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Cover image: *Kryptolebia marmoratus*
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ARTICLE

Transformation of a Traditional, Freshman Biology, Three-Semester Sequence, to a Two-Semester, Integrated Thematically Organized, and Team-Taught Course

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Abstract: Biology faculty at San José State University developed, piloted, implemented, and assessed a freshmen course sequence based on the macro-to micro-teaching approach that was team-taught, and organized around unifying themes. Content learning assessment drove the conceptual framework of our course sequence. Content student learning increased significantly in 12 of the categories examined using pre and post assessment instruments. Focus and individual student interviews revealed that students experienced a sense of ownership after completing two, five-week guided inquiry projects. Pass rate for the second semester class increased significantly from 55% to 85%. The percentage of underrepresented students passing the new sequence was higher than 72%, and was 86% at the end of the second year of full course sequence implementation.

Keywords: Team teaching, macro to micro teaching approach

INTRODUCTION

Traditionally, freshmen biology course sequences at the university level begin with basic chemistry concepts, have an extended animal and plant taxonomy component, and end with ecology, regardless of the intellectual maturity of the students taking the course. Concepts are organized as silos and instructors assume that students can make connections between disparate content (Gardner & Belland, 2012). Making matters worse is that most chosen textbooks are encyclopedic in nature.

In traditional biology freshman courses, both instructors and students place an emphasis on learning definitions, recalling memorized information, or recognizing word patterns in order to answer multiple choice exam questions (Martin, 2015; Momsen et al., 2010). Information learned at this low level is only retained for the exam. Content superficiality is not amenable for the construction of cognitive conceptual scaffolds that aid in learning more complex concepts in upper division courses, where

application of knowledge is essential (Momsen et al., 2010). Furthermore, some biology university faculty stress the importance of learning facts without questioning what students should learn, how the concepts are taught, and when students should learn the material (Gardner & Belland, 2012; Momsen et al., 2010).

Several national reports have stressed the importance of teaching biology not as a collection of historical facts, but as an active, participatory endeavor that should mimic the way science is done (Committee on undergraduate education to prepare research scientists for the 21st century, NRC, 2003; PCAST, 2012). Furthermore, the Vision & Change Report provided the biology community at large with core concepts that a modern biology university education should follow (American Association for the Advancement of Science, 2011; Musante, 2011).

Our previous freshman biology sequence consisted of three semesters (Plant Biology, Animal Biology, and Cell Biology), with 3 hr lectures and 2 hr lab sections per week.

The first two semesters (Plant Biology and Animal Biology) were taxonomy heavy. Content was organized in silos and there was no reinforcement of concepts within each semester. Students had low retention rates and were unprepared for upper division work. The new two-semester course sequence was designed to increase student persistence, reduce the failure rate for students enrolled in the new core (without reducing academic standards), increase conceptual understanding, and incorporate active learning strategies that were absent in the previous freshmen sequence.

We present results from the development, piloting, and implementation of a highly innovative two-semester freshman biology sequence. We present several lines of evidence that demonstrate that students' success (such as concept gains, increase passing rates) can increase in a large freshman class, at a public comprehensive university.

METHODS

Data included in this article, such as: students' demographics, passing rates, pre/post concept assessment, SALG (Student Assessment of their Learning Gains) responses, surveys, students interviews, were from those who consented to participate in a research approved by San José State University IRB (protocol F1002051). Participation rates exceeded 90% during the study (2009-2012).

Developing an innovative freshman biology foundational sequence

In 2009, three faculty in the Department of Biological Sciences embarked on the development, piloting, and implementation of the entire freshman sequence. This process provided an unparalleled opportunity to examine curriculum at the freshman level that has not been done in our institution since the 1960s. Revision of the underlying teaching philosophy also brought the challenge of additional efforts in terms of developing team-taught lectures, a new activity/problem solving component, new

lab exercises, two short research projects, and the development of assessment strategies to examine the success or failure of this sequence. We implemented the team teaching model described by Friend & Cook (2010, p168-169), in which one instructor led the lectures and two others observed and answered questions when needed. Two sets of objectives (success and pedagogy) were used to guide our curriculum implementation at the freshman level. The success objective was to reduce the failure rate for students enrolled in the new core, without reducing academic standards. The following five pedagogical objectives were used: (a) students will be able to formulate hypotheses and design experimental approaches to answer research questions, (b) students will be able to use quantitative analysis to understand complex scientific concepts, (c) students will be able to work effectively in groups to solve problems, (d) students will be able to use multiple approaches to answer complex questions, and (e) students will be able to construct logical conclusions based on the different types of data they collect.

The new two-semester sequence implemented a macro-micro approach that began with biodiversity (including microbes) in the first semester, and ended with cancer in the second semester. In this approach students begin with material that is more familiar and contain larger levels of biological organization (for example biomes) followed by more abstract and smaller levels of biological organization (molecules and cells). Several biology instructors at different institutions have reversed the traditional organization of the freshmen biology sequence and have implemented a similar approach (Gwynee, 1997). There were several reasons for using this conceptual approach of covering the material. First, students (of the three-semester sequence) had a better understanding of macro concepts (such as biodiversity, ecology, development), and had great difficulty with micro concepts

(such as cell-cell communication, cellular energetics, translation). Second, the material was organized in themes in order to make conceptual connections easier. Third, students needed to understand concepts covered in the first semester of the freshman Chemistry sequence in order to do well in the Cell Biology portion of the class. Therefore, the first semester of the freshman Chemistry sequence became a co-requisite of the first-semester biology sequence, and a requirement for the second semester. In the three semester sequence, Soto & Anand (2009) demonstrated that a strong predictor of students succeeding in the cell biology portion of our institution freshmen sequence was passing the first semester of college Chemistry with a grade of “C” or better. Thus, we anticipated that students would do better in the cell biology & physiology semester if they had passed the first semester of Chemistry with a “C” or better.

Pass/fail rates analyses

Historical (2005-2009), aggregated without personal identifiers, pass data from the three-semester Biology sequence were compared with the total number of students who passed the new sequence and were willing to participate in this study (two-semester sequence, 2010-2012). Pass rates of underrepresented (URM) students as defined by the National Science Foundation (African American, Latina/o, and Pacific Islanders) were collected from students who consented to participate in our study and enrolled in the two-semester sequence.

Core concept assessment

Pre and post surveys were given to the students who were enrolled in the three-semester sequence in 2009-2010 and in the two-semester sequence (2009-2012). The content pre and post surveys contained questions on: scientific method, natural selection, phylogenetics, mitosis/meiosis, developmental biology, plant evolution, ecology, anatomy, taxonomy, mendelian genetics, population genetics, protein function, amino acids, energetics, protein structure, enzymes, nucleic acids,

electrophoresis, carbohydrates, membrane structure, cancer, extracellular matrix, Krebs’s cycle, glycolysis, electron transport systems, DNA structure, DNA replication, transcription, alternative splicing, gene structure, and action potential. Data from 2010-2012 courses were aggregated for pre- and post-assessment results and compared with data collected from the previous course sequence (2009-2010) for statistical significance using T-tests.

Students’ self-assessment of gains

Students enrolled in the two-semester sequence (2010-2012) were given a modified SALG (Students Assessment of their Learning Gains) instrument to assess their learning gains related to the attitudes regarding their behavior in each component of the course. Two hundred and twenty students responded to the survey. The SALG site (www.salgsite.org) analyzed collected data as means +/- standard deviations.

Students’ interviews

Jerry Everhart interviewed students (one-on one, focus groups, and Skype) at several times during the duration of the project (2009-2012). Focus group interviews occurred after lab sections. The purpose of the interviews was to gather students’ impressions about course design, study strategies, and the research projects in the labs. Two hundred students were interviewed from the new sequence (2010-2012). The notes were transcribed without identifiable information, and the information reported as is.

Videos

Students’ research presentations were videotaped. A random sample of 22 videos was evaluated to examine if students exhibited acceptable scientific practices. Observations were transcribed and reported as is. These included: use of scientific terminology contextually, appropriate information, apply useful information, use lab techniques to answer questions and test hypotheses, and consider alternative explanations.

RESULTS

Student Sample

Fig. 1 shows the data sample for the two-semester biology freshman sequence examined in this study, including the number of URM students. URM students corresponded to 19% of the total number of students who were willing to participate in our study (2010-2012). This percentage composition was the same when the total number of students enrolled was considered.

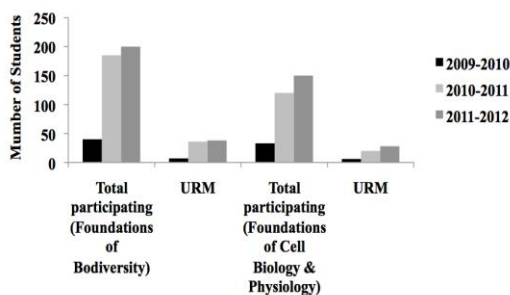


Fig. 1. Total and URM student participation in this study.

Pilot

In 2009-2010, faculty in the Department of Biological Sciences confronted many philosophical and logistical issues to deliver an innovative, introductory course to biology majors (mostly freshmen). The team consolidated a three-semester, topic-driven sequence into a two-semester, team-taught, integrated, theme-based experience (Tables 1 and 2; Fig. 2). Students chose to be enrolled in the pilot course. Participants had to qualify to participate in the piloting of the two-course sequence. From the students willing to participate in the course, academic advising staff selected 40 students based on academic criteria (not remedial, able to co-enroll in the freshman Chemistry sequence, and English composition courses).

Three substantial changes were made to the new courses. First, a team of three instructors delivered lectures in weekly classes. The instructors represented various areas of expertise within biology. All

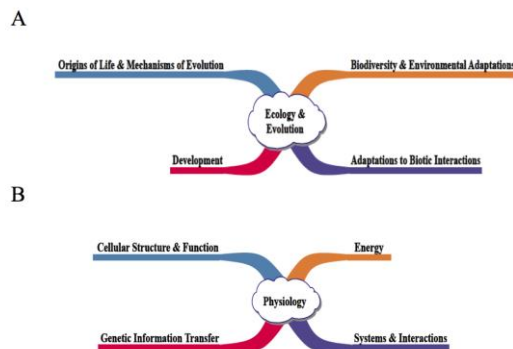


Fig. 2. Conceptual Framework of the freshman, two-semester biology sequence. (A) First semester: Foundations of Biodiversity. The unifying theme was ecology & evolution. (B) Second semester: Foundations of Cell Biology & Physiology. The unifying theme was physiology.

attended each lecture and contributed information as subject matter emerged. Second, the laboratory portion of the course was aligned to the concepts presented in lecture. A short research component was added to the lab with expectations that students conduct research, collect and analyze data, and present conclusions to others. Third, a two-hour per week activity component was added. The activity section helped students with complex ideas introduced in lectures by using hands-on, quantitative, problem-based, and kinesthetic approaches to learning. The activity sections emphasized students to do group work and communicate effectively. In the pilot year, upper division students facilitated the activity section.

Several challenges were present. Both Biology freshman sequences were taught concurrently. Delivery of traditional and pilot classes concurrently allowed the instructional team to have a control group, but also increased logistical challenges, as lab technicians could not devote the time needed to implement new labs. One of the logistical consequences was the misalignment of some of the activities/lab exercises with the material presented in lecture. In addition, some of the new lab exercises did not work as planned and new ones were developed as a consequence.

Table 1. Comparison between Plant Biology, Animal Biology, and Foundations of Biodiversity

	Plant Biology (3 semester sequence)	Animal Biology (3 semester sequence)	Foundations of Biodiversity (2 semester sequence)
Chemistry	Not required	Not required	Chem 1A (Co-requisite)
Exam Type	Simple multiple choice	Simple multiple choice	Conceptual short answers, Quantitative problems
Class Components (per week)	3 hr of passive lectures: <ul style="list-style-type: none"> • Silos • Memorization of definitions, and taxonomy groups 2 hrs of labs (“cookbook”) <ul style="list-style-type: none"> • Not linked to lecture material 	3 hr of passive lectures: <ul style="list-style-type: none"> • Silos • Memorization of definitions, and taxonomy groups 2 hrs of labs (“cookbook”) <ul style="list-style-type: none"> • Not linked to lecture material 	3 hr lectures (team-taught) <ul style="list-style-type: none"> • Conceptually integrated • Thematically-organized 2 hrs labs <ul style="list-style-type: none"> • Reinforced lecture material • 4 weeks of research projects • Student research papers 2 hrs activity <ul style="list-style-type: none"> • Modified TBL • Reinforced lecture material • Active learning techniques
Contact hrs	5	5	7
Concepts (new concepts in bold)	Taxonomy of plants Mendelian Genetics Natural selection Ecology Plant physiology Plant Evolution Population demography and life history Plant Development	Taxonomy of animals Population genetics Ecology Species Interactions Animal physiology Animal Evolution Population growth Animal development	Origins of life: bacteria, archae, eukaryotes Mendelian Genetics Natural Selection Speciation Population Genetics Adaptations to living on land (plants & animals) Animal and plant form and function Gas exchange (animals & plants) Population growth Population demography and life history Species interactions Development (animal and plant) Evo-Devo

Table 2. Comparison between Cell Biology and Foundations of Cellular Biology & Physiology

	Cell Biology (3 semester sequence)	Foundations of Cellular Biology & Physiology (2 semester sequence)
Chemistry	Chem 1A (Co-requisite)	Chem 1A with a C or better (Pre-requisite), Chem 1B (Co-requisite)
Exam Type	Short answers	Conceptual short answers, quantitative problems
Class Components (per week)	3 hr of passive lectures: <ul style="list-style-type: none"> • Silos • Memorization of concepts 2 hrs of labs (“cookbook”) <ul style="list-style-type: none"> • Not linked to lecture material 	3 hr lectures (team-taught) <ul style="list-style-type: none"> • Conceptually integrated • Thematically-organized 2 hrs labs <ul style="list-style-type: none"> • Reinforced lecture material • 4 weeks of research projects • Student research papers and poster presentations 2 hrs activity <ul style="list-style-type: none"> • Modified TBL • Reinforced lecture material • Active learning techniques
Contact hrs	5	7
Concepts (new concepts in bold)	Organic molecules found in cells Cellular structure Enzymes and enzyme regulation Cellular energetics DNA replication, transcription, translation Alternative splicing Membrane structure and transport Cell-cell communications (signal transduction) Cell cycle and Cancer Cancer	Molecules of life Membrane structure and transport Cellular structures Molecular evolution (origin of chloroplasts and mitochondria) Genome evolution Enzymes and enzyme regulation Digestive system Respiratory system Cellular energetics DNA replication, transcription, translation Nervous system, action potential Endocrine system Cell-cell communications (signal transduction) Plant hormones Cell cycle and Cancer

Finally, students were not comfortable with students facilitating the activity sections.

Implementation

During the first year of implementation, all of the freshmen students who were academically prepared to take the new sequence were allowed to do so. In addition, the three-semester sequence was discontinued.

Intense planning and anticipation of potential problems made the transition to

full implementation relatively free of major problems. Activity and laboratory exercises were linked with the concepts presented in lecture. Although the lecture component had large enrollments (over 120 students), activity section enrollment was limited to 22 students per section. The activity exercises were greatly refined and faculty began to facilitate these sections. The instructors in charge of the entire sequence had weekly meetings with lab and activity instructors.

Table 3. Assessed concepts that were not different in the three- and two-semester sequences.

Concept	Course where it was assessed
Mitosis/meiosis	Plant Biology Foundations of Biodiversity
Plant evolution	Plant Biology Foundations of Biodiversity
Plant anatomy	Plant Biology Foundations of Biodiversity
Animal anatomy	Animal Biology Foundations of Biodiversity
Protein structure	Cell Biology Foundations of Cell Biology & Physiology
Protein function	Cell Biology Foundations of Cell Biology & Physiology
Amino acids	Cell Biology Foundations of Cell Biology & Physiology
Nucleic acids	Cell Biology Foundations of Cell Biology & Physiology
Carbohydrates	Cell Biology Foundations of Cell Biology & Physiology
Membrane structure	Cell Biology Foundations of Cell Biology & Physiology
Electrophoresis	Cell Biology Foundations of Cell Biology & Physiology
Gene structure	Cell Biology Foundations of Cell Biology & Physiology
Extracellular matrix	Cell Biology Foundations of Cell Biology & Physiology
Cancer	Cell Biology Foundations of Cell Biology & Physiology
Membrane structure	Cell Biology Foundations of Cell Biology & Physiology

Concept Learning Gains

Learning gains of concept comparisons between old and new courses yielded mixed results. Pre-assessment results indicate that students in both types of freshman core sequences had comparable concept understanding (Fig. 3A). The only differences were in the concept of transcription and translation, where students from the three-semester sequence scored significantly higher in the pre-assessment test ($p < 0.001$).

When the post-assessment scores were compared, there were no statistically

significant differences between both sets of students in 15 categories (Table 3). Students who enrolled in the three-semester sequence outperformed students enrolled in the two-semester sequence in three categories: plant and animal taxonomy and alternative splicing (data not shown).

Fig. 3B shows the statistically significant gains of concept competency in specific areas of biology covered in the three-semester and two-semester sequences ($p < 0.001$). Students who took the two-semester sequence outperformed students who took the three-semester sequence in 12 concept categories: scientific method,

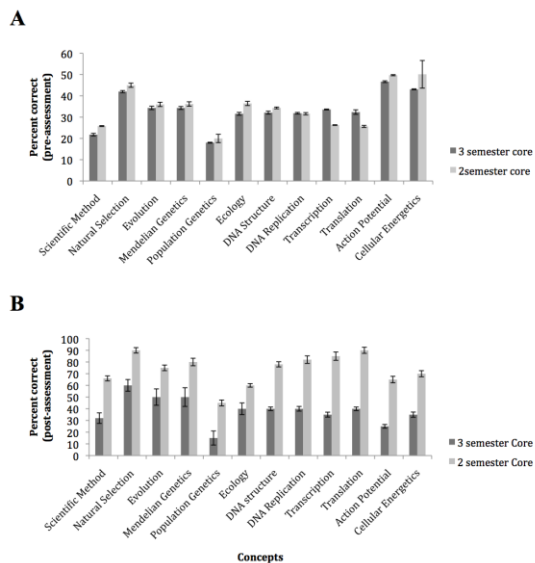


Fig. 3. Conceptual Learning Gains. (A) Pre-assessment. (B) Post-assessment. Differences between the 3-semester and the second semester post assessment data were significant ($p < 0.001$).

natural selection, Mendelian genetics, population genetics, ecology, DNA structure, DNA replication, transcription, translation, action potential, and cellular energetics. Faculty members were invited to give guest lectures and write activity problems for several concepts. For instance, Mendelian and population genetic problems were designed by the faculty who teach in the upper division Genetics course. The included problems were examples of some of the basic concepts students have difficulty in their upper division Genetics course. The department's neuroanatomist gave guest lectures on the nervous system and wrote conceptual problems that included action potential. One of the instructors, a cell biologist, designed kinesthetic modeling activities to reinforce the concepts of DNA replication, transcription, and translation. In these kinesthetic activities, students create models of these processes using props and themselves as part of the models. The models, then, were scored for accuracy.

Pass rates

Pass rates were compared between historical data (2005-2009) and students who agreed to participate in this study (2010-2012). Comparisons were made with

appropriate course equivalencies (Tables 1 and 2; Fig. 4A-B). Thus, the Plant Biology and Animal Biology (one semester each) courses were compared with the Foundations of Biodiversity (one semester) course. Cell Biology, the third course in the three-semester sequence, was compared with the Foundations of Cell Biology & Physiology, the second course of the two-semester sequence. Data analysis indicated no statistically significant difference between the pass rates of the two-semester, taxonomy-heavy, Plant Biology and Animal Biology courses ($77.37\% \pm 9.87$) and the Foundations of Biodiversity course ($86.17\% \pm 7.69$, Fig. 4A). However, there was a statistically significant difference between the pass rate of Cell Biology ($63.9\% \pm 4.34$) and the Foundations of Cell Biology & Physiology course ($85.9\% \pm 4.04$, Fig. 4B).

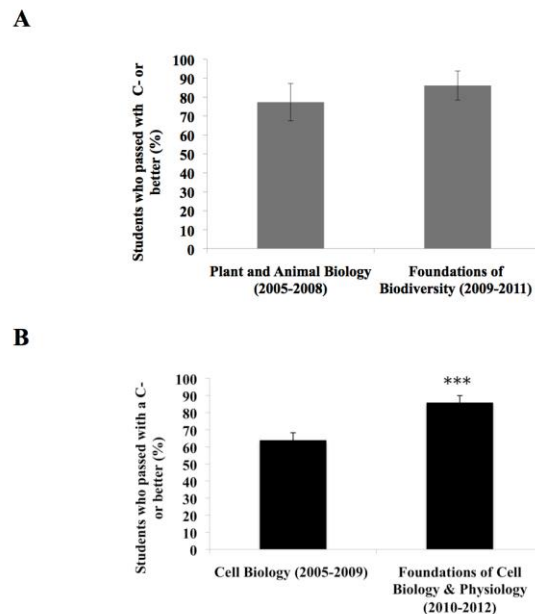


Fig. 4. Pass rate comparisons between the three- and two-semester's sequence. (A) There were no statistical significant differences between the pass rate of Plant Biology and Animal Biology and the first semester of the two-semester sequence (Foundations of Biodiversity), $p > 0.5$. (B) Significant increased pass rate of students enrolled in the second semester of the two-semester sequence (Foundations of Cell Biology & Physiology). $***p < 0.001$.

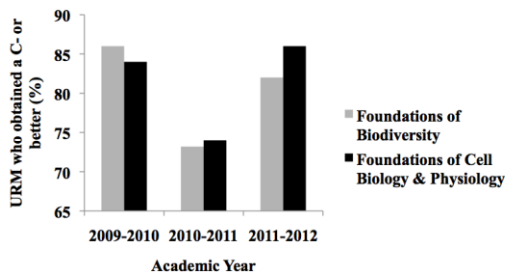


Fig. 5. URM pass rate in the two-semester sequence

The URM pass rate was also calculated for students enrolled in the two-semester sequence (2009-2012). Fig. 5 shows the percentage of URM students who obtained a C- or better. For academic year 2009-2010, the pass rates were 86% and 84% in the first and second semester, respectively. However, it is important to note that this sample size was small, 7 students in the first semester and 6 students in the second semester. For the academic year 2010-2011, the first year of implementation, the pass rates were 73.2% and 74% in the first and second semester, respectively. The sample size was 36 students in the first semester and 20 students in the second semester. For the second year of implementation, 2011-2012, the URM pass rate increased to 82% and 86%, for the first semester and second semester, respectively. The sample size was 38 students in the first semester and 28

students in the second semester.

Students Perceptions about their own learning

SALG results captured students' perceptions about what components of the class were beneficial to their own learning gains (Table 4). Overall, students found the activity sections to be the most beneficial aspect of the 2-semester course sequence.

All the students interviewed believed that they were ready for advanced biology coursework. Students appeared pleased at their ability to make connections among concepts. They stated that they better understood "*how science works*". The most surprising finding was the use of social media as a study tool.

Student Research Projects

Students performed a 4-week research project in each lab component of the two-semester sequence. During the first semester, students were responsible for writing a research paper presenting their findings. During the second semester, students were expected to present a group poster presentation of their research project. A biodiversity project was used in which in semester one, students examined plant biodiversity using traditional field techniques, and during the second semester students examined the genetic diversity of mitochondrial genes of the samples

Table 4. Active learning techniques used to teach concepts with statistically significant learning gains.

Concept	Class Component	Technique
Scientific Method	Labs in both courses	Two, 4-week Research Projects
Natural Selection	Activity	Simulation
Evolution	Activity	Simulation
Mendelian Genetics	Lab	Fruit fly Crosses
Mendelian Genetics	Activity	Quantitative Group Problems
Population Genetics	Activity	Quantitative Group Problems
DNA Structure	Activity	Conceptual Group Problems
DNA Replication	Activity	Kinesthetic Group Modeling
Transcription	Activity	Kinesthetic Group Modeling
Translation	Activity	Kinesthetic Group Modeling
Action Potential	Activity	Conceptual Group Problems
Cellular Energetics	Activity	Conceptual and Quantitative

collected during the first semester. Students in the pilot were surprised at realizing the connections between fieldwork and genetic analysis. However due to logistical issues, research projects were unlinked during implementation. Students thought that the research project assignments (group research projects, research papers, and poster presentation) helped their learning (Table 5).

Student poster research presentations were videotaped and analyzed. After examining the video presentations, patterns in the qualitative analyses indicated that students were able to: 1) use scientific terminology contextually and with fluidity; 2) recall and sequence information consistent with accepted scientific practices; 3) locate and apply useful information; 4) employ lab techniques to answer questions and test hypotheses; and 5) consider alternative explanations.

DISCUSSION

Success and pedagogical objectives were achieved in the implementation of the two-semester sequence. Pass rates were significantly increased in the most difficult part of the freshman sequence. This increase was not the outcome of making the sequence easier. Exams consisted of conceptual questions in which students were expected to demonstrate information synthesis rather than a memorization of factoids. Students had to demonstrate concept understanding by performance in

both the activity/problem solving and lab sections and by communicating research findings technically in both oral and written form. Of the strategies we implemented into the two-semester sequence, problem solving (Freeman et al., 2007) and group discussions (Dori and Belcher, 2005), have been shown to increase pass rates.

All five pedagogical objectives were met in the two-semester sequence. Four of these relate to the goal described by the Vision & Change Report (American Association for the Advancement of Science, 2011) of students understanding and utilizing the scientific process. In the research projects portion of the labs, students formulated testable hypotheses, worked effectively in groups, used multiple approaches to answer complex questions, and constructed logical conclusions based on the data they collected. The quantitative analysis objective was met during the activity/problem-based sections.

Conceptual gains and increased pass rates

Both the three-semester and two-semester sequences have comparable learning gains in 15 of the concepts assessed (Table 1). At first, this result may suggest that the active learning strategies we implemented in our sequence were not very effective. However, this should be considered a success considering that the content was reduced by a third (from three to two semesters).

Analysis of the data collected showed differences in concept learning gains in two

Table 5. Students' perceptions about the effectiveness of research projects on their own learning gains.

HOW MUCH did each of the following aspects of the class HELP YOUR LEARNING? N=220 students	1:no help	2:a little help	3:moderate help	4:much help	5:great help	Mean +/- St.Dv.
Final lab paper Fall semester	5%	22%	37%	26%	10%	3.2 +/- 1.07
Final lab poster Spring semester	5%	15%	30%	25%	25%	3.5 +/- 1.19
Final Research paper spring semester	5%	21%	37%	26%	11%	3.2 +/- 1.07
Group research projects	10%	15%	25%	35%	15%	3.3 +/- 1.22

different situations. First, students enrolled in the three-semester sequence obtained higher learning gains in concepts that were not covered in the new sequence. These gains were in the areas of animal and plant taxonomy and alternative splicing. Second, students who took the two-semester sequence obtained higher learning gains in 12 concept categories where active learning strategies were developed and used. These concepts were reinforced in lab or activity sections with techniques that were developed to help different types of learners (Table 4). The incorporation of active learning techniques in STEM education have been recommended by national reports (NRC, 2015; PCAST, 2012) and have been shown to be effective in increasing academic success in introductory STEM courses (Freeman, et al., 2014; Freeman et al., 2007).

Our data suggest that most of URM students passed our re-developed sequence. However, our URM sample size was too small and we did not evaluate the reasons for this success. The researchers surmise that peer interactions in the activity/problem solving sections contributed to URM success. The 22-student activity/problem solving section with a faculty facilitator provides the environment with greater and more meaningful student interactions that can result in greater academic success (Snyder et al., 2016; Preszler, 2009).

Team-based learning in the activity/problem solving sections

Students self-reported that the most effective portion of the new sequence was the weekly, activity/problem solving section (Table 3). These sections can be described as modified team-based learning or TBL (Metayer et al., 2014). TBL provides means to improve cognition as this approach allows students to analyze data and evaluate information (Metayer et al., 2014). TBL is also an active learning strategy that incorporates problem solving, group discussions, and technology-based activities (Gardner & Belland, 2012). Moreover, TBL

is based on evidence-based teaching (Leisey et al., 2014).

In our modified TBL sections, groups were not pre-formed and the assessment was not based on quizzes but on either graded group problems or accuracy of kinesthetic models. Peer feedback and evaluation was part of our modified TBL strategy. In our activity/problem solving sections, students worked in groups to solve conceptual and quantitative problems, build kinesthetic models, and use computer simulations to extend their learning beyond what was covered in lecture.

CONCLUSIONS

Our data collection and analyses were not designed to determine specific strategies that resulted in students' success as evidence by an increase in pass rates, concept learning gains, and positive attitudes toward biological research. We used a collection of active learning strategies that might have helped our students learn the concepts, but we also changed the entire structure and organization of the class. Based on our results, we suggest that the incorporation of active learning strategies and a re-examination of an entire course structure and delivery in tandem are essential in order to increase students' ability to build high levels of conceptual understanding.

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Null Models for Everyone: A Two-Step Approach to Teaching Null Model Analysis of Biological Community Structure.

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Abstract: Since being introduced by Connor and Simberloff in response to Diamond's assembly rules, null model analysis has been a controversial tool in community ecology. Despite being commonly used in the primary literature, null model analysis has not featured prominently in general textbooks. Complexity of approaches along with difficulty in interpreting results may reduce classroom application of this technique. Yet, readily available software makes this set of tools accessible to everyone from practitioners to educators. This exercise describes a hands-on approach that can be cheaply implemented with students as a stand-alone exercise or as a prelude to use of full-blown simulations in follow up lab sessions. Along with a detailed hands-on approach, we have provided a brief introduction to a computer-based approach. This paper includes a link to 294 data sets extracted from Patterson's Nestedness software and reformatted for use in EcoSim. These exercises demonstrate how to compare the observed number of checkerboard patterns in real community data to a frequency distribution of checkerboard patterns in randomized communities. The hands-on simulation uses fake data as a starting point and dozens of randomizations to produce a histogram. Computer-based simulations generate thousands of simulations to rapidly analyze real data sets. The results provide a springboard for discussion of the underpinnings of inferential science as applied to ecological communities.

Keywords: Null model analysis; hands-on model; simulation; data mining; community ecology

INTRODUCTION

Diamond's (1975) assembly rules were based upon the assumption that ecologists could recognize the fingerprints of competitive exclusion left on the distributions of species in natural communities. By examining the distributions of species pairs on archipelagos it is possible to identify species that never coexist on a single island. Diamond referred to such exclusive patterns as checkerboard distributions and contended that they were evidence of competitive exclusion. Connor and Simberloff (1983) countered that exclusive patterns were as likely to result from many other mechanisms including random chance. Null model analysis provides a way to statistically compare co-occurrence patterns of observed species distributions with those of randomly placed species.

To run a null model analysis, investigators use the following simple steps (Gotelli and Entsminger, 2004):

- 1). First we calculate an index that presumably tells us something about the structure of an observed set of natural communities summarized in a species by site presence-absence matrix (Table 1). For the purposes of this exercise we will use the number of checkerboard distributions based on Diamond's (1975) contention that checkerboard distributions are consistent with competitive exclusion.
- 2). Subject to some constraints, we generate a set of randomized communities assembled absent the community structuring mechanism (competition in our example).
- 3). We measure the index (number of checkerboards) from this randomized community.

Table 1. Initial placement of the beads in the trays. Any set of 7 unique colors will work to represent the species. Letters A through P represent the islands or sites where these species are found. If available ice cube trays have just 14 wells, columns *O* and *P* can be omitted without drastically affecting the results.

Species	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Purple	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	1
Red	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0
Yellow	1	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0
Green	0	0	0	1	1	1	0	1	0	0	0	0	1	0	0	0
Pink	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0
Dark Blue	1	0	0	1	1	1	0	0	0	1	0	0	1	0	0	0
Light Blue	0	0	1	0	0	0	1	1	1	0	0	1	0	1	0	1

4). We repeat steps 2 and 3 many times generating a histogram representing a distribution of communities that are considered *null* with respect to the structuring influence of competition.

5). We ask if the index calculated from the observed natural communities differs significantly from randomly assembled communities.

Rationale

Null model analysis has been an area of active research since its introduction to the field of ecology (Connor and Simberloff, 1979). This approach to data exploration has not been without controversy and yet remains a mainstay in the published literature. Despite prominence in the primary literature, null models may or may not feature prominently in text books aimed at students of general ecology or community ecology. In general ecology textbooks, null models tend either not to be mentioned or mentioned briefly (Molles, 2013; and Ricklefs and Miller, 2000). In community ecology textbooks, a chapter or only a few pages may be dedicated to null model analysis (Morin, 2011; and Mittelbach, 2012). This exercise is intended to help address this mismatch by providing two entry-level null-model exercises that can be

implemented in the lecture setting and/or the laboratory.

The first exercise is an inexpensive hands-on simulation using plastic ice-cube trays to represent an archipelago of islands and colored beads to stand in for the species inhabiting these islands; this activity can run in a 50-minute lecture. The follow-up exercise uses free or inexpensive software to analyze real data from the primary literature and is better suited to a full-length laboratory session. These exercises facilitate discussion of the philosophical underpinnings of inferential science. Can we ever infer mechanism from pattern? What valuable information would be missed by restricting our vision to the narrow lens of experimental science (Diamond, 2001)?

METHODS

Hands-on simulation.

Summary of the approach

An ice cube tray serves to represent an archipelago of 16 (or 14) islands. Beads of different colors represent different species that occur on the islands with the 14 or 16 ice cube tray wells each representing distinct islands. The initial set of beads in the trays as shown in Table 1 and summarized in Table 2, represents a hypothetical observed set of communities. Students work in pairs

Table 2. The number of checkerboards recorded from the observed data set in Table 1.

	L Blue	D Blue	Pink	Green	Yellow	Red	Purple
Purple	0	0	0	0	0	1	
Red	1	1	1	1	0		
Yellow	0	0	0	0			
Green	0	0	0				
Pink	1	0					
Dark Blue	1						
Light Blue							

Total number of checkerboards observed: 7

or small groups to record the observed set of communities in Table 3 and then repeatedly shuffle the beads to generate a distribution of null communities against which to compare the observed data set. Students record the number of species pairs with checkerboard distributions from the original observed and randomized communities. Each student group runs one or more replicate randomizations and the entire class generates a histogram of the number of checkerboards found on the simulated archipelagos against which to compare the

original observed archipelago. The many student replicate randomizations and resulting histogram comprise a null model of presence/absence data that can be compared to the original observed set of communities in the ice cube tray. EcoSim can be used to run computer simulations to repeat the exercise for sets of real communities on real archipelagos from data sets provided here: https://wikieducator.org/Null_Model_Home.

Materials

Each participating group of students needs the following: Labeled ice cube trays

Table 3. Table to be filled by students recording presence or absence of species on islands. Each student or group needs 1 copy to record the initial observed data set and an additional copy for every randomized data set planned for the activity. All entries should be "1" or "0"; no cells should be blank.

Species	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
Purple																
Red																
Yellow																
Green																
Pink																
Dark Blue																
Light Blue																

Table 4. This table is used to record checkerboard distributions by inspection of data collected in table 3. Entries should be recorded as “1” or “0”. The number of checkerboards recorded in this table by each student group is to be recorded in a class-wide histogram on the board.

	L Blue	D Blue	Pink	Green	Yellow	Red	Purple
Purple							
Red							
Yellow							
Green							
Pink							
Dark Blue							
Light Blue							

Total number of checkerboards observed: _____

(Figure 1); beads in 7 colors (Perler® fuse beads work well and are small enough to permit storage of nested trays with beads in place); collecting boxes larger than the ice cube trays to dump beads (shoe boxes are ideal); forceps; a handout made from the pre-filled Table 1; three or four copies of the blank Tables 3 and 4; spare beads to replace the inevitably dropped beads. Note that Table 2 is intended for instructor use.

Labeling the ice cube tray

Labeling should be done on the internal vertical walls of the wells in the ice cube trays. Two labels are necessary in each well:

- 1) Each well should be labeled with a unique letter representing an individual island. Letter labels should be placed on a consistent side of each well so that they are all visible from one end of the tray (Fig. 1 A).
- 2) After rotating the tray 180°, the numbers of species occurring on each “island” should be labeled on the wall opposite the island’s letter label corresponding with Table 1 (Fig. 1 B). An arrow marked down the center of the tray helps to orient the tray.

Initial setup

The initial placement of beads represents a hypothetical set of species occurrences on the model islands. A bead of a given color

in a particular well represents a species on that island. This initial placement of species on islands was designed to yield a reasonable number of checkerboards while leaving enough empty cells in the species-by-site matrix to make randomization possible. Matrices with few empty cells are difficult or impossible to randomize because most species occur at most sites and few novel rearrangements of the communities are possible. The arrangement of species described in Table 1 yields an original ‘observed’ dataset with 7 checkerboard distributions.



Figure 1. A. View of an example ice cube tray showing the letters that represent the names of the islands. B. Opposite view of the tray revealing the numbers of species found on each island. These numbers are used to fix the number of species on each island during the simulation runs.

Running the activity

Original observed data

Ice cube trays with beads in place should be distributed to student groups along with forceps used to handle beads, blank copies of Tables 3 and 4, and boxes used to count and collect beads. The ice cube trays should initially be oriented such that the letters representing the island names face the data recorder. Students should record the observed data matrix of species presences and absences in a copy of Table 3. This original data set (Table 1) created for the purposes of this exercise, is analogous to an observed data set from a natural archipelago. Each species pair that never co-occurs in any one of the islands counts as having a checkerboard distribution and students should record these as a “1” in a copy of Table 4. For example, Purple and Red (in Table 1) have a checkerboard distribution because they are never found on the same island and so a “1” will be recorded (see top data row in Table 2). The purple and yellow species co-occur on island F and on island G (Table 1) and therefore do not have a perfect checkerboard distribution; a zero should be recorded (Table 2). Once every species pair has been scored, the total number of checkerboards should be recorded at the bottom of Table 3 (following the worked example in Table 2). This number is the “Observed number of checkerboards” from the original dataset and will subsequently be compared to the number of checkerboards in the null model, IE a histogram from the randomized data sets.

Randomized data sets

The beads should be dumped carefully into the empty box and mixed. It is essential to work only with the starting set of beads; adding beads will alter the constraints in the null model. The ice cube tray should now be rotated 180° such that students can see the number of species that had previously occurred per island in the original “observed” data set. In an ideal world we might use true randomization to place the beads back onto the islands in our

simulation, however rolling dice or using random number generators adds an additional logistical layer to this exercise that would make it impractical to implement during a 50-minute lecture. This difficulty presents an opportunity to discuss the differences between true randomization and haphazard placement of experimental units or, in this case, beads in wells or species on islands. The beads should now be placed haphazardly into the ice cube tray wells subject to 2 constraints: Constraint 1: The number of species per simulated island should equal the number of species that existed on that island in the observed data set. Constraint 2: Beads of identical color should not be placed in the same well. Once the beads have been placed, bead distribution should be assessed and data recorded in Tables 3 & 4. The output of each simulation will be the number of checkerboards recorded from the randomized species distributions. Each student group’s data should be recorded as a single point on a class-wide histogram (Figure 2). The simulation phase should be repeated until 20 or more points have been added to the histogram. Even with a large class it would be worth repeating the

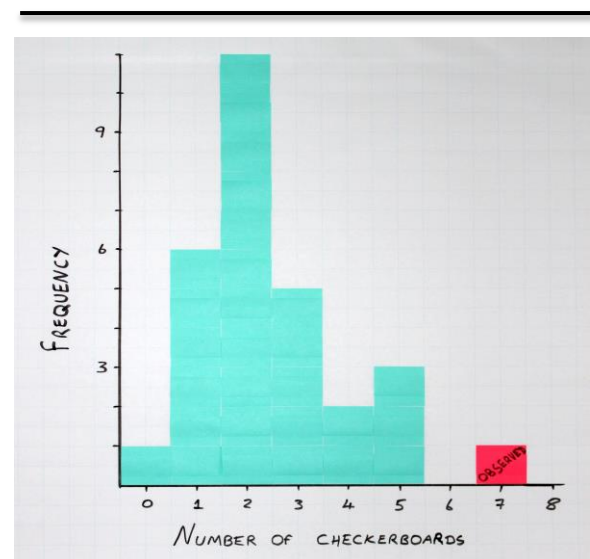


Figure 2. Class-wide histogram for the hands-on null model. Each student or group’s reported number of checkerboards was placed on the histogram using a sticky note to represent the result of their randomization

simulation at least twice per student group to emphasize the point that many replications are needed to generate a null distribution. Figure 2 is the result of four repetitions of the exercise generated by seven student groups in a Saint Michael's College class of 22 students.

Interpretation

The constraints used in this hands-on simulation are the fixed-fixed constraints frequently used in null model analysis. Constraint 1 fixes the number of species per island. Constraint 2 fixes the number of islands upon which a particular species occurs. These constraints provide ample opportunity for student discussion on the nature of null models. The approach to bead placement used to generate the in-class histogram facilitates discussion of true randomization and other alternative approaches.

Computer-based null model.

Summary of the approach

Like the hands-on approach, the computer-based simulation uses the checkerboard index ostensibly to suggest competitive exclusion. Whereas the hands-on method used entirely fictional data, the simulations add realism by utilizing data sets from published literature. We start by measuring the number of observed checkerboards in a published data set. This is followed by measuring this same index from 5,000 data matrices generated by randomly reassigning the original species to islands. Standard statistics are used to compare the observed index to the index measured from the randomized data sets.

Data and software

The EcoSim 2004 software (Gotelli and Entsminger 2004) can be downloaded for free from the following link: <http://www.uvm.edu/~ngotelli/EcoSim/ecosim7.zip>. An updated version of the software is available commercially: <http://www.garyentsminger.com/ecosim/>. After installing the software, data sets extracted from Atmar and Patterson's (1995) Nestedness software can be obtained from

this webpage:

<http://wikieducator.org/NullModelData>. The datasets can be saved as *.txt* files that can be opened directly from EcoSim. The fake data from Table 1 are also hosted on this web site and can be used for comparison with the hands-on simulation.

Initial setup

Once EcoSim opens, click *open* and search for your saved data set. Data should open automatically and you can skip straight to *Running the activity*. If data sets fail to open, the contents of *.txt* files can be copied and pasted into EcoSim software. To do this, click *Edit* and *Edit matrix as text* (this option not available in the commercial version). Delete the existing data and paste in the copied data. Note: Delete any empty lines that may be present before or after the numerical data. Finally, close and click *Yes* to save changes to the main grid.

Running the activity

In EcoSim, you can run the co-occurrence module to check for number of species combinations, number of checkerboards, *Cscore* etc. To do this click *Analyze* and then *1 Co-occurrence* to see the EcoSim Co-occurrence Options screen. Under the *Preferences* tab, there will be a drop-down box directly under the co-occurrence index. As default, it should say *C-score*, click the down arrow and choose *number of checkerboards*. Leave all other settings at their defaults: the fixed sum for both row and column constraints emulates the fixed/fixed constraints discussed above. Under the *General* tab; click *run*. The software will randomly shuffle species onto islands and generate 5,000 random matrices subject to the fixed/fixed constraints. From each of the matrices, Ecosim will count the number of checkerboards and generate a histogram of the results. You will be transferred automatically to the Co-occurrence results screen when the randomizations have been completed.

Data output

Ecosim generates information displayed under a series of tabs:

- *Input matrix* tab: the original observed data set can be seen here.
- *Simulation* tab provides one example of the 5000 randomized data sets.
- *Index* tab contains the histogram of the number of checkerboards recorded from the 5,000 null communities. An average number of checkerboards from the simulated data is calculated and can be compared to the observed number of checkerboards from the raw data. Also presented on this tab are the probabilities that the observed number of checkerboards differs from the randomized number of checkerboards. By convention, we can reject this null hypothesis if the p value is less than 0.05. Two p values are presented representing the left and right tail probabilities. Typically ecologists are interested in p value at the bottom of the display; it refers to the right-hand tail of the distribution, or more checkerboards in the observed data than in the randomized data; the upper value refers to the left-hand tail of the distribution, or fewer checkerboards in the observed data than in the randomized data. The last three columns form the histogram window that summarizes the distribution of checkerboards for the simulated data. The low and high columns are the boundaries of 12 evenly spaced histogram bins representing the number of checkerboards in the randomized data sets. The # simulations column records the number of simulated indices in each bin and could be used to construct a traditional histogram.
- *Summary* tab includes a standardized effect size (SES) of the difference between observed and simulated. SES is expressed in standard deviations and is of value when comparing matrices of very different sizes. For data sets with significantly more checkerboards than in the randomized data, the SES value will exceed 2.

RESULTS AND DISCUSSION

Sample Results

Hands-on ice cube tray simulation

There are seven checkerboard distributions in the hands-on ice cube tray model (Table 2). The 28 randomizations performed by the Fall 2015 Community Ecology Class at Saint Michael's College

yielded an average of 2.36 checkerboards (Figure 2). A one-sample t test can be used to compare the observed value, 7, to the distribution of the randomized values generated in the classroom.

Ecosim analysis of ice cube tray data set

The data from Table 1 can also be downloaded from the Wikieducator site (<https://wikieducator.org/NullModelData>) and opened in Ecosim to run the computer-based null model. The observed number of checkerboards in the starting data set will of course be 7. The average number of checkerboards calculated from the simulated datasets will vary slightly from run to run and in my example (Figure 3) was 2.08 which compares quite well with the value of 2.36 from the average generated from the hands-on simulation (Figure 2). The p value is quite small (tail probability value < 0.0002) indicating that the observed value (7 checkerboards) is significantly larger than the average of the randomized communities (2.08 checkerboards) confirming that the 'species'.... or beads in this case, were indeed non-randomly placed in the trays in the original data set. The authors can

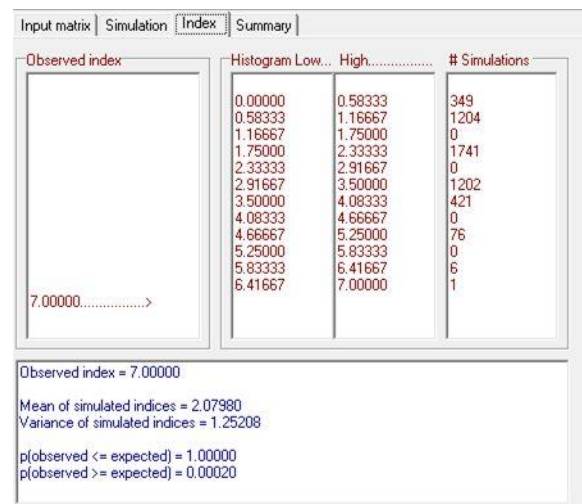


Figure 3. Example Co-occurrence results for computer-based null model using EcoSim 2004 using data from the Ice cube tray simulation. We used Ecosim to run 5000 randomizations and determined the average number of checkerboards (2.08) from the randomized data sets to construct a null model against which to compare the observed number of checkerboards (7).

certainly confirm that we did indeed design the data set in a non-random fashion. Statistically, this p value is defined as the probability that the observed value (7) is greater than or equal to the average of the simulated values (2.08 checkerboards).

Ecosim analysis of Harris' (1973) Galapagos Island bird data set

Because 18 checkerboards were observed in the raw data (Figure 4), we know that there were 18 species pairs among the birds of the Galapagos Islands that never co-occurred on the same island. The mean number of checkerboards from the 5000 simulated data sets that constitute our null model was 6.3 and the observed value (18 checkerboards) was significantly greater than the number in the randomized data or null model (tail probability value < 0.004).

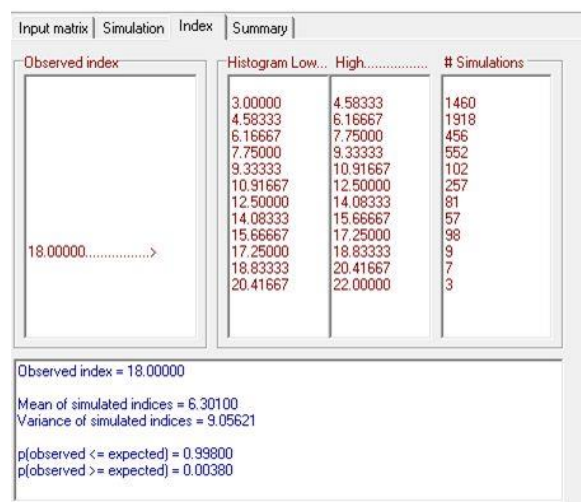


Figure 4. Example Co-occurrence results for computer-based null model using EcoSim 2004. Data set from Harris' (1973) study on 23 bird species on 15 islands in the Galápagos. We ran 5000 iterations to determine the average number of checkerboards in null communities.

Interpretation:

After completing this exercise, we hope you'll agree that running a null model analysis of community data is comparatively easy. However, it is most important that students learn to exercise caution when interpreting the output generated by null model analysis. It is tempting to reach beyond what can be said with certainty and to arrive at illogical conclusions. Many

mechanisms can produce checkerboard distributions, and it can be a valuable exercise to have students come up with a list of such mechanisms. For example, simple differences in habitat requirements could confine one species to rocky locations, and a second species to sandy locations. Such a species pair would have a checkerboard distribution that had absolutely nothing to do with competitive exclusion.

Null models in the context of ecological community development

Historically, some ecologists have considered each ecological community to be a tightly interdependent species group comprising a super organism (Clements, 1916) whereas others saw communities at particular sites to be far more coincidental (Gleason, 1926). Reality lies between these extremes but it is fair to say that biotic, abiotic, and entirely stochastic mechanisms interact and influence the development of biological communities. Null model analysis can reveal patterns that are more or less consistent with each of these mechanisms and suggest experiments that might reveal specific causal relationships. Competition leading to exclusive relationships among species pairs would yield a community with a checkerboard score (Diamond, 1975) in the right tail of the null distribution and would be consistent with an inhibition model of community development (Connell and Slatyer, 1977). The tolerance model of succession (Connell and Slatyer, 1977) might initially yield communities consistent with null communities but with increasing numbers of checkerboards as succession progresses and competitive exclusion intensifies; students could test this using Rey's (1981) defaunation/recolonization data (see "Fumigated Spartina" data sets on the WikiEducator site). Communities with fewer checkerboards than expected by chance appear in the left tail of the null distribution and this pattern would be consistent with the facilitation model of

community development (Connell and Slatyer, 1977).

CONCLUSIONS

The hands-on activity introduces the co-occurrence concept and provides students with a user-friendly path to understanding the null model approach to data exploration. Following the hands-on exercise with the computer-based null model activity will introduce students to powerful null model analysis tools used for research publications (Gotelli and McCabe, 2002). The activities provide entry points into a controversial and often contentious approach to data analysis that continues to be employed by community ecologists. The combined activities facilitate discussion of the value of non-experimental data sets and also the limits inherent in observational data exploration.

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The Use of *Kryptolebias marmoratus* Eggs as an Educational Tool for Embryology Education

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Abstract: Plastic embryological models lack the excitement of seeing real, live embryos. Chick embryos are often used to demonstrate embryological development and blood circulation to students but this necessitates the death of the organism. *Kryptolebias marmoratus* embryos are large and can be viewed by means of a light microscope without need to harm the organism. Eggs are easily obtained from captive fish; and are easy to display to students. Embryological features common to early human development are readily visible in the *K. marmoratus* embryos: early brain development, eye development, somites, limb buds, blood circulation and pigment cell migration. Embryos also twitch when exposed to light and the beating heart is readily viewable. Use of the embryos in a class room has proven rewarding, students marvel at observing embryological development and are more eager to consider the common embryology and evolution of chordates.

Key Words: *Kryptolebias*, embryos, gastrula, vitelline artery, melanophore, erythrophore, somites

INTRODUCTION

Kryptolebias marmoratus (Poey, 1880) are small hermaphrodite fish found in mangrove swamps along the shoreline of the Gulf of Mexico and the Caribbean (Taylor, 2012). These fish lay large, 2 mm diameter eggs (Huber, 2015) and are easy to care for in captivity where they will breed freely. The eggs are clear and the developing embryo can be easily observed by aid of a dissecting microscope, which make this fish an interesting and useful educational tool for use in both anatomy and embryology courses.

In spite of its self-fertilizing biology and relatively low genetic diversity (Tatarenkov et al., 2015), *K. marmoratus* remains phenotypically plastic. It survives in a wide range of water conditions, from soft acidic water to full strength sea water and can tolerate temperatures from 18 °C to 38 °C (Huber, 2015). It can survive long periods (days) immersed so long as it remains moist (Wright, 2012), and is often encountered in large numbers hiding above the water level, beneath bark and under logs in mangrove

swamps (Taylor, 2012). This hardiness facilitates uncomplicated captive maintenance. *K. marmoratus* reaches a maximum size of 75 mm (Huber, 2015) and requires little space per individual fish meaning large colonies can be maintained without the need for large aquaria. More interesting still is that these fish, having lived as self-fertilizing hermaphrodites for much of their lives, can change into fully functional males that are able to spawn with and fertilize the eggs of hermaphrodite fish. Environmental conditions (such as temperature stress) can stimulate the development of males from eggs (Turner et al., 2006).

As the large eggs develop and without killing the organism, students can use a dissecting microscope to observe gastrulation, the development of the neural tube, somites and the circulation of blood. The embryos twitch when exposed to light, which means they can be used to facilitate a discussion of motor system synapse formation.

A detailed study of *K. marmoratus* embryology has been published by Mourabit

et al. (2011) as well as a means to manipulate the embryos for microscopic studies (Mourabit & Kudoh, 2012). The current article discusses the basic care of *K. marmoratus* in the teaching lab and presents micrographs of observations made using a dissecting microscope.

METHODS

Acquisition of fish

Fish were obtained from hobbyists within the American Killifish Association (<http://www.aka.org>) but they are also available from research labs such as my own or others such as Dr. Ryan Early (University of Alabama, <http://rlearley.people.ua.edu/>).

Fish Maintenance

Fish used in these studies were maintained in accordance with the ethics standards of Northwestern College, Iowa, and the University of Cape Town, South Africa.

Fish are housed individually in 500 mL plastic snap-fast tubs half-filled with a 14 g/L salt solution. The tubs are floated in an aquarium maintained at 25 °C (Fig. 1 A) with a 12 hour per day light cycle. A small hole punched into the lid of each tub is used for ventilation and to feed the fish. The fish are fed a staple diet of *Artemia nauplii*. The water in the tub should be refreshed at least once a week. Salt insensitive aquarium plants, such as Java moss and Java fern, were grown with the fish to aid in maintaining water quality.

Collecting eggs

The fish spawn daily and will deposit their eggs on fish spawning mops made from acrylic yarn (Fig. 1 B and C). Spawns number from 1 to 5 eggs at a time. This species is reported to eat its own eggs so the mops need to be checked several times a day and the eggs removed for incubation. The eggs are carefully handled by hand and placed on damp cotton wool to incubate (Fig. 1D) or into a petri dish with 14 g/L salt solution. Infertile eggs will turn a murky white and should be removed when they became visible. The eggs develop at room

temperature (20–22 °C). To ensure a steady supply of eggs and to increase the probability of observing a specific developmental stage, several tubs of fish should be set up. Individual fish will take a break from spawning and these breaks are of unpredictable timing and duration.

Depending on incubation conditions and the strain used the fry hatched will hatch out between 20 and 40 days after the eggs are laid. The fry are large enough to eat *Artemia nauplii* on hatching and growth was rapid. The fry can be communally raised and then separated into individual tubs when adult. Fish raised together learn to tolerate each other but egg production is poor under such conditions. Once individual fish are separated into tubs of their own their territorial instincts dominate and the fish will not coexist with each other in the aquarium again.

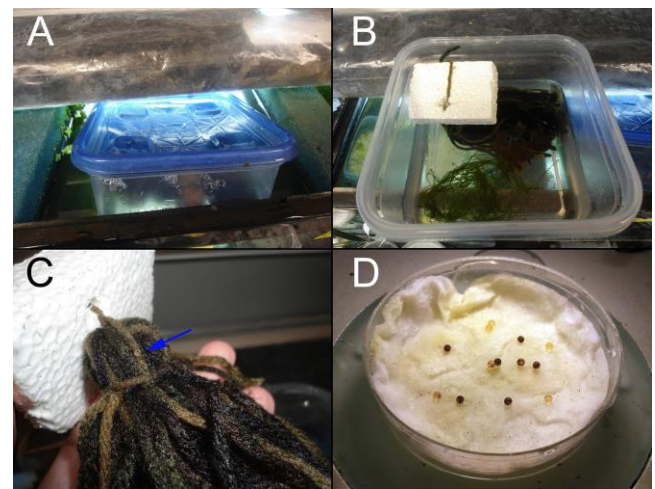


Figure 1: Captive spawning and maintenance of *Kryptolebias marmoratus*. A: Plastic tubs holding individual fish. The tubs are floated in a larger aquarium maintained at 25 °C and 14 g/L salinity. B: Fish and spawning mop in a holding tub. C: Freshly laid egg in spawning mop. D: Eggs in various stages of development incubating on damp circular cotton wool pads. Embryos are visible in the eggs.

Microscopy

A Zeiss Primo Star microscope with AxioCam ICc 1 camera and AxioVision SE64 Rel V 4.9.10 software was used to capture images of the embryos. The 4× objective was used for most images to

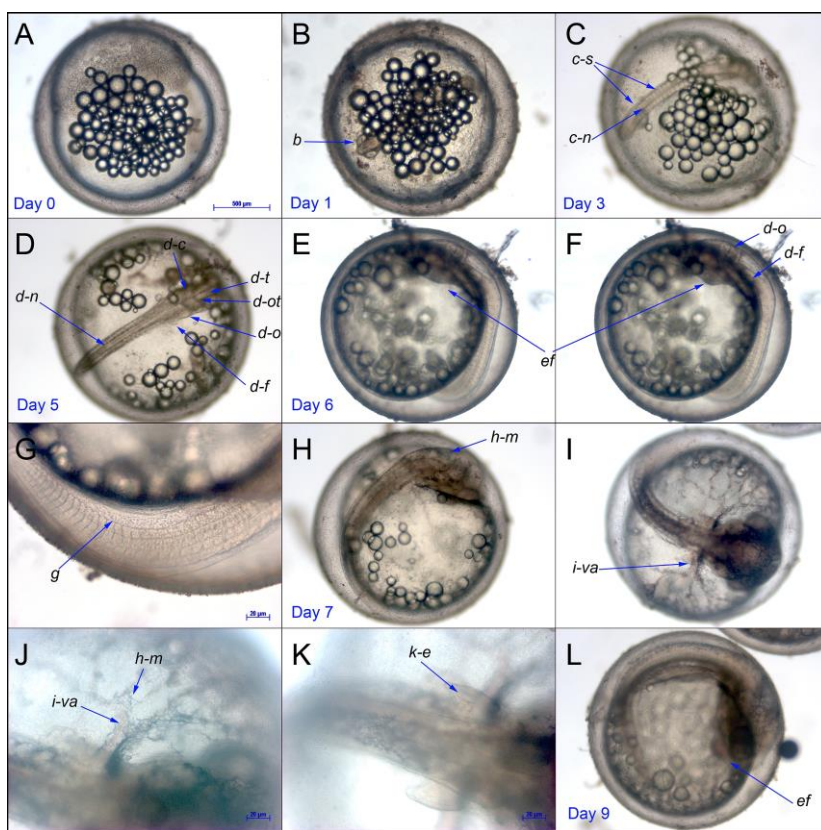


Figure 2: Developing embryos of *Kryptolebias marmoratus*. A: Day 0 embryo. Scale bar represents 500 μm . B: Day 1 embryo showing eye-buds (b) and brain development. C: Day 3 embryo showing somites (c-s) and notochord (c-n). D: Day 5 embryo showing nervous system structures (notochord, d-n; cerebellum, d-c; telencephalon, d-t; optic tectum, d-ot), otic vesicles (d-o) and fin buds (d-f). E-G: beating heart on Day 6 (ef); and unpigmented blood in the aorta (g). H-I: Day 7 embryo showing melanophores (h-m); and pigmented blood flowing through the vitelline artery (i-va). J & K: 10 \times objective images of pigmented blood in the vitelline artery (i-va) as well as melanophores migrating along the vitelline arteries (h-m) and erythrophores (k-e) on the developing pectoral fin. Scale bar represents 20 μm . L: Day 9 embryo with pigmented blood filled beating heart readily visible (ef).

simulate what can be observed using a regular bench dissecting microscope. The 10 \times objective was used for more detailed images.

Images were manipulated using Adobe Photoshop CS2. Individual images were pasted into an array and each image was manipulated using the image adjustment levels tool to set the white point for each image. Scale bars for each objective were calibrated using a stage calibration slide and then inserted into the published figure using Photoshop.

Use in a classroom

Eggs of day zero to day 9 were set out in the classroom in a 5 cm petri dish with enough water to cover the embryo. Dishes with eggs were positioned under a microscope for the students to view using a 4 \times objective.

Before viewing the embryos the students were shown images (Figure 2) and a brief explanation was given as to what they could observe in the eggs. Students were instructed to turn the microscope lamp off

after viewing to prevent overheating of the embryos. Human embryological models were set out for comparison as well as selected illustrations from textbooks including the student's required textbook. While asking students questions about what they had seen, the microscope was checked to make sure it was still positioned correctly or that the embryo hadn't moved.

RESULTS

The eggs of *K. marmoratus* develop internally for the first day (Koenig & Chasar, 1984) and are laid at the gastrula stage. The images shown in Fig. 2 are labeled based on the day of collection starting at Day 0. In Fig. 2A a Day 0 embryo is visible. A large cell mass (gastrula) is visible. Twenty-four hours later (Fig. 2B) the head has begun to form (arrow b) and eye-buds are visible along with the ventricles in the eyes. Brain development is also visible with the brain furrow clearly defined as a dark shadow between the eye-buds. Somites are obscured by the lipid droplets. On Day 3 (Fig. 2C) the somites (c-

s) and notochord (c-n) are easily observed. It is also possible to distinguish the fore-, mid- and hindbrains (not shown). By this age the heart is beating but is difficult to discern. There is no blood circulation.

By Day 5 it is possible to discern the optic tectum (d-ot, Fig. 2D) as well as the cerebellum (d-c) and telencephalon (d-t). The otic vesicles (d-o) and fin buds of the developing pectoral fins (d-f) are also observable. The lipid droplets are now more diffuse and do not obscure the embryo as much as before. By Day 6 the beating heart is easily observed by orientating the embryos in profile (ef, Fig. 2E–F) and the blood, still unpigmented, can be seen to flow in the aorta of the embryo when viewed under higher magnification (10× objective, Fig. 2G).

By Day 7 (Fig. 2H–K) melanophores can be observed along the head (H, h-m) as well as the vitelline blood vessels extending into the yolk sac (J, h-m) as well as erythrophores in the developing fins (K, k-e) and along the dorsal surface. The erythrocytes in the blood vessels (I, i-va) are now pigmented. At this stage of development, and later, the blood vessels and erythrocytes are most easily observed in the vitelline artery (J, i-va). Erythrophores are visible in the fin buds of the embryos (K, f-e). The erythrophores and melanophores have a similar dendritic morphology with the latter having much longer dendrites. By Day 9 the heart is red with pigmented erythrocytes (Fig. 2L, ef) and can be easily observed to beat when the embryo is observed in profile.

As the embryo develops the pigmentation increases and features such as those described above become harder to observe. Late in development, the beating heart and blood coursing through the vitelline arteries are still easily observed. The eye (iris, pupil, sclera) are observable in mature embryos.

From Day 3 onwards the tail of the fish can be seen to twitch. On Day 5 the embryo is responsive to light. When illuminated under the microscope the heart rate will

increase and the tail will twitch more regularly.

DISCUSSION

Eggs of *K. marmoratus* are large and easily observable using a dissecting microscope. The embryological features that are visible at 4× magnification are useful for the discussion and learning of important topics of embryological development such as blood circulation, brain development and body segmentation. The embryo is easily contrasted with human models to show evolutionary and functional similarities. The use of descriptive lecture, plastic models and the live embryos help the students to properly contextualize the sequence of embryonic development as well as the anatomical structures.

The idea for using *K. marmoratus* embryos came about as a means of avoiding the emotional disturbance experienced by medical students at observing chick embryos. Some students were upset by the idea that the chick was killed simply for observational purposes. Using the fish embryos avoids this ethical issue and needless killing of an organism. The embryos can be viewed without harm, and the eggs can go on to hatch.

The author has employed these embryos in classes for college students studying medicine (at the University of Cape Town) as well as biology, nursing and kinesiology anatomy (at Northwestern College, Iowa). The embryos have also been used in presentations for junior school children. Both college and junior school learners were excited to see the embryo twitch and its heartbeat.

The similarity between the fish embryo and early human embryos was apparent to the students. For many it was the first time they had seen a beating heart and they were awed to see the blood circulating. Amazement was expressed that the tiny embryo already had all the adult structures and that it would grow up to be a 75 mm fish. The speed of development also

impressed students. Tail flicks were observed by some students and was met with a sense of wonder. Many students were unable to observe the fin buds suggesting that instructors should be more explicit in pointing out the smaller structures in the pre-lab talk.

The demonstration of blood supply and the muscle twitching have served as useful starting points for the discussion of fetal development of the circulatory and nervous systems. The somites serve as a starting point for discussing segmentation in vertebrates, blood vessels and nerve development and how this relates to the sclerotome, myotome and dermatome.

The presence of multiple chromophores in this species of fish can facilitate a discussion in human pigmentation and the use of different pigments by different species. While it isn't obvious by observing the embryo a discussion can still be held as to the origin of melanophores and melanocytes from the neural tube and the similarity between melanocytes and nervous tissues. The migration of the melanophores of the fish along the blood vessels also serves as a starting point for discussion of the arteries as highways for the migration of various cell types and structures, such as nerves.

There is great potential for the use of these fish in behavioral, ecological and environmental experiments. Readers are encouraged to read the review by Taylor (2012). For instance, it has been observed that the more polluted the water the more time the fish will spend out of the water (Bruce Turner, Dept. of Biology, Virginia Tech, pers comm). It would not be difficult performing such an experiment in a classroom setting.

The fish are able to live in very small volumes of water. Prof Bruce Turner maintains his experimental fish in stackable finger bowls (approximately 300 mL when filled). This means that it is possible to house many fishes for classroom experiments in a small space. The small

water volume and living space do not constitute cruelty to this fish species, where in the wild they will often inhabit the burrows of crabs (Taylor, 2012). They can live for years in such small quarters without any sign of discomfort.

These fish will take most foods offered but because of the small volumes of water foods that might foul the water should be avoided. For this reason *Artemia nauplii* are used as a staple food. The fish are naturally amphibious (Pronko et al, 2013) and adventurous and without a secure lid on the tubs the fish will exit the tubs and aquarium to perish on the laboratory floor.

This small fish, with its ease of maintenance, is amenable to experimentation in a classroom setting and its large embryos are excellent vehicles for embryology teaching.

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Web-based Interactive Video Vignettes Create a Personalized Active Learning Classroom for Introducing Big Ideas in Introductory Biology

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Abstract: The typical “flipped classroom” delivers lecture material in video format to students outside of class in order to make space for active learning in class. But why give students passive material at all? We are developing a set of high-quality online educational materials that promote active, hands-on science learning to aid in teaching of core concepts for introductory biology at the college level. Interactive video vignettes (IVVs) incorporate evidence-based teaching strategies to address known areas of confusion for entering students. Each IVV includes a live-action scenario with undergraduates investigating a biological problem with a realistic experiment that users participate in. Through the course of each 10-20 minute video, users are required to make predictions, answer questions, collect data and draw conclusions. Branching and reflection of previous answers allows each user to have a personalized experience. Research into how students learn with these tools is being used to develop entire modules that will incorporate the IVV as a priming activity to be done as homework, along with suggested activities to be done in class that take the introduced concepts deeper and/or broader.

Keywords: Online learning, flipped classroom, student engagement, prediction

INTRODUCTION

Most members of the post-secondary biology education community are aware of the national calls for college biology education reform (Alberts, 2008; Woodin et al., 2010; Singer et al., 2012).

Undergraduates need to understand the “process of science, the interdisciplinary nature of the new biology, and how science is closely integrated within society. Students also should be competent in communication and collaboration, as well as have a certain level of quantitative competency, and a basic ability to understand and interpret data.” (AAAS, 2011). Educators should encourage critical thinking, focus on unifying concepts, de-emphasize rote memorization, and allow students to practice experimental design and analysis of data and scientific models (DiCarlo, 2006). This shift in emphasis necessitates the use of student-centered, interactive instructive “active-engagement” practices, which have been shown to be directly related to increased student learning gains (Knight & Wood, 2005; Armbruster et al., 2009; Smith et al.,

2009; Freeman et al., 2014). Some instructors may choose to convert their whole course into a “flipped classroom” or may choose a combination of different student-centered activities.

Unfortunately, despite best intentions, it is often difficult for an instructor to redesign an entire course to incorporate evidence-based pedagogies centered on student-centered activities. Plus, in an effort to increase depth of coverage, instructors may struggle to decide which of the plethora of topics and concepts to focus on, particularly in broad, foundational courses such as Introductory Biology. Without easy-to-incorporate research-based pedagogical tools, many instructors may abandon the idea of trying to create a more student-centered, active engagement classroom. In order to help instructors, we are developing a set of high-quality educational materials that promote active, hands-on science learning to aid in teaching of core concepts for introductory college-level biology. The materials will be packaged as Modules for Interactive Teaching or MINTs. Each

MINT will be grounded in an Interactive Video Vignette (IVV) that is completed online by students prior to class. Each vignette combines narration, dialogue, real world video segments, question-based branching and video analysis tools to enable students to master concepts or participate in data collection and/or analysis techniques in a hands-on manner. The video analysis methods can range from measuring positions or dimensions by clicking on a video frame, to data collection and analysis. Question-based branching enables a vignette to address a user's specific needs by sending the user to different pages based on the user's answer. The high quality nature of the IVV and the attention to dialogue and scenarios make the IVVs engaging and enjoyable for the typical undergraduate student.

While IVVs as learning tools for physics students have been described (Laws et al., 2015), there are no IVV or IVV-like resources for post-secondary biology education. The purpose of this manuscript is to describe the development of ten biology IVVs that are centered on the core concepts of *Evolution*, *Information Flow*, *Energy Transformation*, *Structure/Function relationships* and *Systems* as well as the process of science and interdisciplinary nature of biology as outlined in the AAAS/NSF Vision and Change Report (Woodin et al., 2010; AAAS, 2011). In order to create high quality IVVs a multidisciplinary group of individuals was recruited, with expertise in Biology Education Research (BER), curriculum/instructional design, IVV-based teaching tools, video production, software development, and assessment.

METHODS

Our IVVs are designed for first and second year college biology majors, but most are appropriate for non-majors biology courses and Advanced Placement high school classes. Each scenario incorporates undergraduate science students involved in

projects that are realistic and feasible for undergraduates. Each IVV is also aligned with one or two major biology concepts (AAAS, 2011) and centers around a “Big Idea” — an important biological principle that many undergraduate students struggle with. Table 1 provides a synopsis of each of the ten IVVs that have been produced thus far.

IVVs: Grounded in Education Research

IVVs incorporate lessons learned from education and cognitive research on how people learn. High quality IVVs are designed to promote “learning while doing,” engaging learners with real-world problems, providing “scaffolding” support, reflection on their own learning processes, and feedback and guidance as learners progress (Bransford, et al., 1999). IVVs use principles of cognitive learning theories such as elicit-confront-resolve and constructivism to support deep learning of core concepts in biology. Unlike many videos made for teaching biology, IVVs are live action, require active participation of users, and depict a real-life scenario that requires solving a biological problem. An important and unique feature of our vignettes is that they require students to make predictions and then compare their predictions to experimental results. This strategy may help create cognitive dissonance required to overcome incorrect knowledge, especially if experimental results disagree with the original prediction. Education research has shown that allowing students to predict results, invent models, or construct a formula before being given the “correct answer” is a powerful way to improve student learning. For example, students who created graphs to describe data sets from psychology experiments had increased learning when compared to peers who summarized a chapter on the same experiments (Schwartz & Bransford, 1998). Allowing students to invent a mathematical formula before instruction also resulted in learning gains compared with students who were simply told the formula beforehand

Table 1. A description of each IVV aligned with core biology concepts and big ideas. Full IVV synopses may be found at <http://ivv.rit.edu/bio>.

IVV Title	Vision and Change Core Concepts	Big idea
<i>How do you find a needle in a haystack?</i>	Evolution Information flow	Mutations exist prior to selection
<i>Why is my Phenol Red Yellow?</i>	Structure/Function Systems	Buffers regulate pH by absorbing and releasing protons
<i>Why didn't you write that down?</i>	Structure/Function	Osmosis is a specialized diffusion resulting from the presence of a semi-permeable membrane
<i>Marfamily</i>	Information Flow	Mechanism of genetic inheritance
<i>To Ferment or Not to Ferment: That is the Question</i>	Energy Transformation	Environmental conditions (O ₂) influence metabolic pathways
<i>Extra Credit Project</i>	Energy Transformation	Biosynthesis and cell growth are dependent on photosynthesis
<i>Whose graph is better?</i>	Systems	Populations exhibit variability due to abiotic influences
<i>Dead thing by a tree</i>	Systems Energy Transformation	The carbon link between decomposition and plants happens via gaseous carbon dioxide.
<i>Do you want salt with your eggs?*</i>	Systems	Populations exhibit variability due to genetic influences.
<i>Going green*</i>	Information Flow	Nonsense mutations affect protein expression but not transcription or replication.

* In production, available Spring 2017.

(Schwartz & Martin, 2004). Our own work demonstrated that having students participate in a constructivist model-building activity primed them for future learning of biology concepts related to information flow (Wright & Newman, 2011).

IVVs are designed for web delivery as out-of-class priming activities to prepare students for in-class discussion and problem solving. IVVs leverage practices that have been shown to be effective for online learning tools. For example, research comparing the utility of online learning pedagogies to traditional instruction found online tools that let users control their interactions, encourage reflection and increase interactivity enhance the online learning experience (Zhang et al., 2006; Means et al., 2010).

IVVs: User interactivity is a key component

Despite being high quality, the vast majority of online educational material is passive videos (e.g. blood cells moving through vasculature), animations of cellular

processes (e.g. DNA replication), structural animations (e.g. structure of a glucose molecule), or narrated tutorials (e.g. how X-ray crystallography works). These tools are helpful for demonstrating processes and reviewing essential concepts, but they typically do not involve the user in the process of science or resolving cognitive dissonance when confronted with actual data. While existing online tools have the potential to enhance learning, they are not interactive and none of them contain the combination of real-world problems, scaffolding, reflection, and feedback that IVVs do. For example, in *Whose Graph is Better*, the actor directly asks the user for feedback on a graph created from data collected during the IVV scenario (see Fig. 1). As in all IVVs, the page will not advance until the user has answered the posed question. Feedback from the user is requested numerous times during this IVV, and as the user progresses through the IVV the characters also progress in their

understanding of how to construct valid representations of their data.

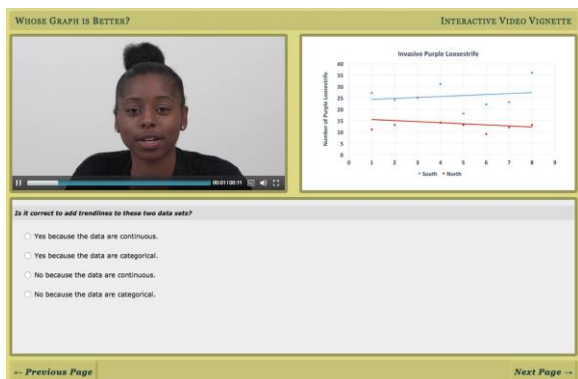


Fig. 1. A page from *Whose Graph is Better?* Here, the user is asked for feedback on a graph that was constructed by a character in the scenario.

Another feature of our IVVs is that all questions posed to the user are answered during the IVV. We did not want users puzzling about an answer choice or frustrated because a reasonable answer choice (in the eyes of a novice student) is marked as “incorrect”. In some cases the question posed to the user is answered on the very next page of the IVV. Prediction questions, however, are purposely not answered on the following page because the prediction question often anchors the upcoming experiment in the IVV. In the IVV *Extra Credit Project*, the user is asked to predict the shape of the growth curve if an algal culture is placed in a vessel containing only water and trace elements while being exposed to air and light. After the user has observed the experiment and analyzed the data in the IVV, the original prediction is brought back and the user is asked if his/her original prediction is supported by the data (see Fig. 2). This strategy gives rise to cognitive dissonance, as the user must reconcile their original conception with actual data. The user is also supported in their new realization through the dialogue and wrap-up scenes that conclude each IVV.

At the end of each IVV, the user is asked to reflect on what they learned and questions they have about the topic. Reflection is an essential criterion of constructivist teaching, believed to support learning by reinforcing

or transforming conceptual links in the student’s mind (Baviskar et al., 2009; Harvey et al., 2016). The reflection may also be formative feedback for the instructor allowing the instructor to determine which concepts were mastered and which require further instruction with their class.

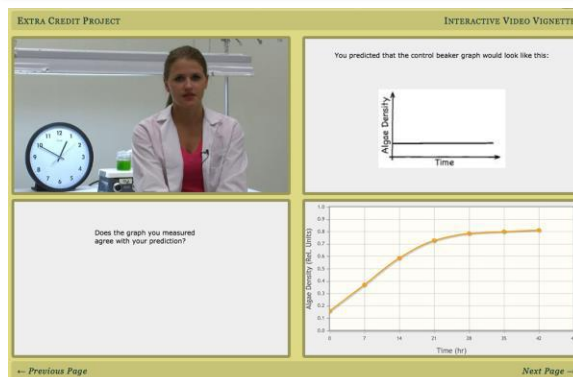


Fig. 2. A page from *Extra Credit Project*. Here, the user’s original prediction is brought back to them in juxtaposition with the actual experimental data.

IVVs use principles of Universal Instructional Design

In order to accommodate a wide range of undergraduate students, IVVs are constructed with the principle of Universal Instructional Design in mind. This principle suggests that any strategy that helps one population of students is likely to positively impact the whole class (Pliner & Johnson, 2004). We argue that Interactive Video Vignettes may be an important tool to reach many groups of biology learners. For example, the IVV scenarios and dialogue are meant to be accessible to students with little biology background. While the team did focus on challenging biology concepts, we purposely did not incorporate unnecessary technical and/or overly complicated language. Each IVV is close-captioned so that students who are Deaf or Hard-of-Hearing or English Language Learners can fully participate in the IVV experience. Each page of an IVV also gives the user the option to go back so students may review or re-watch pages as many times as they need to feel comfortable with the material.

Students, if they choose, may redo the entire IVV; there is no limit on the number of times an individual user can participate in an IVV.

Another consideration is the growing number of college students with learning disabilities, Autism Spectrum Disorder (ASD), Social Anxiety disorders or other diagnoses that may impact success in the college classroom. A recent report from the US Department of Education looking at enrollment at 2 and 4 year colleges found that 73% of all post-secondary institutions enroll students with hearing difficulties, 86% enroll students with specific learning disabilities, and 35% enroll students with speaking and/or language impairments (Raue & Lewis, 2011). Taking into account the increase in the past decade of persons diagnosed with ASD (Baio, 2014), colleges will most likely experience, if not already experiencing, an increase in the number of undergraduates with ASD. Students with ASD in post-secondary settings face a host of challenges, such as the struggle of how to be engaged and interact with others in the classroom. IVVs as learning tools allow users to privately experience interactivity and “active engagement” in the comfort of personal space, which may be beneficial for students with ASD, social anxiety, or extreme shyness. In addition to creating IVVs that are accessible to users of varying backgrounds, the team has made an effort to incorporate visually diverse actors to try and overcome issues related to exclusiveness and bias that are part of our current science culture (Xu, 2008; Strayhorn, 2010; Reyes, 2011).

Creation of the IVVs

Each IVV is more than just a story about biology. Because our IVVs incorporate prediction questions, experiments, data analyses activities, and real-world scenario/dialogue, we relied on a number of resources to inform construction of each IVV. We began with the five core Vision and Change concepts for undergraduate biology education (AAAS, 2011). We

reviewed the literature on the construction of biology concept inventories and reviewed the items in tools such as the Osmosis and Diffusion Conceptual Assessment (Fisher et al., 2011), the Introductory Molecular and Cell Biology Assessment (Shi et al., 2010), the Photosynthesis and Respiration Concept Assessment (Haslam & Treagust, 1987), the Genetics Concept Assessment (Smith et al., 2008), the Dominance Concept Inventory (Abraham et al., 2014), and the Conceptual Inventory of Natural Selection (Anderson et al., 2002). Many of these publications about biology concept inventory tools also illustrate common misconceptions or alternative conceptions held by biology students, which was useful during our process. Finally, three project leaders have extensive experience teaching a variety of college biology courses and laboratories (Introduction to Biology, Cell Biology, Molecular Biology, Microbiology, and Genetics), and were able to use these classroom experiences to help focus the IVVs on problematic concepts and incorrect ideas commonly held by students.

Once a central scenario is agreed upon, the IVV team designs, tests, and revises the central experiment that is featured in the IVV. The central scenario must be applicable to the “real world”, align with one of the Vision and Change core concepts, make sense with the central experiment in the IVV, and be accessible to potential student users from a variety of backgrounds. Because IVVs use live action, the team does not depend on computer animations or simulations for the central experiment. The experiment must be justified by the scenario and feasible for undergraduates to accomplish. For example, the scenario in the IVV *Why didn't you write that down?* begins when undergraduate lab partners realized no one in their group wrote down the glucose concentrations on their two bottles of growth media. Unable to make more, the students figure out a way to test the media using common laboratory equipment and determine which bottle

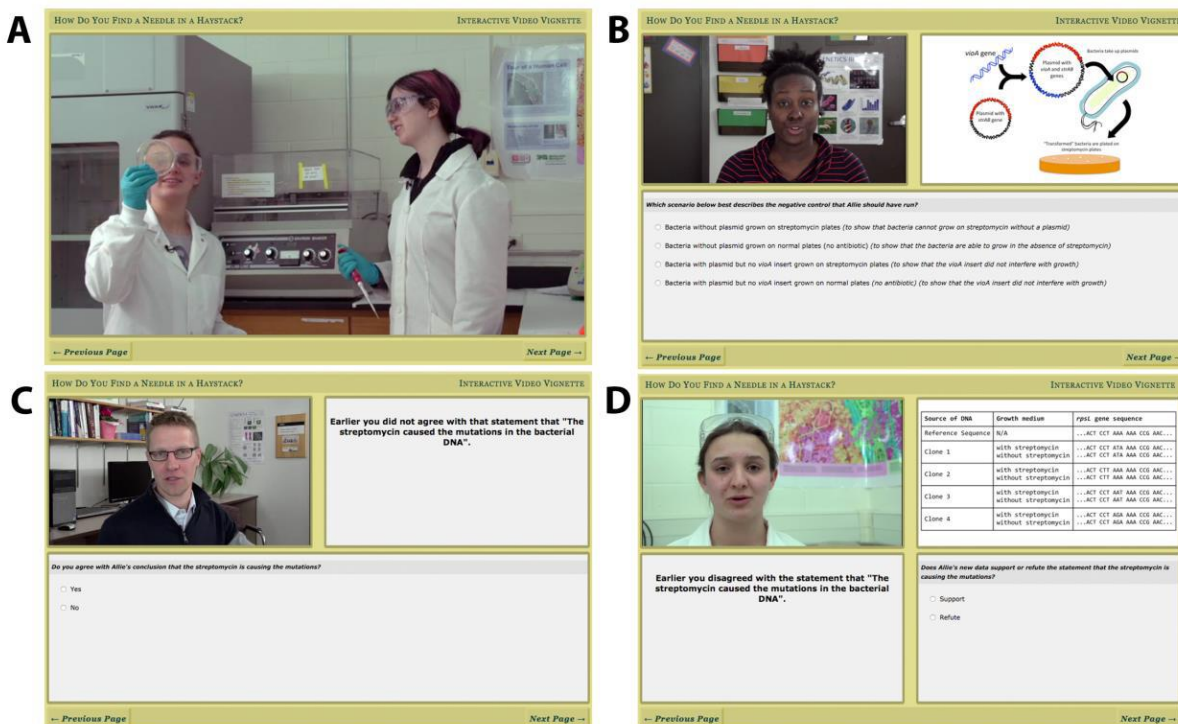


Fig. 3. Selected pages from *How Do You Find a Needle in a Haystack?* A) An undergraduate student, working on a research project, is excited to see that her bacterial transformation finally resulted in growth of a few clones on an antibiotic selection plate. Unfortunately her clones do not contain any plasmid DNA nor the gene of interest (they were just false positives, although she does not realize it yet). B) During a lab meeting the student explains her results and frustrations to her lab group. The post-doctoral fellow asks her about negative controls and the undergraduate student becomes confused. Here, the user is asked which negative control should have been used in the cloning and transformation experiment. C) The student does some research and learns about endogenous antibiotic resistance genes and mutations. During another lab meeting the two undergraduate students come to the incorrect conclusion, shared by many novice biology students, that the antibiotic in the media caused mutations in the bacterial DNA. Here, the user is asked whether they agree. D) The students set up a new experiment using replica plating and DNA sequencing of bacterial clones that have or have not been exposed to the antibiotic. The user is asked to analyze DNA sequence data and then is asked if the data supports or refutes the statement that antibiotic causes mutations. After further discussion with the lab group, the students come to the correct conclusions about random mutations that exist in a population and how antibiotic resistant populations become problematic due to overuse of antibiotics.

contained 5% vs 20% glucose. In another IVV, *Why is my Phenol Red Yellow?*, the student actors puzzle over the visible red-to-yellow color change that tissue culture media turns as mammalian tissue culture cells grow and age, which provides a logical transition for a discussion about pH indicators and chemical buffers. Later in the IVV the students design an experiment to test buffering capacities of each ingredient found in the growth media.

Once the team is satisfied with the scenario, the experiment, and the experimental results, the team creates the prediction questions and determines how the future user will be involved in the IVV. For example, in *How do you find a Needle in a Haystack?* the user must use the genetic

code to determine outcomes of various mutations documented by DNA sequencing. In *Whose Graph is Better?* the user helps the IVV actors go through a series of steps to figure out the best way to display analyzed data. At this point, the remainder of the dialogue is written and revised as necessary. Finally, the team creates a storyboard, recruits actors, and works with a motion picture science team to determine a location and schedule for the video shoot. Video shoots for all scenes for a single IVV takes an average of 2 working days.

Figures 3 and 4 illustrate selected pages and descriptions of two of the IVVs we have produced. Each IVV, on average, takes 10-20 minutes for the user to complete. Each IVV incorporates prediction questions that

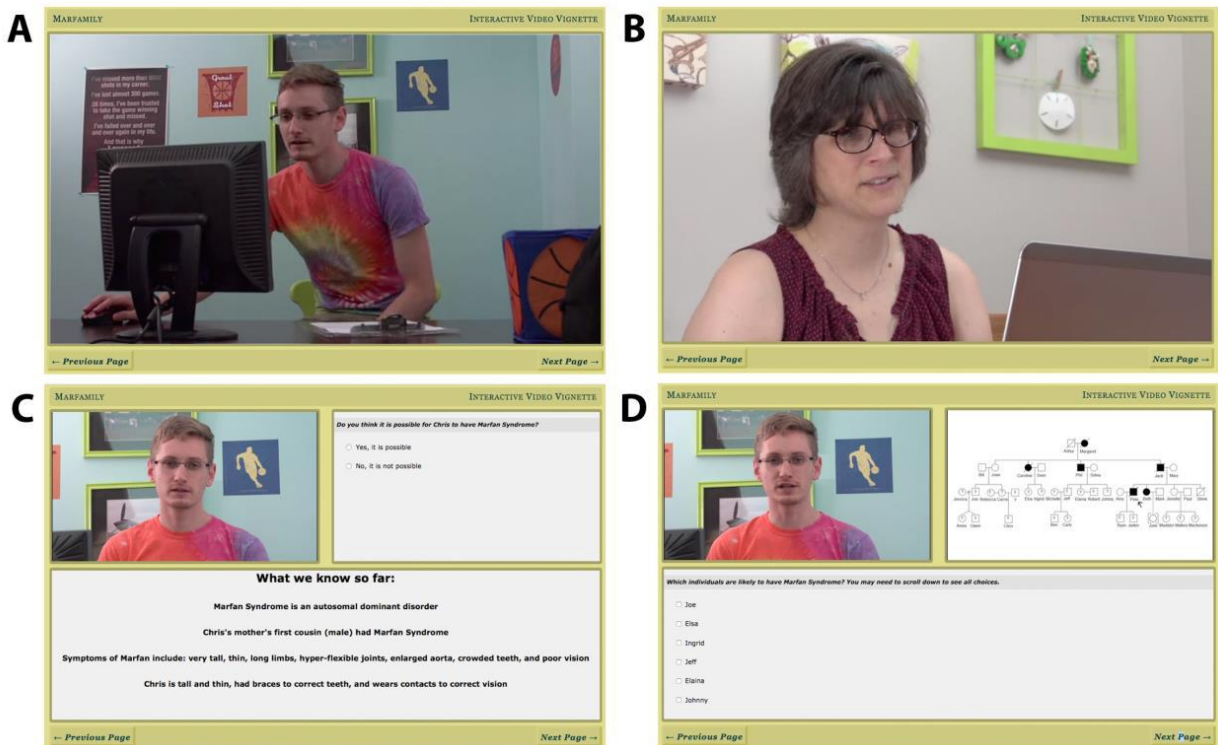


Fig. 4. Selected pages from *Marfamily*. A) While video-chatting with his Mother, a college student (Chris) learns that his Mom’s cousin has died, very unexpectedly. Tests revealed the cousin had Marfan Syndrome, which was surprising news to the family. B) During the video call, Chris and his mother learn about the basic genetics and clinical symptoms of Marfan Syndrome. The Mother has many questions such as “What is a gene?” and “What does dominance mean?” The user is invited to answer the questions to help learn about important genetics concepts. A branching feature is part of this IVV. The next page of the IVV is dependent on how the user answers the questions. C) The user learns that Marfan Syndrome is an autosomal dominant disorder and that individuals with Marfan syndrome are generally very tall with long flexible limbs, poor eyesight and crowded teeth. Unfortunately these symptoms describe many people in the family! Based on the available data, the user is asked to predict whether Chris (who is a tall basketball player) could have Marfan Syndrome. D) Through back and forth dialogue Chris and his Mom build a family tree and the user learns about proper pedigree construction. Physical and health characteristics are provided for each individual of the family, and the user is asked to determine which members of the family most likely have Marfan Syndrome. In the end, Chris, his Mom, and the user are relieved to learn that Chris could not have inherited Marfan Syndrome after all.

are often rooted in areas of documented confusion for biology students. For example, the IVV *How do you find a Needle in a Haystack?* is based on the prevalent misconception that organisms mutate/change/evolve in response to an environmental condition (Andrews et al., 2012). Students often do not realize or cannot articulate that random mutations are already present in a population. In *Marfamily* the user is asked to answer genetics questions that are known to be problematic for biology students such as, “What is meant by dominance?” The incorrect “distractor” choices are based on student misunderstandings that have been documented in the literature and/or observed

in actual college classrooms. For example, many students incorrectly think that “dominant” means “stronger” or “more common.” Knowledge of common misunderstandings or misconceptions allows the research team to incorporate believable distractors into each item (Towns, 2014). Prior to the development of the IVV *Whose Graph is Better?*, several college-level biology instructors were questioned about the types of mistakes that novice students often make when constructing graphical representations of data. The common mistakes were then incorporated into the IVV as a way to let the user think about and receive feedback on how to display quantitative data.

Table 2. Alignment of learning goals with novice ideas and IVV embedded-ideas from the IVV *Why is my Phenol Red Yellow?*

Novice Ideas	Ideas addressed in the IVV	Learning Goals of IVV: By the end of the IVV users should be able to...
Acids are defined by a pH < 7 Acids are compounds that “burn through” metal or other things	An acid is a proton (H+) donor	Identify the correct definition of an acid
Water and carbon dioxide do not react Water and carbon dioxide react to make glucose	When carbon dioxide (CO ₂) reacts with water (H ₂ O), carbonic acid (H ₂ CO ₃) is produced. The production of carbonic acid can lower the pH of a solution	Describe why release of carbon dioxide in an aqueous solution lowers the pH of that solution
Buffers are “magic boxes” that interact with acids and bases	Buffers protect against a decrease in pH of a solution by binding to free protons (H+) in the solution	Analyze experimental data to determine which chemical compound has buffering capabilities
Buffers exist to maintain homeostasis	Molecules such as amino acids have chemical structures that allow them to act as buffers	Correlate amino acid structure to function of buffer
Buffers “balance” pH	There is a limit to the quantity of protons that a buffer can bind to	Define how buffers act to regulate pH change

An important part of the IVV construction process was articulating the learning gains that are the desired outcome of each IVV. Along with learning gains, the IVV research team used the literature and classroom experience to identify novice ideas that students often hold about the subject. Table 2 illustrates the alignment of novice ideas and learning goals in the IVV entitled *Why is My Phenol Red Yellow?* In this case, the novice ideas are incorrect or incomplete ideas that beginning biology students often hold about acids, bases, chemical buffers, and interactions between carbon dioxide and water. Novice ideas were taken from the literature (Ross & Munby, 1991; Orgill & Sutherland, 2008) as well as our own experience working with undergraduate students. More advanced ideas discussed in the IVV and intended learning goals are also included in the table.

IVV Software and Video Production

Interactive Video Vignettes are web applications that are written in HTML5 and JavaScript. These technologies are compatible with a variety of devices such as laptops, desktops, and tablets. While the IVVs will play on smart phones, we do not

recommend using them due to limited screen size. The software team is currently developing a Java application called Vignette Studio so that, in the future, other instructors or developers may create their own IVVs (Laws et al., 2015). The application package will incorporate a drop-and-drag interface for users to easily add images, videos, and multiple-choice questions to particular pages of the vignette. The software will also allow developers to add branching multiple choice questions so that a user experiences a different page depending on which of the multiple-choice options are chosen.

After the videos for an IVV are shot, they go through several weeks of post-production. This includes video editing and creating the final web application. As described earlier, all IVVs are close-captioned so they are accessible and usable for hearing impaired users. Each IVV starts with an instruction page that includes a space for users to enter their name, and ends with a summary page that displays the user’s name, date, amount of time taken to complete the IVV, and their final reflection answers. The final page can be printed or

captured as a screenshot as proof to instructors that their students completed the assignment. During the research phase of the project, IVVs are being hosted on an internal server at RIT for student use. A public website (<http://ivv.rit.edu/bio>) containing full MINTs (links to IVVs and activities, full descriptions of the IVVs, learning goals, assessment resources, advice for instructors, etc.) is under development. A preliminary version of Vignette Studio software is available for download on Compadre (<http://www.compadre.org/IVV/studio.cfm>). The Compadre website has more details about the creation and use of IVVs.

FUTURE WORK

In order to determine IVV effectiveness, the team has created multiple-select assessment questions to address the intended learning objectives for each IVV. The multiple-select format assessment has the potential to more accurately characterize student mental models than forced choice or short answer questions (Couch et al., 2015; Newman et al., 2016). Deep analysis of the choices students make will help the team understand which parts of the IVVs are most effective and where incorrect student ideas still persist. Detailed analyses of these results allows us to refine the materials, to create appropriate assessments of learning, and to inform instructors of common areas of confusion that can be followed up through additional activities and discussions. These will be disseminated as MINTs: modules that not only include IVVs but also contain activities and ideas for instructors on how to implement the IVVs as integrated lessons from pre-homework through assessment. Our eventual goal is to have a set of materials that could be used to teach an entire introductory biology course, but which is also customizable for each instructor to pick and choose topics and materials.

The materials developed in this project will impact biology students across the

country, both directly (by providing them with tools to promote deep learning) and indirectly (by providing biology education researchers with new sources of data that will be used to improve education). Using research-based methods of development ensures the quality of the materials and maximizes their effectiveness. The investigation into student thinking is opening new avenues of research for future work, such as how students think about the relationship between genes and traits, or how students think about systems.

CONCLUSION

IVVs are a fun and informative way to introduce students to important biology concepts. To date we have piloted the use of the completed IVVs in several first-year biology courses at two institutions. Anywhere from one to seven IVVs have been assigned in one-semester courses, and students had positive reactions to them. We aim to have production of remaining IVVs complete in spring 2017, followed by publication of entire learning modules (MINTs). The MINTs will include not just IVVs but complete lesson plans for major concepts covered in an introductory biology course. MINTs will provide instructor-focused notes, best practices for incorporation of the IVV with in-class materials, and evidence for their effectiveness. The combination of IVVs and MINTs will provide introductory biology instructors high quality, ready to use, student-centered learning tools to aid in teaching of core biological concepts.

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PERSPECTIVES

Understanding by Design: Mentored Implementation of Backward Design Methodology at the University Level

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Abstract: Unless sought out by the individual, University and College faculty typically receive minimal, if any, pedagogical training as part of their career development. This perspectives essay first introduces pedagogical training for instructors in higher education by comparing it to the training required for primary and secondary school educators. Using this as a backdrop, it then discusses the stated goals of higher education and contrasts these goals with the type of preparation that is traditionally offered to future faculty during graduate and post-doctoral training, with emphasis given to the general lack of teaching mentorship and practical application. It goes on to describe a future faculty member's journey of seeking out higher education pedagogical training, and the process of implementing a student-centered course based on a backward design model, highlighting the importance of experienced mentorship in this process. This essay concludes with a reflection on the backward design process as a whole, the imagined difference in the quality of curriculum and implementation in the absence of mentorship, as well as a discussion about how this experience speaks to pedagogical preparation of higher education teachers in the United States.

Key words: Backward design, pedagogy, teacher preparation

INTRODUCTION

Post-secondary education in the United States serves over 20 million students per year, with students enrolling in over 1,700 two-year and 2,900 four-year colleges and universities (Snyder and Dillow, 2013). Although scope, structure, mode of delivery, and graduation requirements can vary significantly across institutions, the type of training they offer can be divided into two major categories: technical training and liberal education. Technical training prepares students to work as experts in specific careers, focusing on skills and knowledge directly related to the field of study. Liberal education, on the other hand, focuses on a two-pronged approach exposing students to broad knowledge of many disciplines as well as deep knowledge within a particular field of study, with the intention of developing flexible communication, intellectual, and decision-making skills. Where technical training is

career-focused, liberal education could be considered to be life-focused (Miller, 2012).

The pathway to college starts with primary and secondary school instruction. The vast majority of primary and secondary school educators in the United States are required to participate in extensive pedagogical training through classroom instruction and mentored teaching before assuming responsibility as lead instructor. In 46 of 50 states, initial or temporary certification to teach requires student teaching experience, with 23 states requiring additional mentoring of new teachers in the classroom for periods of one to three years (compiled from data at www.teach.org/teaching-certification). In contrast, post-secondary educators in the U.S., whether employed at teaching-based or research-focused institutions, receive little pedagogical training and have no required certification standards. Instead, faculty are generally hired based on advanced degree status, often with research acumen

demonstrated by publications and extramural funding leading the hiring decisions.

While content knowledge is essential, and extramural funding might be necessary, these qualifications do little to prepare a faculty member to contribute to the *a priori* goal of all colleges and universities: educating their students. Although many institutions of higher learning require evidence of teaching ability prior to hiring a new faculty member, the fact remains that pedagogical training is hard to come by and even discouraged by some faculty mentors because of the required time away, diverted from the primary research focus. Cumulatively, these observations indicate that unless a graduate student or post-doctoral fellow explicitly seeks a Discipline Based Education Research or Integrative Graduate Education and Research Traineeship Program placement, the training that would prepare these individuals for future faculty positions is lacking. This highlights a disconnect between the stated goals of a higher education institute (student learning) and the metrics for placement into faculty jobs (advanced research-based degree and extramural funding). A few universities and foundations have attempted to bridge this gap through optional certification programs in subjects such as community college teaching (e.g., California State University Dominguez Hills), college teaching (e.g., Michigan State University, University of Minnesota), or specialty teaching, such as online instruction (e.g., The Sloan Consortium). Even where such programs exist, however, and certainly in their absence, graduate students and post-doctoral fellows generally must be explicitly encouraged to participate in pedagogical training during their career preparation.

The following essay discusses the apparent misalignment between higher education learning goals and future faculty training, and continues with a reflection on the shared experience of a postdoctoral fellow who sought out mentoring in

pedagogical practice, specifically backward design (Wiggins and McTighe, 2011), from a scholar in discipline-based education research. This shared experience produced tangible benefits for both the fellow and the mentor, and led to collective revisiting and rethinking of the real world complexity of applying backward design theory to produce and demonstrate effective instruction. In addition, this partnership led to a reflection on what it means to teach at an institute of higher education, as well as a discussion about how this experience speaks to pedagogical preparation of higher education teachers in the United States.

HIGHER EDUCATION LEARNING GOALS

Although education has by definition been a focus of higher education institutions from their inception, the explicit articulation of institutional goals for student learning is a relatively new activity. The goals that cut across the many departments and programs that make up a university generally reflect the overarching institutional purpose. Technical training institutions focus on mastery of skills for career success, while liberal education institutions—whether larger research universities or smaller liberal arts colleges—help students become informed citizens and versatile thinkers (Jaredleza et al., 2013; http://www.aacu.org/leap/What_is_liberal_education.cfm).

What this means in practice is, unfortunately, difficult to pinpoint. What skills must students obtain during their college tenure for a university to give its ‘stamp of approval’ upon graduation? Do post-secondary institutions have explicit mechanisms in place for measuring improvement and progress towards meeting goals? Although some organizations are moving towards institutional level assessment metrics, such as the American Association of Colleges and Universities (AAC&U) through its VALUE and other rubrics (Rhodes and Finley, 2013), most

colleges and universities rely on measurement of achievement within the classroom. Therefore, it generally falls on faculty members to design courses with an eye towards learning goals, defined both within the classroom as well as aligned with the broader goals of a liberal arts education. In an effort to achieve this, a faculty member must implement aligned and effective teaching methodologies and develop assessments of student learning that allow accurate tracking of student progress toward mastery of knowledge and skills associated with a liberal arts education.

Given this, the training that most graduate students or post-doctoral fellows receive does not bring about the development of efficacious teaching strategies and accurate measurement of student achievement. New classroom instructors face a wide range of bewildering questions. Where do I begin if I need to design a course? How do I determine the focus of content for a given course? How do I get the training I need to be an effective teacher? How do I know if my students are actually thinking and not just memorizing? What the heck is a learning goal, anyway?

PEDAGOGICAL TRAINING FOR HIGHER EDUCATION

The lack of pedagogical training that faculty members receive becomes apparent when a new instructor has to teach a course for the first time. This lack of training becomes even more apparent when one has to design a course from scratch. Many instructors will solicit colleagues for existing syllabi, lectures, etc., using previously developed material to guide lecture content, while feverishly writing exams in the days preceding the students' summative assessment. Although this approach may save preparation time upfront, it often results in an increased workload during the semester because these "inherited" courses often lack explicit direction. Delivering another's content does little to enhance the quality of instruction

over time because there is little to no self-reflection on the part of the new instructor to consider whether they agree with existing course structure, learning goals, course alignment or enrichment of the student experience with modern pedagogical methodology. But when such little training is part of professional development preceding a faculty position, often there is little choice.

Luckily, at many universities, faculty members are offered teaching seminars and workshops to (finally) introduce some pedagogically based practices in their courses. Many of these sessions are open to graduate students and post-doctoral fellows should their mentors allow the time away from research. These training sessions can range from one-hour seminars spattered across a semester to intensive workshops lasting a few days (For an example of such a schedule see:

<http://create4stem.msu.edu/event/upcoming.>) These sessions can be overwhelming with foreign terminology and complex ideas. Terms like "aligned assessments," "Bloom's Revised Taxonomy," "student-centered teaching" and "backward design" are often introduced, described, and reinforced throughout. Depending on the length of a session, time may be allotted to the participants to work through a newly introduced methodology. During her first multi-day pedagogical science seminar as a postdoctoral fellow, the first author was exposed to a number of pedagogical concepts that supported the practice and implementation of a backward design approach to course design. Below, the pedagogical practices are identified and related directly to the theory of backward design.

Identify your learning goals

Prior training for most new faculty has likely been at the level of a teaching assistant, a role in which one rarely instructs beyond a laboratory setting and has little, if any, input into course design or content. Discussion regarding how courses emerge,

dialogue concerning theory, or discourse related to best practice in design are new when it finally comes time to teach. As a result, faculty members (old and new) tend to teach the content that has traditionally fallen within the purview of a given course, without considering the current purpose of teaching specific content, the student demographic (e.g. majors vs. non-majors), or the alignment of the content with the overall course, department or institutional goals.

Identifying learning goals turns the aforementioned “inheritance” practice on its head, and says that, prior to the start of any instruction, broader learning goals or competencies should be identified to give the course direction. Everything else within the course, including formative and summative assessments and specific course content, should be developed after course goals are identified, and align with and reinforce those broad learning goals. This notion of alignment implicitly introduces a theory of curriculum and lesson design that is not always talked about directly: backward design. The idea in itself is simple: identify what you want your students to learn before you fill in the specifics of the course, and then backfill assessments and lessons, ensuring they are aligned with the explicitly stated learning goals. If not aligned, that subject should be removed or goals revised to include the essential topic. When done well, backward design eliminates most of the questions that arise when trying to create fair exams, as well as the difficulty of breaking away from traditional lecture content in the “inherited” course practice. Although backward design sounds elementary and intuitive, applying it is far more difficult in practice, and not commonly implemented at institutes of higher learning.

Aligning your assessments with learning goals.

This pedagogical principle again falls in line with the theory of backward design, and states that formative and summative

assessments should be aligned with the broad course learning goals and should evaluate progress toward and mastery of those goals, respectively. If assessments are further aligned with programmatic and even institutional learning goals, universities can then look to student achievement in the classroom as a measure of progress for the overall institutional mission.

Working up to higher levels of Bloom’s Revised Taxonomy in curriculum.

Following a backward design model, once the learning goals are set and the assessments are created, the instructor turns attention toward identifying the specific course content and designing individual lessons.

Recognizing the importance of incorporating higher Bloom’s levels (Anderson and Krathwohl, 2001) encourages instructors to move away from a traditional lecture model, commonly associated with higher education classrooms. This approach challenges faculty members to design learning activities that allow their students to move beyond recall, providing an opportunity to apply course content to problem solving, evaluating primary literature or problem sets, and potentially creating problems, experiments, or models on their own. As researchers we recognize the value of thinking beyond simple concepts and place high value on new ideas, models, and innovations. As higher educators, we should place the same value on implementing instructional techniques that work up to higher Bloom’s levels to develop those critical thinking skills in our students, whether students are budding scientists or aspiring informed citizens.

Implementing active learning in curriculum.

This practice goes hand-in-hand with achieving higher Bloom’s levels. Regardless of how an individual might feel about the buzz surrounding “active learning,” the principle is well founded and, when applied effectively, has been shown to

increase student achievement (e.g., Haak et al., 2011). The idea is, again, a simple one—move away from lecturing to allow students the opportunity to take an active role in their own learning. This may be achieved by creating student-centered learning activities that reinforce course content, such as open-ended lab experiments, case-studies, analyzing data sets, etc.

When approaching course development using a backward design model, each of these modern pedagogical approaches lends itself to holistic course development. Although presented here simplistically, the actual implementation of backward design, however, can certainly present a variety of challenges.

PRACTICAL APPLICATION

Much like any transition from the classroom to the real world, the practical application of backward design is far more intensive than the backward design models presented in books and workshops. To illustrate this, we present our own personal perspectives of what it was like to collaborate on backward designing a course on Brain and Behavior. In this process, the first author engaged in the detailed development of goals, assessments, and curriculum, while the second author acted as a sounding board during semi-weekly meetings. In all, the backward design process for this course took roughly six months.

A new instructor’s perspective—the first author.

I had learned a bit about backward design in seminars during my graduate and postdoctoral training and was very excited about the opportunity to apply this method to my introductory, non-majors 200 level Brain and Behavior course. I had learned that backward design was an efficient strategy for creating a course in which the learning goals, content and assessments were well aligned, and that it allowed for the planned incorporation of active learning strategies. However, when I sat down to

actually develop my course, I wasn’t sure where to begin. Backward design instructs that course goals should be identified before assessments are created and the syllabus is planned, but without identifying the content of the course, I wasn’t sure how to identify course learning goals. It was clear that if I wanted to develop a course using backward design, I was going to need help.

Fortunately, I was lucky enough to know a senior faculty member who had practical experience with backward design and, more importantly, was willing to help me work through this process during my first course development.

I became aware of the work of my co-author via a STEM education email blast soliciting interest in a potential course offering the upcoming semester. As directed by the solicitation, I emailed her directly, expressing my interest in her course with an additional request to discuss discipline-based education research and backward design methodologies. Our first meeting established the dynamic of all our future encounters: casual, yet focused. We would meet, chat about life and move on to discuss teaching and progress toward our goal. I would be given my ‘assignment’, leave, do my homework and come back for the next step or revision. This process worked because we each did what we said we would do and, as a result of the demonstrated commitment on both of our parts, this partnership and its final product (a backward designed Brain and Behavior course) were a success.

The process of backward designing Brain and Behavior was far more iterative than I ever imagined prior to actually doing it. During the preparatory semester preceding instruction, my first assignment was to put away the text, previous syllabus, and notes, and then outline everything someone who took an introductory Brain and Behavior course should be able to do by the end of the semester. Next, I was to identify the themes that emerged from all of these elements. Through this process, I was actually

identifying the course learning goals. After the course goals were defined, I outlined the content and formative assessments and, for each component, identified the targeted cognitive domain(s) of Bloom's Revised Taxonomy (Anderson and Krathwohl, 2001). As I developed the outline, I would revisit my overall course goals, checking for alignment and revising the outline repeatedly. I soon realized that it was very easy to get lost in the detail and incorporate components that were beyond the scope of the overarching course goals. But this 'deviant' behavior turned out to be an essential lesson in the practice of backward design: it is a cyclical, dynamic and adaptive process.

Once the outline of goals and aligned assessments was completed, it was time to shape the syllabus and develop the specific course content. Just as with the outline, it was necessary to continually revisit my course goals and assessments to ensure that the content I was including (lectures and learning activities) could be mapped onto my overarching course goals.

When the semester for instruction arrived, I began instruction by explicitly identifying the course learning goals to my students and over the instructional semester, I also pinpointed how specific course content mapped onto the overall course goals, always bringing the specifics back to the bigger picture. Throughout this process, it was fascinating to see not only the evolution of the course, beginning with basic principles and building to analysis and creation, but more importantly the progression of the students' understanding and ability.

The iterative nature of the design process continued during the semester of instruction in simple ways: revising lessons and class period learning goals, tweaking activities based on what was actually covered and student feedback, refining exams to reflect emphasis, etc. As the course progressed, I realized I had done all of the hard work during the preparative semester. I was not

frantically creating exams or scrambling for direction. My goals were outlined, assessments developed and activities designed. I knew where I was headed, where I wanted to bring my students, and most importantly how I planned to get them there.

An experienced instructor's perspective—the second author.

Although I had been teaching at the college level for almost fifteen years when this collaboration began, I had never been presented with a new instructor asking to be mentored through the entire backward design method. This was at first a daunting task, and I wondered if I really had enough understanding of backward design to guide someone through the process. My personal introduction to backward design was informal, and arose from my interest in discipline-based education research.

Although without a formal mentor, I learned through seeking out workshops, articles, books, and websites that provided suggestions for best practices in course design. My use of backward design approaches was mostly trial and error; I estimate that it took about a decade of my own practice before I became confident in my knowledge of backward design. More formally, I am in a position where I provide guidance for faculty in development of assessments that are aligned with course objectives. Although backward design figured prominently in my own career, taking responsibility for someone else's professional development is another thing entirely. I ultimately decided that mentoring a new instructor through the curriculum design process is much like mentoring in research, with similar needs for direction, innovation, independence, and review.

The process began with simple discussion of backward design—what it is, how goals are identified and clarified, the role played by assessment, and how curriculum should reflect goals and align with assessments. The limitations of backward design immediately became

obvious in this process. For example, courses sit in larger programmatic and institutional contexts. Although designing courses from learning goals alone would be ideal, course content must often reflect values and culture. That is, some content simply must be included because the community at large expects specific topic coverage. In the case of the Brain and Behavior course, I was intrigued to see which concepts were absolutely necessary from a community norms perspective as well as where student learning goals could drive the content.

The back-and-forth nature of our mentor-mentee interactions provided invaluable opportunity to return repeatedly to discussion of the nature of assessment and instruction. The first assessments designed by my co-author focused more closely on “what should be taught” rather than “what should be learned.” Through numerous meetings and discussions, assessments were transformed from a reflection of teaching practice to sources of evidence that could be used to inform instruction and evaluate student learning. Most exciting, these assessments were designed, and re-designed, to provide mechanisms for both reporting outcomes to students (i.e., grades) and conducting research on student learning. This research on student learning provides the instructor with data that can be used in course redesign, as well as data that can be published with appropriate human subjects approval.

Of course, by the time the goals and assessments had been thoroughly developed, the content that needed to be covered was obvious. Although my home discipline sits far afield from the content of the Brain and Behavior course, I could easily see how the goals, assessments, and course lectures and activities fit together to meet both overarching course goals and specific content goals. I thoroughly enjoyed hearing about the progress of the course as my co-author began teaching. In fact, in many ways, watching a new instructor evolve into

someone who is truly practiced in backward design turned out to be one of my favorite experiences as an academic. The academy spends precious little time developing faculty as scholarly teachers and this experience has encouraged me to more formally introduce backward design to the scholars engaged in research within my lab. After all, many of my own research students may find themselves in my co-author’s shoes, developing their own courses.

REFLECTION

Much as in research, a big difference exists in teaching between learning about something and actually doing it. For first-time instructors, working through the backward design process can be involved and challenging, often frustrating and deflating, and certainly time consuming and overwhelming. Despite all of these aspects, backward design is a superb curriculum model and has the potential to generate courses with direction and purpose that would otherwise be missing. In our experience, backward design produces curriculum that can be easily executed: the entire course is laid out through careful design of goals and assessments, leaving only the relatively simple task of filling in the content that aligns with the learning goals.

Without backward design as a curriculum model, the Brain and Behavior course discussed here would have been dramatically different for both the instructor and, by default, the students. This difference arises simply because the course could easily have been directionless, no more than an amalgamation of concepts garnered from years of prior coursework. Similarly, the process of engaging in backward design would have been different without an experienced faculty mentor assisting in the process. Certainly, having a trained eye scrutinize the course development, especially during its inception, provided needed confidence to the new instructor that the process was being done correctly, as

well as redirection when needed. It is also entirely possible that the backward design process would have been abandoned completely without this mentoring. The first author would likely have fallen back on a syllabus provided by a previous instructor as the guide to building the course, filling in content based on the “subject” of a given day in the existing syllabus or chapter of the course textbook, and then writing an exam that cannibalized lecture content. There may have been little thought put into how cohesively the course concepts fit together, nor to whether the material tested on the exams was actually what was important for students in the course to know and apply.

This experience raises a larger issue of pedagogical training and practical teaching experience. Both authors have been truly lucky to have had mentors—in college, graduate school, as postdoctoral fellows, and as new instructors—that support pedagogical training as a necessary component of professional development for academics. This component of training requires time away from the lab to participate in teaching workshops and seminars, and to practice these pedagogical skills in the classroom. It is the sum of these experiences that provides the knowledge and maturity needed to be successful as a university instructor. As any graduate student or post-doctoral fellow can tell you, training and mentorship in scientific research are the foundations upon which new scientific minds are developed. Future faculty members and new instructors need commensurate training and mentorship in teaching. Sadly, these are rare commodities.

The experience described in this Perspective suggests that a mentored approach to training in teaching could be just as effective as the mentored approach taken in the laboratory. Incentivizing senior faculty to participate in such mentorship, perhaps by offering course load credits in exchange for mentorship, as a component of doctoral and/or post-doctoral training could go a long way towards addressing the

discrepancies that exist between how we train future faculty, how future faculty are evaluated, and the value we place on efficacy in undergraduate education. In short, by presenting the tangible benefits of this mentored experience, we would encourage deeper discussion around what it means to teach scientists to become teachers themselves.

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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*.

Color figures: When color is involved in a figure, it should be encoded as RGB and the resolution should be 300 dpi. Manuscripts that include color figures accepted for the May issue (online only) will appear in color at no charge to the author(s). For color reproduction in the December issue (print and online), there will be a page charge of \$300. Author(s) will be notified of the costs and will have the option of either delaying publication until the May issue or paying the page charge. There is no fee for color in an image used on the cover of *Bioscene*.

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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