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Articles

A Ten-Year Assessment of Core Concept Retention by Biology Majors

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Abstract

Here, we present a ten-year assessment of core concept retention, with an emphasis on evolution, by senior biology majors at a small, private liberal arts college. For concepts that are regularly revisited throughout the biology curriculum, we found that knowledge retention was robust. However, for concepts that are encountered only during the introductory sequence of the freshman year, retention was weak. Furthermore, while our students seem to accept evolution as the source of biological adaptation, their understanding of the concept of natural selection is inconsistent.

Key Words: Introductory biology, core concepts, evolution education

Introduction

Biology is the most diverse of all the STEM (science, technology, engineering, and math) disciplines (Brownell et al. 2014). Introductory biology course sequences for majors are typically taught as a survey of biological concepts, from molecules and cells to organisms and their physiologies to ecology and evolution. As new discoveries in the laboratory and field broaden the scope of biology, it becomes increasingly difficult for instructors of these courses to cover all aspects of the life sciences in the introductory sequence (Wood, 2009). Furthermore, as more instructors attempt to incorporate pedagogically-sound but time-consuming active learning strategies into the classroom, less time can be devoted to covering concepts.

Gregory, Ellis, and Orenstein (2011) addressed this issue by surveying more than 300 members of the National Association of Biology Teachers (NABT) who were responsible for teaching their institutions' introductory sequence for biology majors. Input from these instructors was used to generate a list of the 25 most essential topics for an introductory sequence of courses for biology majors (Table 1). Limiting the minimum core to 25 topics would translate into roughly one topic per week over the course of two semesters, giving instructors sufficient time to engage students in active learning activities to foster a deeper understanding of course content. As a follow-up study, Gregory, Lending, Orenstein, and Ellis (2011) surveyed a wider population of biology faculty (n=742) who taught both introductory and upper-level biology courses. The lists of 25 essential topics generated by the two surveys were very similar. Each list was topped by evolution, specifically evolution by natural selection, the concept considered most essential for biology majors to understand.

Evolution is often taught as one discrete topic in the biology curriculum. It is likely more appropriate to treat the concept of evolution as a thread woven into the fabric of the entire curriculum (Stover & Mabry, 2007; Wei et al., 2012). Most references to evolution in the scientific literature are associated with research in genetics or research investigating adaptations in populations of organisms (Blackstone, 2009). However, in 2009, the Association of America Medical Colleges (AAMC) and the Howard Hughes Medical Institute (HHMI) published *Scientific Foundations for Future Physicians*, establishing evolution as a key component of medical science. Both disease-causing organisms and their victims evolve over time. Understanding the process by which changes in gene frequencies lead to adaptations can inform how diseases are treated. Furthermore, while evolutionary theory is often absent from scientific literature associated with cell and molecular biology, it is critical to understanding

Rank	Essential Topic	Rank	Essential Topic
1	Evolution	14	Genetic recombination
2	DNA structure and replication	15	Populations and communities
3	Membranes and membrane transport	16	Bioenergetics
4	Protein synthesis	17	Animal diversity
5	Cellular respiration	18	Plant diversity
6	Photosynthesis	19	Animal reproduction
7	Enzymes	20	Population genetics
8	Meiosis	21	Classification
9	Cell cycle	22	Plant reproduction
10	Mendelian genetics	23	Chemical structures
11	Ecosystems and conservation	24	Cell communication
12	Speciation	25	Viruses
13	Cell structure and function		

Table 1: Top 25 essential topics for introductory biology (adapted from Gregory, Ellis, and Orenstein, 2011)

the ultimate aspects of cellular and macromolecular function (Blackstone, 2009).

College students, including science majors, often possess ideas regarding natural phenomena that do not align with scientific evidence (Coley & Tanner, 2012). Evolution, in particular, can be very challenging for undergraduate students to understand (Ziadie & Andrews, 2018). While some research indicates that many students reject evidence supporting evolution due to a perceived conflict with their religious beliefs (Dagher & BouJaoude, 1997; Sinatra et al., 2003), other studies demonstrate an overall acceptance of the theory, but a lack of understanding of the mechanism behind it. Undergraduates often only associate evolution with "survival of the fittest." Consequently, they think that new traits only arise in a population because they are needed for survival. This teleological reasoning undermines Darwin's theory by discounting the impact of variation and the somewhat random process of natural selection in populations (Stover & Mabry, 2007; Gregory, 2009). Some students still use a Lamarckian approach, the inheritance of acquired traits from the previous generation, to explain changes in populations of organisms over time (Settlage, 1994; Crow, 2004).

Davis & Elkins College (D&E) is a very small, private, four-year liberal arts college that emphasizes small class sizes and strong faculty-student interactions. We were curious as to whether our students were being given sufficient exposure to essential topics to promote long-term retention. The present study represents a ten-year assessment of core concept retention, with an emphasis on evolution, by graduating biology majors at D&E.

Methods

Using the 25 essential topics generated by Gregory, Ellis, and Orenstein (2011), we created a 50-question content assessment test that was administered to graduating biology majors at the end of each spring semester from 2013 to 2022. The multiple-choice questions addressed fundamental concepts that students first encountered in the introductory biology sequence, which was taught by author MLM for the entire span of the study. Each of the 25 essential topics was the basis for at least one content assessment question. The topic of evolution, however, was emphasized. As indicated by the two surveys that were the impetus for the current study, the concept of evolution by natural selection is the most important topic for biology majors to understand. There were six questions on the test devoted to evolution (Table 2). For each of the six questions, four possible answers were provided to represent the following categories: Lamarckian, teleological, creationist, and Darwinian. Lamarckian responses indicated that physical changes experienced by organisms during their lifetimes were transmitted to offspring. Teleological responses indicated that adaptations had a specific purpose, allowing a specific goal to be achieved. Creationist responses suggested that no change in gene frequencies had taken place. Organisms were created exactly as they exist today. Finally, Darwinian responses suggested evolution by the

Test Question	Subject Matter of Test Question
Q1	Foundation of Darwin's concept of natural selection
Q15	Non-functional eyes of cave salamanders
Q19	Sprinting speeds of cheetahs
Q21	Antibiotic resistance in bacteria
Q23	Initial and subsequent effectiveness of AZT as HIV treatment
Q25	Chemical toxins produced by plants

Table 2: Subject matter of evolution questions on the content assessment test.

process of natural selection. We had used the same evolution questions rather effectively in a previous study on student understanding of natural selection (Stover & Mabry, 2007).

Content assessment scores, as well as categorical responses to the specific evolution questions, were subjected to a multiple comparison analysis of variance (ANOVA). For the evolution questions, the ANOVA compared responses within each individual question. Fisher's least significant difference test was employed to compare specific groups within the ANOVA. An alpha level of $P < 0.05$ was regarded as statistically significant.

Results

A total of 60 D&E biology graduates completed the content assessment test between 2013 and 2022. This may seem to be a small sample size for a 10-year study, but D&E is a very small college. Total enrollment was between 650 and 800 students for the time span of the study. We graduated, on average, about six biology majors per year. Every biology graduate completed the content assessment test. Our benchmark score for the test was 70%. While only 36 of the 60 students reached the benchmark, the average score on the assessment test over the 10-year span of the study was 70.8%. Statistically, there was no significant difference between individual content assessment scores. Individual variability in terms of students' academic strengths did not seem to be a major factor. Furthermore, there was no significant difference between assessment scores before and after the COVID-induced shift to online learning in 2020.

Of the 44 assessment questions unrelated to evolution, five were answered correctly by at least 90% of graduating biology majors. Another five, however, were answered correctly by less than 50% of graduating biology majors (Fig. 1).

For the six evolution questions, creationist responses were significantly less common than other categorical responses. For four of the six questions, there were no creationist responses. The percentage of correct Darwinian responses was significantly greater than that of other categorical responses for Q21 and Q25. Teleological responses were statistically similar to Darwinian responses for Q1, Q15, and Q19. Lamarckian responses were statistically similar to Darwinian responses for Q1 and Q23 (Fig. 2).

Discussion

Forgetting is a natural component of memory (Hardt et al., 2013). Many factors can influence retention of knowledge, including individual differences in learning ability, prior knowledge, and the degree of importance assigned to the information being learned. Perhaps the most important factor contributing to retention is repetition. Knowledge retention is improved by one or more exposures to previously learned knowledge. Each revisit to the previously learned material slows the rate of knowledge loss and facilitates knowledge retention (Custers, 2010; Kooloos et al., 2020).

Of the five assessment questions unrelated to evolution that were answered correctly by at least 90% of our graduating biology majors, four were related to the chemical structure of macromolecules (lipids, amino acids, nitrogenous bases, and covalent bonding), and one was related to membrane transport (simple diffusion). Like all the essential topics, macromolecules and membrane transport are first introduced during the introductory biology sequence. These particular topics, however, are revisited in our genetics and cell & molecular biology courses, both of which are required for all biology majors. The genetics course is almost always taken in the fall semester of the sophomore year, while the cell & molecular course is generally taken in the spring semester of the sophomore or junior year. Furthermore, the very same topics are encountered again in several elective courses, including human physiology and functional histology, taken by our pre-medical and pre-veterinary biology majors

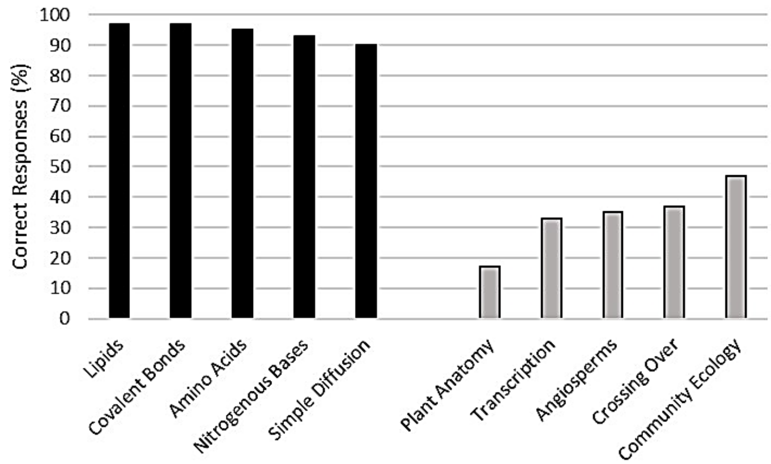

Figure 1: Top five (black bars) and bottom five (gray bars) concepts unrelated to evolution on the content assessment test. Black bars represent questions that at least 90% of students answered correctly. Gray bars represent questions that fewer than 50% of students answered correctly.

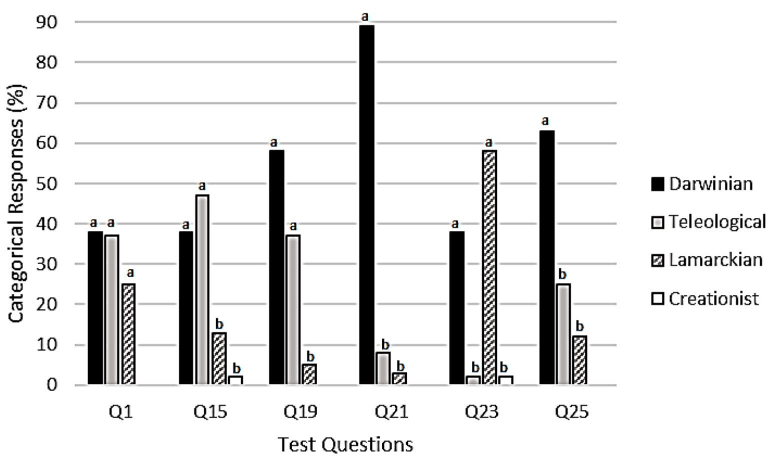

Figure 2: Categorical responses for each of the evolution questions. Each evolution-based question had four possible responses: creationist, Lamarckian, teleological, and Darwinian. For each question, different superscripts (a, b) indicate significant differences

(Table 3). Many of those same students will also take biochemistry, where macromolecules and membrane transport are visited yet again. Revisiting previously learned material can reinforce a student's foundation of knowledge, making it easier to expand on that knowledge Kooloos et al., 2020). This type of "spaced education" has been shown to be effective for medical students and residents (Matos et al., 2017; Chugh & Tripathi, 2020). It seems that D&E biology majors may also be benefitting from this strategy.

Of the five assessment questions unrelated to evolution that were answered correctly by less than 50% of our students, two were related to plants (plant anatomy and angiosperms) and one was related to ecology (community ecology). The vast majority of our biology majors are interested in healthcare-related careers. Very few of them take elective courses that cover botany or ecology. As a result, they are exposed to these concepts only once, during the freshman year (Table 3). Knowledge of these concepts is long forgotten by the time they take the content assessment test just prior to graduation. The other two "bottom five" concepts, however, cannot be explained by a lack of exposure. Transcription is a component of the essential topic of protein synthesis, while crossing over is a component of meiosis. Both topics are introduced during the introductory sequence, and both are revisited by all biology majors in genetics and cell & molecular biology. Poor performance on assessment questions related to transcription and crossing over appears to be the result of misconceptions. Students were asked to identify the enzyme associated with the addition of nucleotides during the process of transcription. It seems that many students do not distinguish between DNA polymerase and RNA polymerase. Some have a hard time distinguishing between DNA replication and transcription, in general. Furthermore, students were asked to identify the phase of meiosis during which crossing over

	Introductory sequence	Human physiology	Genetics	Functional histology	Cell & molecular
Macromolecules	YES	YES	YES	YES	YES
Membrane transport	YES	YES	YES	YES	YES
Plant anatomy	YES	NO	NO	NO	NO
Community ecology	YES	NO	NO	NO	NO

Table 3: Coverage of selected topics in core courses and popular electives (Human Physiology and Functional Histology)

occurs. A considerable number of students incorrectly associate crossing over with metaphase of meiosis, when homologous chromosomes come together at the equator of the cell, instead of prophase.

As demonstrated in a previous study (Stover & Mabry, 2007), our students seem to accept biological evolution as the basis for differential gene expression in populations over time. However, a considerable number of them do not have a good grasp of the mechanism driving the theory, as indicated by the prevalence of teleological and, to a lesser degree, Lamarckian responses in Figure 2. This is a bit discouraging, as all of our biology majors are required to take a 300-level evolution course prior to graduation.

Twenty-two students selected the teleological response “Organisms adapt according to their needs” as the foundation for Darwin’s theory of evolutionary change in Q1. That would explain why so many students felt that the cave salamanders in Q15 “had to adapt to darkness in order to survive” and the cheetahs in Q19 “had to adapt to capture fast-moving prey in order to survive.” Responses were inconsistent, however. For Q23, which dealt with HIV mutation reducing the effectiveness of AZT treatment, 35 students selected the Lamarckian response, indicating that “the virus gains resistance as it is exposed to the drug, and subsequent generations of viruses inherit the resistance.”

The good news is that a significant number of students selected the correct Darwinian responses for Q21 and Q25. The first of those questions addressed bacterial resistance to antibiotics. Fifty-three students correctly selected “As a result of mutation, there is a great deal of variation within a bacterial population. Those that survive antibiotic exposure will be able to reproduce, and resistance will become more prominent in the population.” The concept of antibiotic resistance is briefly introduced in the introductory sequence, but it is a major component of the microbiology elective taken by many pre-medical and pre-veterinary students. Furthermore, it is revisited again in the required evolution course. Q25 was related to the production of chemical toxins in plants, making them resistant to consumption by herbivorous organisms Thirty-eight students correctly indicated that “There is a great deal of variation in the plant population. Those plants that are able to synthesize toxic chemicals are more likely to survive and reproduce.” Again, with the exception of the topic of photosynthesis, which is covered in both cell & molecular biology and biochemistry, the only curricular exposure to plant-related biology for most of our students is in the introductory sequence. For some reason, the majority of students did not resort to teleological reasoning when answering this question. It may be that students are less likely to imagine plants as “needing to adapt in order to survive,” a concept that they readily applied to the vertebrate animals in Q15 and Q19.

The ten-year assessment of core concept retention has revealed both strengths and weaknesses in the biology curriculum at D&E. For concepts that are revisited multiple times in the curriculum, knowledge retention seems to be robust. However, for concepts that are encountered only during the introductory sequence, retention is very weak. If we want all biology majors to understand plant anatomy and community ecology, we will either have to revise the core requirements or find a way to incorporate those concepts into existing requirements. We also need to address common misconceptions, like those associated with the concepts of transcription and crossing over.

In terms of evolution education, we also found both strengths and weaknesses. While our students appear to readily accept evolution as the source of biological adaptation, their understanding of the mechanism driving that change (natural selection) is inconsistent. Teleological thinking, especially when it comes to adaptations in populations of vertebrate animals, is still quite prevalent. Students need to understand the critical role that variation plays in the shifting of gene frequencies over time. Evolution does not have a "goal" in mind. Variation introduced by sexual reproduction, mutation, etc. simply allows for some members of the population to be better adapted for specific circumstances. Those members will survive longer and reproduce more. We need to make the concept of evolution by natural selection even more ubiquitous in the curriculum to ensure long-term retention of the most important topic in biology.

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Increased Course Structure Enables Instructors to Increase Introductory Biology Exam Rigor

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Abstract

In courses with a heterogeneous student population, instructors are often challenged to balance successful course completion with rigor. This difficult task can be confounded in foundational, gateway courses, such as introductory biology, which serves a mix of freshman majors at various levels of preparedness. Research suggests that changes in course design, such as increasing course structure, can offer a solution. We hypothesize that increased course structure enables instructors to increase exam rigor without coincidentally increasing failure rates. Sixteen sections of general biology classes over the course of eight semesters were analyzed; eight sections had relatively low class structure (i.e., mostly Socratic learning and clickers), while eight sections had moderate structure (i.e., including class note summaries and practice exams). Weighted Bloom's Index of 150 exam questions was used to facilitate comparisons between designs. Although exam rigor increased (as gauged by WBI), in moderate structured courses, student exam scores, perception of the difficulty of the subject matter and failure rates did not change in comparison to low structured courses. This study supports the use of increased course structure to balance student success and rigor. Additionally, it supports the use of Weighted Bloom's Index as a method for assessing exam equivalence across institutions.

Keywords: general biology, course structure, exam rigor, weighted Bloom's taxonomy

Introduction

For teachers, the increased access to higher education means that there is a high variability in student preparedness for college. In the 2000s, only 51% of high school student who took the ACT college entrance exams are ready for college-level reading (ACT, 2006). In courses with such a heterogeneous student population, instructors are often challenged to balance successful course completion with rigor. This difficult task can be confounded in foundational, gateway courses, such as introductory biology, which serves a mix of freshman majors at various levels of preparedness.

Research suggests that simple changes in course design, such as increasing course structure, can offer a solution (Freeman et al., 2011). Although a course's rigor can be defined at multiple levels (e.g., fast-paced, high degree of time and energy), this study focused on cognitive expectations, particularly the depth of question asked during summative assessment such as exams. To help instructors qualify the rigor of their exams, Freeman and colleagues developed the weighted Bloom's index scale (WBI). Bloom's taxonomy of learning identifies six levels of understanding any topic (Bloom, 1956). The WBI summarizes the average Bloom's level of exam questions weighted by the points possible.

Increases in the index indicate an increase in higher-order cognitive skills and are associated with increased cognitive complexity (Anderson and Krathwhol, 2001). Higher level cognitive processes are a criterion by which rigor is defined (Wyse and Soneral, 2018). Thereby, the WBI is a valuable tool in assigning a value of rigor to an exam and by association to a course.

Increasing rigor has been shown to increase student engagement (Paige et al., 2013). Students rise to the occasion as long as they perceive that they are supported in their endeavor (Adams, 2020). Teachers unnecessarily worry that increasing rigor will lead to increased failure rates (Attis, 2016). Indeed, there is a low correlation between a student's perception of rigor and their learning (Duncan et al., 2013).

The aim of the study presented here was to determine whether increasing course structure enables an instructor to increase exam rigor without coincidentally increasing failure rates.

Course Structure Format	Low	Moderate
Lecturing	√	√
Thin-pair-Share Activities	√	√
Clickers	√	√
Practice Exams		√
Class Note Summaries		√
In-class Group Activity		√

Table 1: Criteria Defining Low/Moderate Course Structure

Materials and Methods

Sixteen sections of an introductory (for majors) general biology (BIOL101) class were analyzed; eight sections had relatively low class structure, while eight sections had moderate structure (see table for criteria defining structure). Classes were taught over the course of eight semesters; two sections taught per semester by the same instructor.

Class size and majors data were collected using TurningPoint® (Turning Technology), i.e., clickers. Over the eight semesters in which the classes were taught, no significant patterns were noted in either parameter. Grand View University, where these classes were taught, is a primarily undergraduate university with a 97% acceptance rate with a total enrollment hovering at about 1,800 students (~85% of full-time students). Class size for both course structures was 23 ± 3 students (N=8 course sections for each).

Weighted Bloom's Index of each exam was used to facilitate comparisons between designs. 150 exam questions (fill-in and multiple choice) per semester separated over five exams given progressively through the semester were indexed. Each exam question was classified according to the complexity of the mental processes involved and assigned a rank based on Bloom's taxonomy of learning (knowledge, comprehension, application, analysis, synthesis and evaluation). Ranks (1-6) were used to calculate the index as follows (where P is points per question, B is Bloom's rank, T is total points):

$$Weighted\ Bloom's\ Index = \\ \left(\left(\sum_{1}^{n} P * B\right) / (T * 6)\right) * 100$$

To further clarify, a student taking a low course structure class (Student Low) would expect to spend the majority of time in class listening to a lecture. Periodically, they would participate individually in a clicker question and as a group in a think-pair-share activity. Alternatively, a student taking a moderate course structure class (Student Mod) would expect to have the same experience as a student in a low course structure class. However, "student mod" would be provided with class note summaries and participate in a bi-weekly in-class group activity (e.g., codon bingo). Approximately every three weeks, "student mod" would participate in an in-class group practice exam (note: optional with no points).

In both low and moderate course structured sections, a multiple choice exam was scheduled approximately every three weeks for a total of five semester exams. "Student low" would take four exams with a WBI of <30 (i.e., indicating mostly recall) and one exam with a WBI of ~30 (i.e., indicating an increase in higher order cognitive skills). "Student mod" would take four exams with a WBI of >30 (i.e., indicating mostly conceptual questions) and one exam with a WBI of ~30 (i.e., indicating mostly recall).

Student perceptions of course were evaluated using IDEA diagnostic form reports (IDEA student ratings system, Kansas City University). This evaluation system poses 40 multiple choice questions to the students asking them to evaluate their progress on relevant course learning objectives, instructor teaching methods and overall impression of the instructor and course. Failure rate data was collected by instructor with Student Success Collaborative (SSC) software (educational advisory board, EAB) providing historical data.

Statistical analysis using one-way ANOVA supplemented with post-hoc Tukey HSD multiple comparison was performed with Astatsa statistical calculator.

Results

In a moderate course structure class increasing Weighted Bloom's Index did not alter exam grades in comparison to a low course structure class. In the general biology lecture course, five exams were taken progressively throughout the fifteen-week semester. Each exam was assessed by Weighted Bloom's Index (WBI). WBI ranges from 0-100 and progresses from lower-order to high-order cognitive skills. The average ± SD WBI when considering all five exams was 24.8 ± 3.6 for low versus 33.9 ± 3.5 for moderate course structure. The WBI of low course structure indicates mostly recall, while the WBI of moderate course structure indicates mostly conceptual. WBI for each of the five exams administered to low and moderate course sections had a WBI ranging from 22 to 38 with 30 being the median (Figure 1 bottom).

The mean grade was calculated for each exam for low and moderate course structure (average ± SD for 8 class sections each). The average ± SD exam grade when considering all five exams was 71.9 ± 3.5 for low and 72.1 ± 1.3 for moderate course structures. Overall, no significant difference in exam performance was noted between low versus moderate structured courses for exam 1, 2 and 5 where exam WBI was tailored for the corresponding course structure. (Figure 1 top).

To evaluate whether course structure was linked to type of exam administered was increased for one exam (exam #3) in a low course structure class and WBI was decreased for one exam (exam #4) in a moderate course structure class This design disrupted the association of low course structure sections being administered low WBI exam and vice versa. The increase in an exam's WBI to mostly conceptual questions was associated with a significant dip in exam performance in low course structure in comparison to moderate course structure. Whereas the decrease in an exam's WBI to mostly recall did not significantly alter exam performance in moderate course structure in comparison to low course structure (Figure 1 top).

Student perception of the difficulty of the subject matter not altered by increased exam rigor. Sixteen sections of general biology classes over the course of eight semesters were analyzed; eight sections had relatively low structure (i.e., mostly Socratic learning and clickers), while eight sections had moderate structure (i.e., including class note summaries and practice exams). Student perception of difficulty of the subject matter assessed by IDEA diagnostic report using a 5-point scale (1 being much less and 5 being much more than most courses) showed no significant difference (Figure 2).

Change in course structure did not alter failure rates. Exams points made up >50% and no more than 65% of any class. Classes were composed of 23 ± 3 students. The percentage of

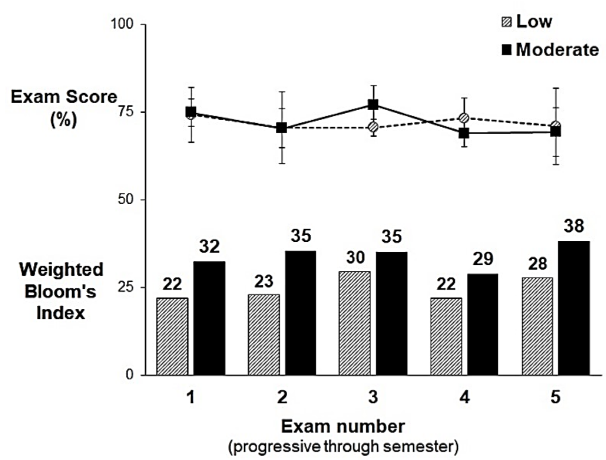

Figure 1: Relationship between Each exam's Weighted Bloom's Index in low and moderate course structure sections with mean exam score.

Five exams were taken progressively throughout the semester. **Bottom:** Each exam was assessed by Weighted Bloom's Index (WBI); low (diagonal stripe bar) and moderate (black bar) course structure. WBI ranges from 0-100 and progresses from lower-order to high-order cognitive skills. Class size for both course structures was 23 ± 3 students (N=8 course sections for each). **Top:** The mean grade was calculated for each exam for low (dotted line with circles) and moderate (solid line with squares) course structure (average ± SD for 8 class sections each).

Exam number 3 = $p < 0.05$ low course structure vs. moderate course student mean exam score.

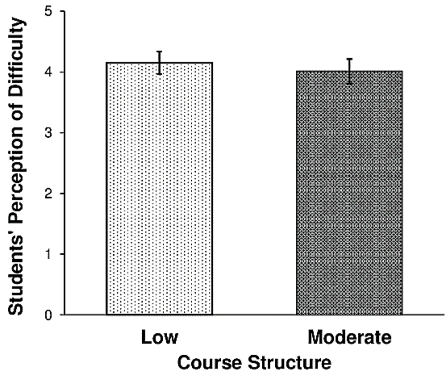

Figure 2: Although exam rigor increased in moderate structured classes, student perception of the difficulty of the subject were not altered.

Sixteen sections of general biology classes over the course of eight semesters were analyzed; eight sections had relatively low structure (i.e., mostly Socratic learning and clickers) [lightly dotted bar], while eight sections had moderate structure (i.e., including class note summaries and practice exams) [heavily dotted bar]. Student perception of difficulty of the subject matter assessed by IDEA diagnostic report using a 5-point scale (1 being much less and 5 being much more than most courses). Classes composed of 23 ± 3 students. Bars are average ± standard deviation; *N=8 sections.*

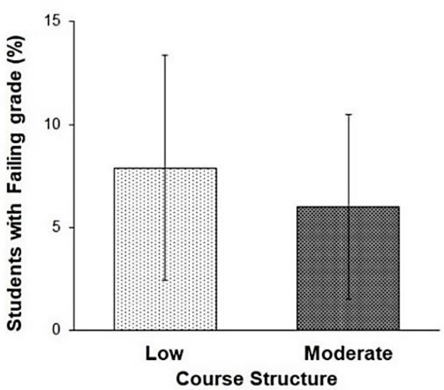

Figure 3: Although exam rigor increased in moderate structured classes, student failure rates were not altered.

Sixteen sections of general biology classes over the course of eight semesters were analyzed; eight sections had relatively low structure (i.e., mostly Socratic learning and clickers) [lightly dotted bar], while eight sections had moderate structure (i.e., including class note summaries and practice exams) [heavily dotted bar]. Percentage of students in each section who were assigned a grade of "F". Classes composed of 23 ± 3 students. Bars are average ± standard deviation; *N=8 sections.*

students in each section who were assigned a grade of "F" (defined by obtaining less than 60% of the overall points for the course) showed no significant difference between low and moderate structure classes (Figure 3).

Conclusions

The data presented here supports the study aim that increased course structure in introductory general biology courses helps balance student success and rigor as judged by cognitive expectations on summative assignments, i.e., exams. Without fearing impacting failure rates, a teacher can effectively increase the rigor of the course, particularly increasing conceptual skill questions on exams, by making small course structure adjustments such as adding class summaries, group activities and practice exams.

Students in low structured course sections challenged with a higher WBI exam showed a significant dip in exam performance in comparison to students in moderate structured course sections. This data supports the idea that exam rigor should only be increased with an associated increase in course structure. Alternatively, students in moderate course sections administered a lower WBI exam showed no significant change (positive or negative) in exam performance in comparison to students in low structured course sections. Although this result will require further investigation into student mindset., it does support the idea that WBI could be increased beyond the 35 in moderate structure courses.

Beyond summative assessments, designing a moderate course structure fortuitously increases other forms of rigor. Pacing, time and energy are alternate ways of defining rigor (Winston et al., 1994). In order to practically conduct in-class mock practice exams, class content, which stayed the same between low and moderate course structures, was presented at a faster-pace. In addition, because group activities actively engage students, they require more energy from the students and studying class summaries require more time. Yet, this study shows that increasing rigor in these myriad of ways does not necessarily impact student perceptions of the course rigor. Therefore, modifying an existing course to include moderate course structure should help teachers increase course rigor without fearing reducing student success.

Additionally, this study supports the use of Weighted Bloom's Index (WBI) as a method for assessing exam equivalence across semesters and across institutions. A teacher could practically use WBI calculations of exams as a tool to gauge exam rigor. However, caution should be taken to consider other factors when ranking exam questions. Current research indicates that students rank Bloom's questions differently than expected. Often times, these perceptions are driven by questions that unintentionally increase cognitive load (Phillips et al., 2019). For example, a question can add unnecessary information and/or complex scenarios to appear rigorous and yet, the intent is recall or vice versa. In future studies utilizing WBI, cognitive load factors in the design of the exam question should be considered.

Acknowledgments

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The Impact of Participation in Biology Boot Camp, a Collaborative, Peer-Led, Active Learning Program, on Academic Performance in Freshman Biology Students

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Abstract

While a growing body of research supports active, student-centered approaches to teaching, the implementation of such methodologies in the undergraduate STEM classroom has not been widespread. In an effort to increase student success in an introductory course for biology majors, we developed Biology Boot Camp, a peer-led program based on active, collaborative learning. Program participants attended weekly study sessions led by Boot Camp Coaches who had been trained extensively in both course content and pedagogy. During Boot Camp sessions, Coaches engaged students in activities designed to encourage the development of higher-order cognitive skills represented by the upper levels of Bloom's taxonomy (analysis, evaluation, and synthesis). A primary goal of the program was to transform students into active, engaged learners who understand the difference between superficial and deep, meaningful learning. Biology Boot Camp strove to cultivate motivated learners, to promote biology content mastery, and to develop problem-solving skills necessary for future leaders and visionaries in rapidly evolving STEM fields. In this study, we examined the impact of Boot Camp on student success, and we determined that participation in Biology Boot Camp improved academic performance as demonstrated by exam grades, pre-test/post-test gains, and final course averages.

Keywords: collaborative learning, peer-based instruction, active learning, engagement, higher-order cognitive skills

Introduction

Low retention rates in the fields of science, technology, engineering, and math (STEM) are an ongoing national problem. In a study published by the President's Council of Advisors on Science and Technology, less than 40% of US college students who begin their academic careers with an interest in STEM finish with a STEM degree (PCAST, 2012). The PCAST report called for the implementation of evidence-based educational strategies, such as active learning, to mitigate this problem. Active learning can be defined as students constructing new knowledge, building scientific skills, and "doing something other than taking notes" (Handelsman et al, 2011). More specifically, active learning strategies focus on the development of higher order cognitive skills (analysis, evaluation, and synthesis) rather than on rote memorization. A growing body of research supports active, student-centered approaches to teaching (Ebert-May et al., 1997; Prince, 2004; Michael, 2006; McLaughlin et al., 2014; Freeman et al., 2014; Dolan and Collins, 2015). Active learning strategies increase student performance, and decrease withdrawal rates (Prince, 2004; Ruiz-Primo et al., 2011; Freeman et al., 2014). Despite a large body of evidence supporting the effectiveness of active learning strategies, their adoption among STEM faculty has not been widespread (Friedrich et al., 2008; PCAST, 2012; Stains et al., 2018) thus creating a disconnect between scientific evidence and classroom practice. Several barriers such as lack of training in pedagogical strategies, extensive preparation time required for implementation, class time required to employ active learning, and student resistance challenge the widespread implementation of active learning in the college science classroom (Tanner, 2012; Shadle et al., 2017). In an effort to address these challenges, we created an innovative, peer-based instructional program called Biology Boot Camp to equip biology students to become active, engaged participants in their learning process.

Biology Boot Camp provides students with an opportunity to participate in a learning environment that encourages transformational learning, or deep constructive learning that goes beyond the acquisition of knowledge. It serves as a supplement to the traditional, lecture-dominant classroom model as students attend small, peer-led study sessions designed to build both critical-thinking and metacognitive skills as students engage in a wide variety of active learning pedagogies. In addition to transforming students from passive to active, engaged learners, the Boot Camp program might provide a steppingstone to bridge the gap between the typical classroom lecture based on transmittal learning theory and a more active approach to teaching based on constructivist learning theory. During Biology Boot Camp study sessions, students participate in learning activities in order to construct a fundamental knowledge base that will serve as a foundation for their future studies in biology. Students discuss, analyze, summarize, predict, and explain content (Anderson et al., 2001) as they build relationships between new and existing knowledge. When students engage in such a collaborative learning environment, they are able to perform at higher intellectual levels than possible if they worked alone (Vygotsky, 1978; Gokhale, 1995; Freeman et al., 2014; Gorvine and Smith, 2015). Therefore, Biology Boot Camp strives to cultivate motivated learners, to promote biology content mastery, and to develop problem solving skills necessary for future leaders and visionaries in rapidly evolving STEM fields. In order to assess the effectiveness of Biology Boot Camp in promoting content mastery, we conducted a two-semester study (Spring 2018 – Summer 2018) with students taking majors biology (Biology 1107K - Principles of Biology I). We predicted that participation in Biology Boot Camp would increase the academic performance of these students as measured by lab practical exam scores, pre-test/post-test gains, and final course averages earned.

Materials and Methods

Location

This study was conducted on the Gainesville campus of the University of North Georgia, a regional four-year university, and one of six senior military colleges in the US, located northeast of Metro Atlanta, Georgia. The Gainesville campus is a commuter campus with no residential housing. Most of the students on this campus work part-time or full-time jobs. There is a large population of non-traditional students (23 and older), part-time students, military reservists, veterans, and dual-enrolled students.

Boot Camp Coach Recruitment and Training

The Boot Camp faculty directors recruited students who had previously participated in Boot Camp, had successfully completed Biology 1107K, and had demonstrated an excitement for learning to serve as Boot Camp Coaches. While a majority of these recruits had earned an A in the course, demonstration of a growth mindset - believing that effort and attitude determine abilities - was a more important criterion than grade earned. Coaches underwent intensive pedagogy and content training during workshops conducted prior to the start of the semester as well as during weekly training sessions throughout the semester. Pedagogy training focused on how to implement active learning strategies designed to facilitate deeper, more meaningful learning, while content training focused on reviewing key concepts in biology.

Student Recruitment

During the first lab meeting of the semester, Boot Camp Coaches delivered an “Introduction to Biology Boot Camp” presentation to all sections of Biology 1107K. This presentation outlined the pedagogical basis of the program as well an overview of how the program works. Additionally, the Coaches shared their own experiences as Boot Camp participants as well as their reasons for becoming Coaches. Following the presentation, one of the Coaches informed the students of the research study being conducted to assess the effectiveness of the Boot Camp program and explained the IRB process. Students opting to participate in the study were asked to sign the IRB form, while those students choosing not to participate in the research study were still eligible to participate in Boot Camp.

The Program

Boot Camp Coaches attended 1107K lectures, assisted in a lab section, and conducted at least two or three Boot Camp study sessions throughout the week beginning with the second week of the semester. We offered multiple sessions each week at different times of the day and on the weekends to accommodate student schedules. Participation in Boot Camp was voluntary, and students could attend one or more sessions each week. Two Coaches (one experienced and one new) led each study session, providing new Coaches with a peer mentor to assist them as they began to develop their teaching skills. Each session involved specific content review in addition to a collaborative activity designed to facilitate active learning. Boot Camp participants were taught the difference between passive and active learning as they were challenged to engage with the course content. Boot Camp sessions were not instructor-specific, covered the same key concepts, and utilized similar active learning strategies. This provided a familiar structure for each session.

Experimental Design

We used a quasi-experimental design. During the first scheduled lab period, students in all Biology 1107K sections took a 33-question multiple choice pre-test to assess their current biology knowledge. Sixty percent of these questions, obtained from the Campbell Biology 11/e (Urry et al. 2017) test bank, were classified as higher-order thinking questions (application, analysis, synthesis, or evaluation) based on Bloom’s updated taxonomy (Krathwohl, 2002). In addition to pre-test/post-test gains, we also used two standardized, departmental lab practical exams (midterm and final) to evaluate student performance. We used Freshman Index (FI) scores, calculated using high school GPA and SAT or ACT scores, in our analysis to control for differing student abilities.

Data Collection and Analysis

We pooled data from all Biology 1107K courses during the spring and summer semesters of 2018 (15 sections: 325 total students). These courses represented a variety of instructional modalities including the lecture-heavy transmittal model, hybrid classes, classes with elements of the constructivist approach, and short-session summer classes. Several individuals had to be discarded from the complete data set due to missing IRB forms, final letter grades of Withdrawal (W) or Withdrawal Fail (WF), being under the age of eighteen years old, or being a student repeating the course. We considered the complete data set to include freshman index (FI) score, total sessions attended, Lab Practical 1 grade, Lab Practical 2 grade, pre/post-test improvement, final grade percentage, and final letter grade.

Pre-tests were collected and scored during the first week of lab. Personal identifying information was removed, and each student was assigned a unique identification number. At the end of the semester, instructors provided scores for midterm lab practicals, final lab practicals, post-tests (questions embedded within course final exam), as well as final course averages. Additionally, instructors reported if they award extra credit points for Boot Camp participation so that any extra credit given could be removed from the final course average prior to analysis using Excel© (2016).

A one-factor analysis of variance (ANOVA) test was initially performed using basic R v.4.0.0 (R Development Core Team 2020) to determine if there was any difference in number of sessions attended for students who earned letter grades A through F. A post-hoc test using a pairwise T-Test with Bonferroni correction was then performed to determine which grades were significantly different.

Using a series of generalized linear models (GLM), we tested to see if FI scores predict success and/or if Boot Camp attendance improved student’s performance in Biology 1107K. We tested a variety of performance measures in our series of GLMs: final grade percentage (FG), pre-test/post-test improvement (PPT), Lab Practical 1 (LP1), Lab Practical 2 (LP2), and Lab Practical average (LPA). For each performance measure, the first round of GLMs included both FI Score and sessions attended. The second round of GLMs included only FI Scores, while the third round of GLMs only included sessions attended.

Results

The initial one factor ANOVA test shows there is a significant difference in number of sessions attended ($p = 0.02627$) between students earning letter grades A through F (Figure 1). However, the pairwise T-Test with Bonferroni correction shows that only letter grade A and F were significantly different ($p = 0.042$). In the GLMs with both FI Score and sessions attended as predictors of final grade, both predictors were consistently significant whether we considered all students ($p < 0.001$ for both predictors) or only included Boot Camp attendees ($p < 0.001$ for both predictors; Figure 2). Higher-performing students could potentially attend Boot Camp at higher rates, leading to an apparent effect of Boot Camp attendance on student performance. Testing the relationship between FI score and attendance using a GLM revealed that there was no relationship between FI score and attendance whether considering all students ($p = 0.176$) or Boot Camp attendees only ($p = 0.490$; Figure 3). With the exception of pre-test/post-test differences, where session attendance was borderline significant ($p = 0.064$), both session attendance and FI score were significantly associated with improved performance in Biology 1107K ($p < 0.01$ in all cases), for all our performance measures.

Discussion

In this study, we examined the effectiveness of an innovative program designed to improve student performance by engaging students in a collaborative, active learning environment. Participation in Biology Boot Camp improved academic performance as demonstrated by higher exam grades, pre-test/post-test gains, and final course averages. By including freshman index scores in our analyses, we demonstrated that while academic performance was influenced by both FI score and number of Boot

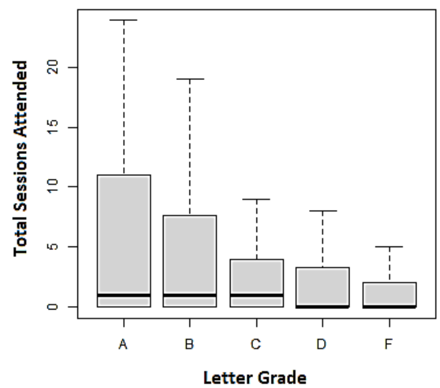

Figure 1: Letter grades as related to number of Boot Camp sessions attended.

Note. Outliers are excluded from the plot.

Probability note. Pairwise T-Test with Bonferroni correction shows a significant difference ($p < .05$) in the number of sessions attended and final letter grade for students who achieved a letter grade of an A or F.

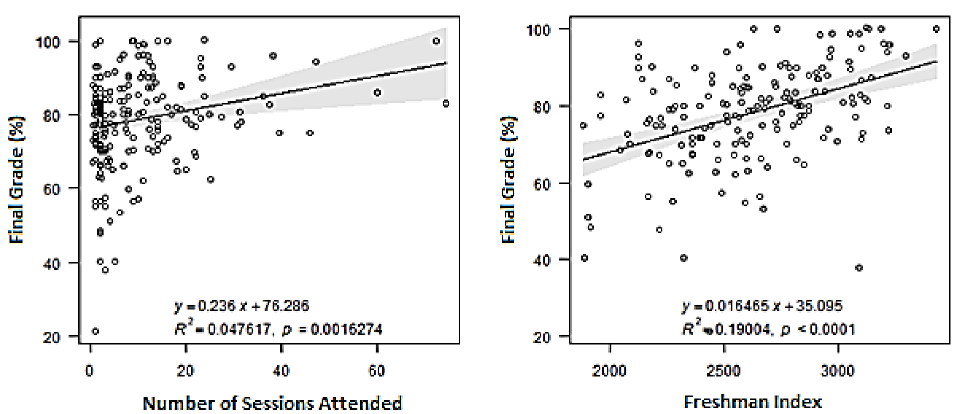

Figure 2: Linear regressions of the total number of sessions attended (left panel) and the freshman index score (right panel) versus final grade achieved in Biology 1107K.

Shaded area indicates 95% confidence interval.

Note. Both factors, freshman index score and number of sessions attended, are statistically significant predictors of final grade achieved whether considering all students or just Boot Camp attendees.

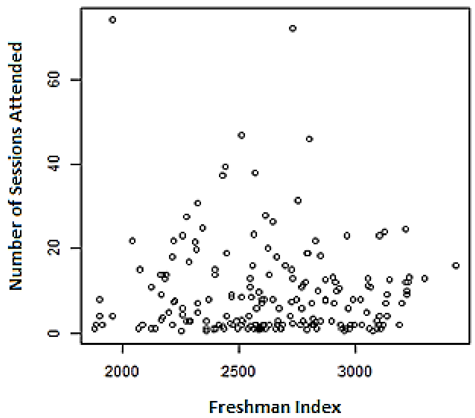

Figure 3: Scatter plot of freshman index score versus number of Boot Camp sessions attended.

Note. Only Boot Camp attendees were considered for these calculations.

Probability note. There is no significant relationship between Freshman Index score and the number of sessions a student chooses to attend ($p < .05$).

Camp sessions attended it could not be explained solely by FI scores. Nevertheless, based on attendance, levels of enthusiasm, conversations with instructors, and Boot Camp Coach feedback, we anticipated even more significant differences between Boot Camp participants and non-participants. Two major reasons for this enthusiasm-versus-performance gap may be that many excellent students do not attend Boot Camp and still do well in the course, inflating the average grades in the "never attended" group, and that some weaker students may attend Boot Camp but may fail to apply the lessons taught in sessions. In addition, in analyzing this disconnect between the expected and actual outcomes of the study, we concluded that while grades and test scores are often used to measure academic improvement, these quantitative measures do not fully measure the types of improvements that active learning strategies facilitate. The conclusions of our study corroborate what Wiltbank et al. (2019) found: grades failed to accurately measure components students considered key during their active learning experience such as enjoyment of class and the desire to learn. Effective active learning engages students in a deeper, more meaningful learning experience compared to passive learning, and it often fosters an enjoyment of learning and a more productive approach to studying. Studying becomes a path to learning rather than simply a means to a desired grade. Several studies support the hypothesis that active learning not only positively impacts higher-order cognitive skills but also student attitudes toward learning (Bonwell and Eison, 1991; Cooper, 2016). Therefore, we need to add qualitative measures to our future research strategies in order to more fully ascertain the effects of Boot Camp participation.

The Biology Boot Camp model is a potential bridge between a transmittal and a constructivist approach to instruction. With STEM instructors slow to adopt active learning strategies for many reasons including time limitations, lack of training, lack of incentives to make pedagogical changes, and perceived negative student responses to active learning, this collaborative, peer-led model provides students with an opportunity to participate in an interactive environment as they construct new knowledge based upon what they are learning in their courses and connect it to existing knowledge. As a result, they might return to their lectures and labs with an excitement for learning and a new set of skills to more effectively master course content. As instructors observe these transformational changes in their students, they may be persuaded to incorporate active learning strategies into the lecture setting. It is time that we base our teaching on current research in cognitive science, psychology, and science education rather than on tradition.

Future Directions

We plan to continue to develop Biology Boot Camp and to make necessary modifications as we continue to draw conclusions based on our assessment of its effectiveness. We will explore student perceptions of how Boot Camp participation impacts their approach to studying. Additionally, we want to follow biology majors as they complete their required major biology courses (cell biology, genetics, ecology, evolution, and senior seminar) to examine the impact of Boot Camp on academic performance in these courses. Many questions arose as we analyzed the results of the current study. Which component of the Boot Camp experience leads to improved student performance? What roles do collaborative learning, building trust, modeling active learning strategies, challenging growth mindsets, and metacognitive development play in student success? How can Boot Camp be improved to achieve our goal of inspiring an approach to learning that centers on the development of higher order cognitive skills rather than on rote memorization? Will Boot Camp participation by both students and Coaches lead to a higher retention rate in the Biology Department? Could the Biology Boot Camp model be a part of the solution to the low, national STEM retention rate? While our data show that Boot Camp participation does correlate with higher exam scores, pre-test/post-test gains, and final course grades, many questions remain concerning why such participation leads to improved academic performance and how the active, collaborative learning environment established by the program contributes to changes in student approaches to and enjoyment of the learning experience.

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Owls and Rabbits: An Active Learning Exercise to Teach the Nature of Science in an Undergraduate Biology Course

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Abstract

We developed and field-tested an active learning exercise designed to provide biology students with the opportunity to consider key aspects of the nature of science as a method of inquiry, particularly the roles of observation and inference in the development of scientific explanations and how scientists deal with uncertainty. In the activity students assume the role of a wildlife biologist, using available evidence to best explain the cause of the decline of a rabbit population in a state park. Using a guided-inquiry approach, students are provided evidence in a sequential fashion. After each bit of evidence is provided, they form inferences and either retain their initial explanation or reject it. Results of the field testing suggest that the activity may positively impact students' perceived understanding of important aspects of the nature of science, and their comfort level in dealing with uncertainty. The investigative, observation/inference-based model utilized shows promise in making the nature of science an organizing theme for the course.

Keywords: Nature of Science, Biology, Observation, Inference, Active Learning

Introduction

Fostering an accurate understanding of the Nature of Science (NOS) by having students engage in authentic disciplinary practices is an important aspect of biology and science education (AAAS, 2011; NGSS Lead States, 2013). The NOS describes the epistemological foundations that define, and in some ways separate, science from other ways of knowing and includes the methods, characteristics and assumptions of science as a method of inquiry. An accurate understanding of this underlying, structural knowledge of the discipline is a fundamental goal of modern science educational practices (Lederman & Lederman, 2014; McComas, Almazroa, & Clough, 1998). For students to have a functional understanding of the NOS they must engage in scientific practices that help them appreciate how knowledge is produced in science, the roles of observations and inference, the tentativeness of scientific knowledge, and how scientists deal with uncertainty (Jaber & Hammer, 2016; Kuhn, Arvidsson, Lesperance, & Corprew, 2017).

Engaging students in activities that foster their construction of scientific knowledge requires explicit instruction on what the NOS entails, including the methods of the discipline as well as its characteristics (Lederman & Lederman, 2014). Scholars in the field (e.g., Lederman & Lederman, 2014; McComas et al., 1998) have identified critical characteristics of the NOS and have encouraged their use in the design of science curricula. Among the important characteristics of science as a way of knowing is that scientific knowledge is durable (supported by multiple evidential lines over time), yet tentative and subject to revision in light of new evidence (McComas et al., 1998). Highly associated with the characteristics of scientific knowledge are the practices used to construct this knowledge. Among the practices that lead to the durability and tentativeness of scientific knowledge is the making of observations and formation of inferences in the collection and interpretation of empirical data.

Scientific explanations of the way the natural world works are based on past and current observations (information gathered from our senses) and inferences (conclusions) based on those observations. When new observations of a phenomenon are made, the additional information can result in changed inferences and revised explanations. Importantly, the making of inferences requires an understanding of the role of uncertainty in the making of claims. For example, hypotheses in science are either supported by data and are retained, or not supported by the data and are rejected. Because of this, absolute proof is never attainable in science, only the elimination of other possible explanations that aren't supported by available data.

The idea that scientific knowledge is tentative and based on available evidence at a given time is important to convey to students and have them experience. It is important because it helps them understand how scientific knowledge can change and become more accurate over time. These concepts also build into larger concepts. For example, observations and inferences can lead to empirical evidence, which can support hypotheses and be used to develop theories which can explain many phenomena in science (e.g., evolution by means of natural selection).

It is essential that instruction in the NOS be executed explicitly, as many of the concepts are implicit and difficult for students to understand (Lederman & Lederman, 2014). However, curricula that support university faculty in instruction directly addressing these concepts is limited. To address this need, we developed an active learning exercise designed to provide biology students with the opportunity to consider key aspects of the nature of science as a method of inquiry, particularly the roles of observation and inference in the development of scientific explanations and how scientists deal with uncertainty.

Procedure

This activity was designed to introduce students to the roles of observation and inference in scientific inquiry by having them work to solve a question regarding the decline of a rabbit population in a state park. During the activity students assume the role of wildlife biologists and form inferences based on observations made in the park. They then propose an explanation for the decline in the rabbit population based on the available evidence. Students are first provided with the following scenario noting circumstances that might be related to the observed decline of the rabbit population:

> Scenario: The rabbit population at Kabetogama State Forest (located in northern Minnesota) is declining. Residents are concerned and suspect the decline is due to an increase in the population of a large, unidentified bird of prey species recently observed in the area. State wildlife biologists are undertaking a study to understand the issue, as several predatory bird species potentially involved are endangered or threatened.

In addition to the scenario, students are provided with a description of Occam's Razor—the philosophical construct and problem-solving principle that suggests when presented with two explanations, the best explanation is often the simplest. Another way to say this is the more assumptions one must make to explain a phenomenon, the less likely that explanation is accurate. The purpose of this addition is to remind students that claims about the rabbit population should be made with the available empirical evidence; however, there is never absolute proof for any explanation.

Working in groups of two to four, students are tasked with providing a claim for which bird of prey species best explains the decrease in the rabbit population. The activity follows a guided-inquiry approach; after initially being presented with the scenario, evidence is presented in a stepwise fashion. That is, students are first provided with information sheets about four bird of prey species (Great Gray Owl, Broad Winged Hawk, Great Horned Owl, Snowy Owl) known to be in the park at different points throughout the year (Appendix A) and are subsequently given additional evidence at designated times during the activity. For example, the only evidence that students use to formulate their initial explanation is a map of the United States (Figure 1a) depicting the known ranges of the four bird of prey species. Students are then provided with a picture of a feather found at the park, near an area where blood and rabbit fur were also found (Figure 1b). Next, an image of a snow print (imprint made in the snow by a bird as it attacked its prey), depicting the bird's complete wingspan is provided, giving students information about the size of the bird (Figure 1c). Finally, audio files of vocalizations heard in the park during the period of the rabbit population decline are provided (Figure 1d). After each piece of evidence is provided, students either retain or modify their explanations, recording their observations and inferences (Appendix A) and then noting which birds are eliminated based on the available evidence and providing an explanation for their reasoning (Appendix A).

After students complete their observations, make inferences and devise explanations for the drop in the rabbit population, we engage them in a discussion in which they are encouraged to share their findings and the reasoning for their conclusions. In our implementation, the Great Gray Owl is best supported by the available evidence (requires the fewest assumptions), but a degree of uncertainty remains as to the cause of the decline in the rabbit population. We use students' responses as a platform to expand the discussion about the tentativeness of scientific knowledge as well as how scientists acknowledge and seek to minimize uncertainty in their findings.

Assessment

We field-tested the activity in two large-lecture sections of a biology course for non-majors at a teaching-focused university in the Southeast. We were primarily interested in students' views of the NOS and their perceptions of the effectiveness of the activity. Using instrumentation and a research protocol approved by the university's Institutional Review Board (blinded for peer review), we collected pre/post-exercise data addressing students' views on the NOS and how they feel about uncertainty in science (Table 1). As a preface to the activity, we reviewed the roles of observation and inference along with the assumptions and characteristics of science as a method of inquiry. We then gave students an opportunity to ask questions and seek clarification about concepts covered before the activity was implemented. To assess student perceptions of their understanding of the nature of science, students utilized a five-point Likert-scale (5: Strongly Agree; 4: Agree; 3: Undecided; 2: Disagree; 1: Strongly Disagree) to respond to seven statements concerning aspects of the NOS.

A total of 81 of 107 students were present for the class in which the activity was conducted and consented to be a part of the study— a participation rate of 76%. A two-sample t-test was used to decide whether data from the two classes could be pooled. There was not a statistically significant difference in students' responses to what they understand/know about the nature of science between the first class (M = 3.9, SD = 1.42) and the second class (M = 4.4, SD = 1.14); (t = -1.91, p = .058). Additionally, we found no statistically significant difference between student responses to how they felt about uncertainty in biology from class one (M = 2.3, SD = 0.46) and class two (M = 2.6, SD = 0.87); (t = -1.13, df = 79, p = .260). Due to there being no differences between the two classes, students' scores were aggregated and assessed for trends and pre/post-activity differences. Before the activity, students' responses ranged in average from 3.7 (empirical nature of scientific explanations) to 4.5 (verifiable nature of scientific knowledge). Scores for items

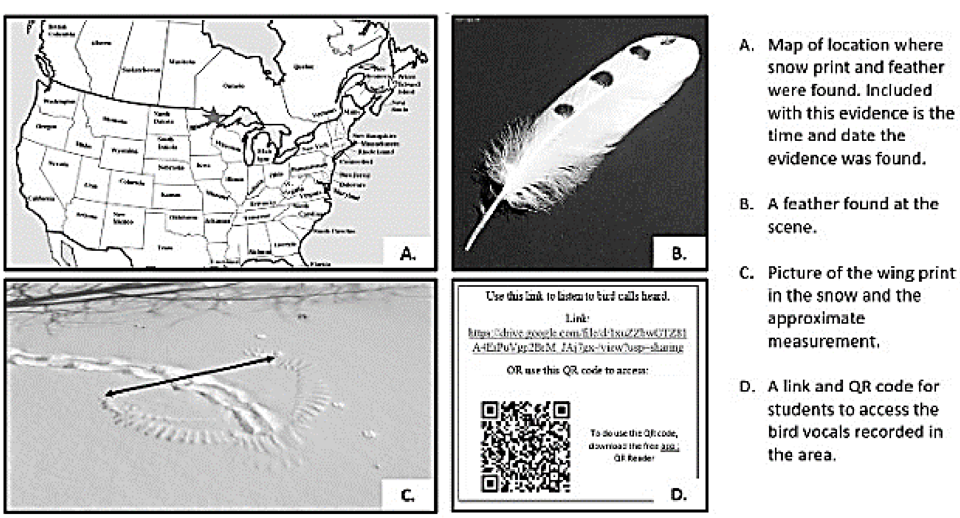

Figure 1. Initial evidence provided to students.

I understand/know

How science works to answer questions (methods of science).

The empirical (data-based) nature of scientific explanations.

The tentative nature of scientific explanations.

The verifiable nature of scientific knowledge is not based on authority, but evidence.

The significance of replication to the validity of scientific findings.

The relationship between evidence and explanation in science.

Uncertainty is an important aspect of knowledge construction in science.

Table 1: Likert-scale items for NOS instrument. (5: Strongly Agree; 4: Agree; 3: Undecided; 2: Disagree; 1: Strongly Disagree)

addressing the empirical nature of scientific explanations and the tentative nature of scientific explanations were particularly low relative to the others, both being below a 3.9 on the 5-point scale. After the activity, students' average responses ranged from 4.2 (empirical nature of scientific explanations) to 4.6 (verifiable nature of scientific knowledge and the relationship between evidence and explanation). We used a student's t-test to compare students' pre and post activity responses following guidelines for analysis of Likert-scale data (Meek, Ozgur and Dunning, 2007; Norman, 2010; Sullivan & Artino, 2013). Students' perceived understanding of the methods, empirical nature, tentativeness, and uncertainty significantly increased after the activity (Figure 2), while no pre/post difference was found with the tenets related to verifiability, replication and the relationship between evidence and explanation.

The survey also included a differential response item addressing uncertainty in scientific inquiry. Using a Likert scale, students were asked how dealing with uncertainty in biology makes them feel along several dimensions (confusing vs clear, comfortable vs uncomfortable, satisfying vs frustrating, pleasant vs unpleasant). In the results, the higher the score, the more negative their perception (Figure 3). In each dimension, students' negative feelings associated with uncertainty in biology decreased. Each differential item decreased significantly ($p < .05$) in value after the activity was finished, suggesting that the activity may have made students feel more comfortable in dealing with uncertainty in scientific inquiry.

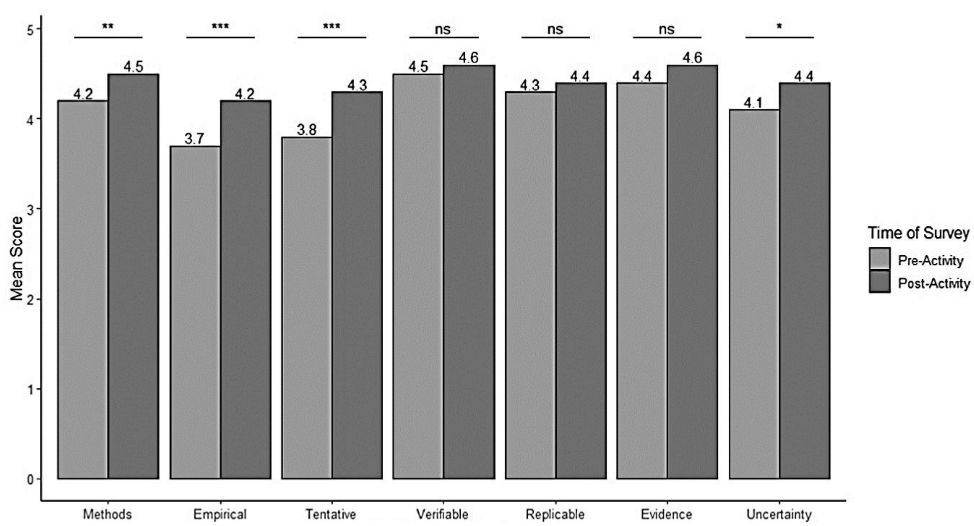

Figure 2: Students' responses to their perceived understanding of the NOS.

p-values are provided at the top of the bars with $p < .05$ used as a significance cutoff. Non-significant comparisons are denoted by ns.

Overall, students appeared to be highly engaged in the activity. The majority of students indicated that the exercise made the content relevant and was worth the instructional time devoted to it. Pre/post-activity increases were found in several, but not all, aspects of the NOS, and student comfort in dealing with uncertainty was significantly improved.

Discussion

An accurate understanding of the nature of science as a method of inquiry is essential to the making of informed personal, health, consumer and lifestyle decisions. For individuals to make these decisions, they must understand the methods as well as the characteristics of science as a method of inquiry. Instructional curricula and strategies that help students develop a functional understanding of science as a way of knowing are, therefore, fundamental to the generation of a scientifically literate citizenry. We sought to develop an exercise that engages the powerful advantages of student-centered, active learning strategies to facilitate student understanding of key features of science as a method of inquiry that are often underemphasized in science education.

The results of this field-testing are preliminary, and demonstrate only short-term effects, but suggest that from the students' perspective the activity may be effective in promoting a more accurate understanding of the process of science as well as important characteristics of science as a method of inquiry. In particular, students showed an increase in their perceived understanding of the methods and empirical nature of science as way of knowing, as well as the tentativeness of scientific knowledge. The activity seems especially effective in helping students deal with the uncertainty often associated with scientific findings. These findings are noteworthy as it is important for individuals to appreciate that scientific knowledge can change in light of new evidence, and that this is a strength of science as a way of knowing, as it allows science to become more accurate over time.

As the biology content addressed in the activity is general in nature, the activity may be suitable for use in other general education science courses. We hope to use the investigative, observation/inference-based model employed in this activity to develop a set of activities to explore the range of biological content in a non-majors biology course and help supply the need for content-specific, active learning exercises for use in the lecture arena (Rutledge, 2008). Use of the model as an organizing theme for the course will provide a means for addressing important aspects of the

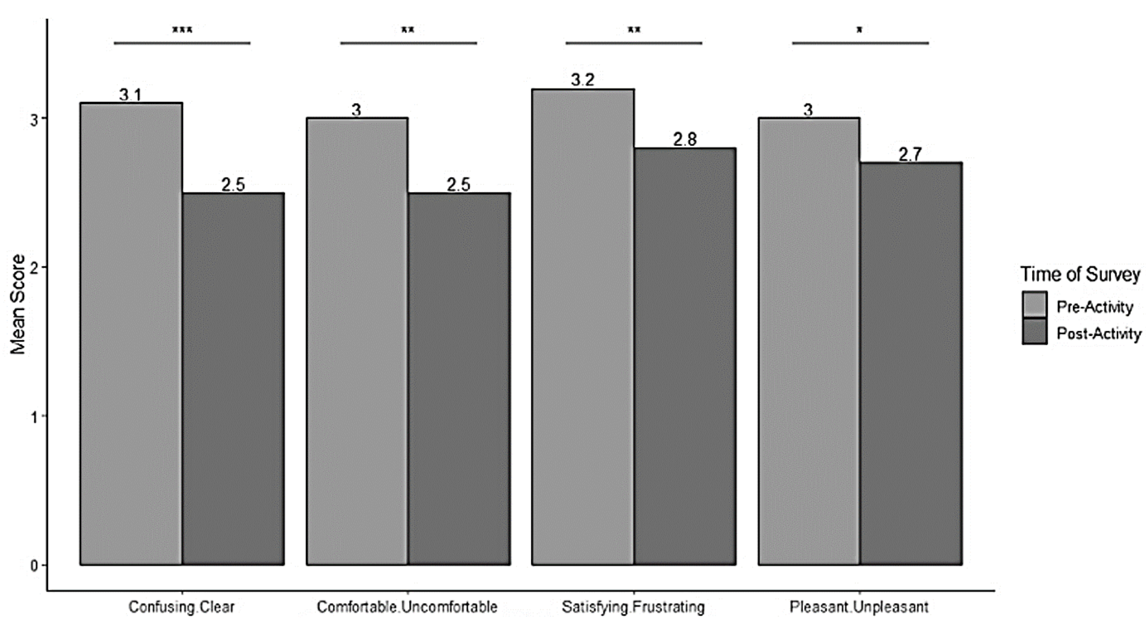

Figure 3: Students' responses to how they feel about uncertainty.
p-values are provided at the top of the bars with $p < .05$ used as a significance cutoff.

NOS multiple times and may help students better understand the characteristics of the NOS that weren't affected by a single implementation.

Editor's note

Appendix A is available in the December issue posted on the ACUBE Bioscene website.

http://www.acube.org/bioscene/archives/

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Bioscene: Journal of College Biology Teaching
Submission Guidelines

I. Submissions to *Bioscene*

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

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

II. Preparation of Articles, Innovations and Perspectives

Submissions can vary in length, but articles should be between 1500 and 5000 words in length. This includes references and tables but excludes figures. Authors must number all pages and lines of the document in sequence. This includes the abstract, but not figure or table legends. Concision, clarity, and originality are desirable. Topics designated as acceptable as articles are described above. The formats for all submissions are as follows:

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

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

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

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

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

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

Two Authors:

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

Multiple Authors:

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

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

D. Example citations are below.

(1) Articles-

(a) Single author:

DeBuhr, L. E. (2012). Using Lemna to Study Geometric Population Growth. *The American Biology Teacher*. https://doi.org/10.2307/4449274

(b) Multi-authored three to seven authors:

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

(c) Mutli-authored more than seven authors

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

(2) Books-

Bossel, H. (1994). *Modeling and Simulation* (1st ed.). New York, NY: A K Peters/CRC Press. https://doi.org/10.1201/9781315275574

(3) Book chapters-

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

(4) Web sites-

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

E. Tables

Tables should be submitted as individual electronic files in Word (2013+) or RTF format. Placement of tables should be indicated within the body of the manuscript. The editor will make every effort to place them in as close a proximity as possible. All tables must be accompanied by a descriptive legend using the following format:

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

F. Figures

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

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

III. Letters to the Editor

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

IV. Other Submissions

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

V. Manuscript Submissions

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

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

VI. Editorial Review and Acceptance

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

- **Suitability:** The manuscript relates to teaching biology at the college and university level.
- **Coherence:** The manuscript is well-written with a minimum of typographical errors, spelling and grammatical errors, with the information presented in an organized and thoughtful manner.
- **Novelty:** The manuscript presents new information of interest for college and university biology educators or examines well-known aspects of biology and biology education, such as model organisms or experimental protocols, in a new way.

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

VII. Revision Checklist

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

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

VIII. Editorial Policy and Copyright

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