	
Encourages participation	Never ask for input from others	Sometimes ask for input from others	Often ask for input from others	Make sure that all group members contribute to decisions about major points	

positive attitude toward learning (see Figure 4).

The psychomotor skill assessment showed that an average of 73.4% students ($p < 0.0001$), strongly agreed that: a) they actively performed the task with the group; b) the group successfully applied principles taught regarding problem solving; and c) they were personally active in application of the principles taught by offering probative ideas, suggesting interpretations, sharing their personal positions, and utilizing interpersonal skills (see Figure 5).

Upon completion of the SGD project, we collated student’s reflections and comments. These demonstrated thoughtful and meaningful contemplation of what they had learned individually, what they learned as a group, how they identified potential problems arising from SGD, and what solutions were achieved while working toward the common goal. A sampling of reflections and comments can be found below:

1. What I liked in small group discussion of case-based problems.

- How our group worked together and finds time to meet and put all our effort and solicit information and ideas.

- It was interesting and familiar yet it challenged our group to brainstorm and use critical thinking skills.
- I liked being able to discuss topics that we learned in class with my group mates and also gave us a chance to apply our learning to a situation.
- It was nice learning something new. I really enjoyed doing this.

2. What I would do in the next small group discussion.

- Utilize computer during out of class discussions to expedite answers or issues brought up, and clearer understanding of resources should also be addressed by our group.
- I would like to see more preparations for the discussion and more verbal input from some group members.
- Picking my own group would be nice. Perhaps can choose our case to work on.
- I do not like group work and would actually prefer not to do another SGD.

3. What do I think about my group participation and attainment of the goal?

- My group was encouraging and we all got along well together.

Table 5. Survey tool on the assessment of collaborative learning.

Fill out the following survey regarding how you interacted within your group. "I" and "me" refers to the student filling out the survey.					
Direction: Kindly answer the questions by putting a check mark on each item according to the rating scale below.					
1- strongly disagree 2- disagree 3- neutral 4- agree 5- strongly agree					
ON KNOWLEDGE	1	2	3	4	5
1. Did I provide an effective learning experience using concepts presented in lecture and reading materials?					
2. Did the use of small group discussion encourage me to think more deeply and understand the subject matter?					
3. Did I provide the opportunity for the application of the presented concepts to solve problems in real life examples?					
ON ATTITUDE					
4. Did it give me an opportunity to express what I know?					
5. Did I motivate group members and encourage collaboration on focused questions or problems?					
6. Did I influence and stimulate the generation of ideas from the group?					
7. Did I develop positive attitudes toward learning and use of presented material?					
ON PSYCHOMOTOR SKILL					
8. Did I perform a task actively with the group?					
9. Did the group successfully apply the principles taught to problem solving in small group discussion?					
10. Was I personally active in the application of the principles taught? (offering probative ideas, suggesting interpretations, sharing personal positions, beliefs, communication and listening)					
Write any additional comments and suggestions about your learning experience.					

- My group had a conflict of finding time to meet, but everyone did great giving their thoughts and opinions.
- Everyone had a lot of interesting and conflicting information.
- Some people did a lot of work and some did very little.

4. General comments on group's activity

- The final paper was hard to write because of many possibilities we thought. But we did it.
- I felt comfortable and confident expressing my opinion in my group.
- Great to have small groups working together, rely on each other, and put our lectures to use in thinking outside the classroom.
- I don't usually like to work with other students, but I thought the case study was very helpful & effective.

The poster presentation of case-based problems was an important part of the small group project. It provided our students with an opportunity to explain their work to an audience, as well as generate active discussion and outside evaluations. A sampling of these reviews can be found below:

- Just wanted to say how impressed I was with the students' work. It was very clear from their presentations how well they all worked together and the wonderful knowledge and experience they gained from this exercise. The confidence with which they discussed their findings was truly inspiring - proves how important it is to give our

students opportunities to go beyond the immediate classroom environment to learn and share with the wider community. So thank you to you and your students - in fact you have given me something to think about for my own teaching! (P. M., MEd, Director, UCCC, TLC)

- Thanks for your work on this project where the students learned teamwork, solving problems and effective communication skills. (G.S., Ph. D., Dean, UCCC)
- All group members presented information in an easy to understand manner and were very informative. Great speaking skills and good visuals. (A.C., HSS Faculty)
- Students knew what they are talking about. The presentation was very informative, presenters were relaxed, and answered questions comfortably, not rehearsed (L. K., Academic Advisor).
- Thank you for the great opportunity for our PTA majors-it was a nice diagnostic approach that included the clue finding in exploring the various conditions to rule out or in. (S. C., PTA Faculty)

DISCUSSION

The integration of basic sciences with patient care has been supported by various studies and has proven to be a valuable strategy in the reinforcement of basic science courses (Percac and Goodenough, 1998; Stalburg and Stein, 2002). However the use of case-based problems facilitated through small group discussion needs to be explored further regarding

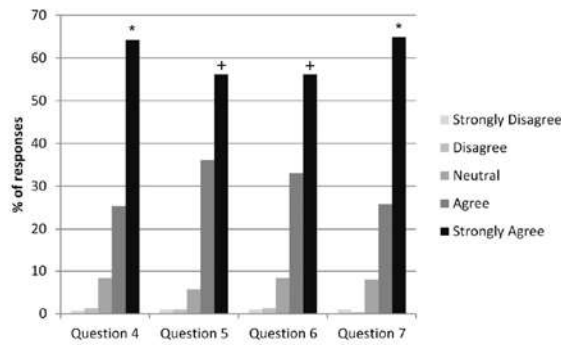


Fig. 4. Percentage of students' responses on the assessment of attitude, $n = 299$, $*p > 0.0001$, $+ p < 0.0025$. Question 4. Did it give me an opportunity to express what I know?

Question 5. Did I motivate group members and encourage collaboration on focused questions or problems?
 Question 6. Did I influence and stimulate the generation of ideas from the group?
 Question 7. Did I develop positive attitudes toward learning and use of presented material?

method of delivery of the learning strategy and its impact on student learning. We approached this study by providing a structured case, with focused questions, to serve as a guide for creating dialogue among each group's members. The case-based approach allows our students to generate a solution by engaging in independent research, analyzing data, and reflecting on their own learning experience. The ultimate objective was to present a clinical diagnosis in a written report and in an oral poster presentation that was a reflection of the entire group's work.

In addition to the cognitive process that they underwent, the students had the opportunity to enhance their confidence in problem solving because of the given chief complaint and brief clinical history. They had to investigate to discover and identify the diagnosis given the various presentations and associated findings. Utilizing the physical presentation, laboratory and radiographic results,

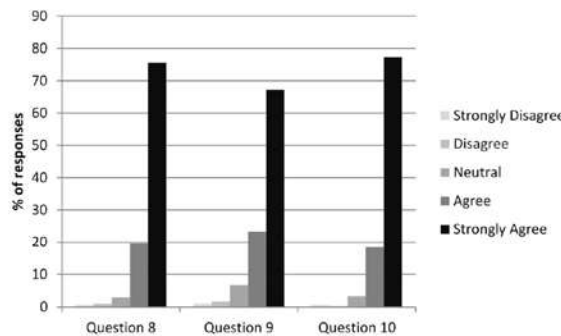


Fig. 5. Percentage of students' responses on the assessment of psychomotor skill, $n = 299$, $*p > 0.001$.

Question 8. Did I perform a task actively with the group?
 Question 9. Did the group successfully apply the principles taught to problem solve in small group discussion?
 Question 10. Was I personally active in the application of the principles taught?

each group had to formulate a diagnosis and present relevant information regarding statistical data, management of the presenting problem, prevention and/or rehabilitation of their patient. Thus early exposure to this is valuable in influencing our students' ability to apply and translate knowledge into a real life, clinical setting.

By utilizing collaborative learning to solve case-based problems in SGD, statistical analysis demonstrated that students who participated in the small group discussion project had a significant improvement in achievement on post-SGD test questions (after participation in the SGD project) compared to pre-SGD test questions (prior to participation in the SGD project). Furthermore, a statistically significant number of students indicated that participating in SGD had a positive impact on their assessment of their own knowledge, attitude and psychomotor skills.

Small Group Discussion fosters an effective learning experience in applying knowledge to clinical problems. In this study, a statistically significant number of students felt that participating in SGD helped them improve their critical thinking skills and academic achievement, as well as develop interpersonal skills.

Future research is needed to investigate the effect of different variables, such as the group selection process (random vs. non-random selection), group size (3-5 vs. 6-10 group members), group composition (major field of study homogeneity vs. heterogeneity), amount of teacher intervention or consultation, and student's preferences as to learning styles (individual vs. small group).

Instructors may apply this study to other disciplines to understand and analyze problem solving, learn critical thinking skills, and ensure group task of the learners. This approach is applicable to a variety of other courses.

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INNOVATIONS

Which Beak Fits the Bill? An Activity Examining Adaptation, Natural Selection and Evolution

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Abstract: Evolution is a unifying concept within biology. In fact, Dobzhansky, a noted evolutionary biologist, argued, "Nothing in biology makes sense except in the light of evolution" (Dobzhansky, 1973). However, often students have misconceptions about evolution. There are a number of available activities where students use tools (representing bird beaks) to collect different food items. These activities enable students to see how various beaks are adapted to feeding on certain types of food. This article describes an inquiry-based activity that takes the process several steps further. In this inquiry-based activity, students not only examine adaptations that birds have for capturing prey, and changes in a bird population over time, but also hypothesize what would happen to the bird population if relative seed abundances change over time. Students then model an environmental change recorded by researchers when observing Darwin's Finches. The Grants observed a severe drought in 1977 resulting in a drastic decline in seed production with small seeds being particularly affected (Grant, 1999; Boag & Grant 1981). Students then test their hypothesis and compare their findings to those observed by the Grants. This activity is well suited for students in general biology, ecology or evolution classes.

Key words: Evolution, natural selection, adaptation, variation in populations

INTRODUCTION

Organisms display variation in traits such as body size, color, speed, and aggressiveness. Variation is found between species and within a species. Many traits of organisms are adaptations to their environment. In birds, for example, there is variability in the size and shape of the beak, or bill, which is utilized for finding and capturing food. Some birds have wide, thick bills used for crushing seeds; some have short, thin bills for picking up small prey; while others have long tubular bills for drinking nectar from flowers.

The adaptations that we see in organisms are a result of evolution by natural selection. Before conducting this activity, I introduce the concepts of adaptation, natural selection and evolution. In class, we discuss variation in bill shape and size in Darwin's finches, and how this variability arose. Then, after discussing evolution by natural selection, the students conduct this inquiry-based activity allowing them to simulate evolution.

METHODS

I divide the class into groups of 5-6 students per group. In each group, one student serves as the timer, and data recorder for the group (students can alternate jobs for Activity 2). The remaining students are "birds" and forage for seeds. Students use tweezers, pliers and other household items to simulate variation in bird beaks within a population of birds feeding on a variety of types of seeds. The

"birds" each select one of five different beaks, such that in each group there are five different types of birds. I provide a range of beaks sizes to choose from. Ideas for beaks include: pointed tweezers, wide tweezers, eyelash curlers, needle nose pliers, regular pliers, forceps, snap clothespins, and different sizes of binder clips. When choosing beak types, choose a range of types including some that are very pointed, and others that are wider. This activity works best if all the pliers are spring loaded.

Each student uses their beak to forage for seeds. I explain that each student simulates a bird's beak. Students represent birds with variability in beak size and shape within a single species (for example, within one species of Darwin's finches).

First, students gain experience using their beak. I have each group assemble four stations, one for every seed type: thistle, safflower, black oil sunflower, and peanuts. Each station contains one cup of a single type of seed placed on a paper plate. Students then practice foraging at each of the stations for 1 minute (with the timer timing them). During this practice period, students use their beaks to collect as many seeds as they can from one of the foraging stations, and place the seeds in their paper cups (their stomachs). While foraging, students can only use their beaks to collect food (they cannot use their other hand to assist). They may only collect one seed at a time (they cannot grab clumps of seeds). If seeds stick to their beaks, students can tap their beak on the side of the tray to remove extra seeds. At the end of 1 minute, students count the number of seeds collected

Table 1. Number of seeds consumed by different beak types while foraging on a single seed type.

Beak Type	# Thistle Seeds	# Safflower seeds	# Sunflower seeds	# Peanut Seeds	Total # of Seeds Captured
Narrow tweezers					
Wide tweezers					
Eyelash curler					
Needle nose pliers					
Regular pliers					

and place their results in Table 1. Seeds are then placed back on the paper plate and mixed. Students then repeat the same procedure at each of the feeding stations.

Questions for students to address before they begin the next section:

- 1) Which seed type is each bird best at capturing? Explain why.
- 2) In an environment with equal quantities of the four seed types, which beak types would you hypothesize will be most abundant in the bird population? Which types would be least common? Explain why.

Activity One: Foraging in an environment with equal quantities of four different sized seeds

Next, students forage in a mixed seed patch containing equal amounts of all four seeds to test their hypothesis. Before beginning the activity, students first write down their predictions for which seed type they expect each bird to be best at collecting.

Each group of students assembles a foraging station with equal quantities (1 cup each) of the four types of seeds mixed together on a tray (e.g. pie or pizza pan). Students then use their beaks to forage for 1 minute, and record their results in an appropriately labeled table (Table 2). Students may forage for any seed type and should try to collect as many seeds as possible (as long as they only collect one seed at a time). When done, the seeds are returned to the foraging station and mixed. Each student forages twice, and calculates their averages.

Students then assess the success of each beak type. **The rules are as follows:**

- 1) The bird that captures the fewest total number of seeds dies (it is unable to consume sufficient energy to meet its

energetic requirements). This beak type will not continue into the next generation.

- 2) Birds that capture between the lowest and the highest total number of seeds, survive. The next generation will begin with one of each of these beak types.
- 3) The bird that captures the highest total number of seeds not only lives, it produces two offspring. The next generation will begin with two additional birds of this beak type (three total).

Students compute the number of birds of each beak type that survive to the next generation, and place their results in an appropriately labeled table (Table 3). Given this new bird population, students then forage again (after replacing all seeds). At the end of 1 minute, they record their results in an appropriately labeled table (Table 2). Then, they return the seeds to the foraging station. Each student forages twice, and calculates their averages.

After calculating the average number of seeds captured, students compute the number of birds of each beak type that survive to the next generation, using the same rules as above, and place their results in Table 3.

Questions for students:

- 1) Given an environment with equal quantities of the four seed types, which beak types are most abundant in the bird population? Was your hypothesis supported? Which beak types are absent? Explain why.
- 2) If this exercise were conducted for many generations, what do you predict will happen in the population? Why?

Table 2. Number of seeds consumed by the birds during Activity (label either Activity One or Activity Two) during th generation (label either first or second generation).

Beak Type	# Thistle Seeds	# Thistle Seeds	Ave # of Thistle Seeds	# Safflower Seeds	# Safflower Seeds	Ave # of Safflower Seeds	# Sunflower Seeds	# Sunflower Seeds	Ave # of Sunflower Seeds	# Peanuts	# Peanuts	Ave # of Peanuts	Total # of Seeds Captured (Ave)
	Trial 1	Trial 2		Trial 1	Trial 2		Trial 1	Trial 2		Trial 1	Trial 2		
Narrow tweezers													
Wide tweezers													
Eyelash curler													
Needle nose pliers													
Regular pliers													

Each student will need four copies of this table: one for each generation of Activity One, and one for each generation of Activity Two.

Table 3. Number of birds of each beak type at the start of each generation for Activity (label either Activity One or Activity Two).

Beak Type	Parental generation	Second generation	Third generation
Narrow tweezers	1		
Wide tweezers	1		
Eyelash curler	1		
Needle nose pliers	1		
Regular pliers	1		

Part Two: Foraging after an environmental change results in unequal availability of different sized seeds

Now consider a scenario where there is an environmental change (a severe warming in the climate over several years) resulting in a drought. The drought causes a decline in seed production, particularly for small seeds. For the two largest seeds, the seed availability declines, leaving $\frac{3}{4}$ cup of each of these seed types in the environment. For the two smallest seeds, the seed availability declines to a greater extent, resulting in $\frac{1}{8}$ cup of each of these seed types in the environment. This situation is analogous to the environmental change noticed by Peter and Rosemary Grant while researching Darwin’s Finches. The Grant’s observed a severe drought in 1977 resulting in a drastic decline in seed production with small seeds being particularly affected (Grant, 1999; Boag & Grant 1981).

Each group of students next establishes a feeding station representing the new environment ($\frac{3}{4}$ c each of sunflower seeds and peanuts, mixed with $\frac{1}{8}$ c each of thistle and safflower seeds on a tray). Before beginning the activity, students record their hypothesis regarding which birds will be best at surviving and reproducing.

Questions for students to address before they start the next section:

- 1) In an environment with greater availability of large seed types, which beak types do you hypothesize will be most common in the population? Which beak types would be least common? Explain why.

As in Activity 1, students use their bills (starting with one student representing each of the 5 beak types) to forage for 1 minute and collect as many seeds as possible. Each student forages twice, calculates their averages, and places their results in a labeled table (Table 2). After computing the average number of seeds captured, students then assess the success of each beak type using the same rules as before. Students compute the number of birds of each beak type that survive to the next generation, and place their results in an appropriately labeled table (Table 3). Given this new bird population, students then forage again (after replacing all seeds). Each student forages twice, and records their averages (Table 2). Students then assess the success of each beak, and compute the number of birds of each beak type that survive to the next generation (Table 3).

Questions for students:

- 1) Given an environment with unequal quantities of the four seed types (with a greater abundance of large seeds), which beak types are most common in the population after several generations? Why? Was your hypothesis supported?
- 2) If this exercise were conducted for many generations, what do you predict will happen? Why?
- 3) How do the results from Activity Two compare to the results from Activity One? Are they different? If so, explain why.
- 4) Obtain a copy of the article by Boag and Grant (1981). They found that as a result of the drought, birds (especially small finches) suffered high mortality, resulting in a change in average bill depth. How do your results compare to those observed by Boag and Grant? Explain similarities and differences.

Safety Considerations

Students should wear safety glasses when conducting these exercises. Students should also be instructed to only use the tools for picking up seeds and to never point them towards other students.

DISCUSSION

This exercise provides an opportunity for students to simulate evolution via natural selection in a population. By actively simulating how populations evolve over time, students gain a better understanding of the process of evolution by natural selection. Students get to examine how traits that improve an individual’s survival and reproduction increase in a population, and how those traits that reduce an individual’s survival and reproduction decrease in a population.

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Bioscene: Journal of College Biology Teaching

Submission Guidelines

I. Submissions to *Bioscene*

Bioscene: Journal of College Biology Teaching is a refereed quarterly publication of the Association of College and University Biology Educators (ACUBE). 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. No subheading is needed for this section. This 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. Disclaimers and endorsements (government, corporate, etc.) will be deleted by the editor.

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. Also, gimmicks such as capitalization, underlining, italics, or boldface are discouraged. All weights and measures should be recorded in the SI (metric) system.

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

Single Author:

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

Two Authors:

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

Multiple Authors:

“...similar results have been reported previously (Baehr et al., 1999).

- C. References: References cited within the text should be included alphabetically by the author's last name at the end of the manuscript text with an appropriate subheading. All listed references must be cited in the text and come from published materials in the literature or the Internet. The following examples indicate *Bioscene's* style format for articles, books, book chapters, and web sites:

(1) Articles-

(a) Single author:

DEBURH, L.E. 1991. Using *Lemna* to study geometric population growth. *American Biology Teacher* 53(4): 229-32.

(b) Multi-authored:

GREEN, H., GOLDBERG, B., SHWARTZ, M., AND D. BROWN. 1968. The synthesis of collagen during the development of *Xenopus laevis*. *Dev. Biol.* 18: 391-400.

(2) Books-

BOSSEL, H. 1994. *Modeling and Simulation*. A.K. Peters, London. 504p.

(3) Book chapters-

GLASE, J.C., AND M. ZIMMERMAN. 1991. Population ecology: experiments with Protistans. In Beiwenger, J.M. 1993. *Experiments to Teach Ecology*. Ecological Society of America, Washington, D.C. 170p.

(4) Web sites-

MCKELVEY, S. 1995. Malthusian Growth Model. Accessed from <http://www.stolaf.edu/people/mckelvey/envision.dir/malthus.html> on 25 Nov 2005.

For references with more than five authors, note the first five authors followed by et al.

D. Tables

Tables should be submitted as individual electronic files in Word (2003+) or RTF format. Placement of tables should be indicated within the body of the manuscript. All tables should be accompanied by a descriptive legend using the following format:

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

E. Figures

Figures should be submitted as high resolution (≥ 300 dpi) individual electronic files, either TIFF or JPEG. Placement of figures should be indicated within the body of the manuscript. Figures only include graphs and/or images. Figures consisting entirely of text will not be allowed and should be submitted as tables. All figures should be accompanied by a descriptive legend using the following format:

Fig. 1. Polytene chromosomes of *Drosophila melanogaster*.

III. Letters to the Editor

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

IV. Other Submissions

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

V. Manuscript Submissions

All manuscripts are to be sent to the editor electronically. *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 within three days. 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. Authors' names will be withheld from the reviewers. 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. Acknowledgement of the reviewers' comments and suggestions must be made for resubmission and acceptance. Further revisions should be made within six months if called for. Manuscripts requiring revision that are submitted after six months 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 back to the associate editor, along with an email stating how reviewers' concerns were addressed.
- B. Make sure that references are formatted appropriately.
- C. Make sure that recommended changes have been made.
- D. Figures and legends sent separately, but placement in manuscript should be clearly delimited.

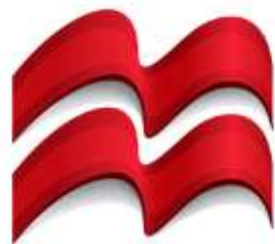
VIII. Editorial Policy and Copyright

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

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