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Online Learning in Biology: An Investigation into Designing Online Learning Resources

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Online Learning in Biology: An Investigation into Designing Online Learning Resources

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by

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ABSTRACT

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As technology continues to advance, many instructors are incorporating online activities into their courses. While online learning has several benefits, there is still debate on how instructors can best develop and utilize these resources in their classroom. This study is split into two smaller projects that both aim to provide further insights on how to develop online activities that target undergraduate biology students. The first project revealed that elaborative feedback in a phylogenetic activity was more useful for students who had some exposure to phylogenetics prior to completing the activity. The results of the second project revealed that the appearance of two simulations' user interfaces does not have a significant effect on learning outcomes. However, many students responded that these simulations did increase their understanding of the concepts, indicating simulations can play an important role in the biology classroom.

DEDICATION

I dedicate this work to my parents, George and Janet Ford. They have always been my biggest fans, and I would never have been able to get where I am today without them.

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CHAPTER 1

INTRODUCTION

Evolution has been described as the unifying theme of biology, and instructors have recently been urged to incorporate evolution throughout their curricula. Unfortunately, many concepts in evolution are difficult to demonstrate in a traditional classroom due to time, space, and budget constraints. However, numerous online resources have been developed in the past several years that have the potential to change how instructors approach evolutionary education. Prior to the adoption of these resources instructors should consider their educational and technological merits, and take an evidence-based approach to developing future online resources.

Importance of Evolution Education

Evolution has historically been limited to just a few chapters in a textbook many classes may not even cover. However, professionals in every field of biology regularly rely on evolutionary principles to inform their research. It is also can be used to demonstrate the nature of science and help students learn more about the scientific method. This is beneficial even for students who do not plan to continue into a career in biology as they will use the scientific method in their day-to-day lives (Olson 2012). As Borgerding et al. (2015) stated “Evolution is the cornerstone of modern biology,” and it is therefore imperative that all students receive at least a basic introduction to evolution.

Several papers have gone into more detail and listed phylogenetics as one of the key concepts of evolution (Meisel 2010; Halverson 2011). Phylogenetics is the study of evolutionary relationships among organisms and how these relationships can inform us about evolutionary processes. These relationships can be visualized using tree-based diagrams, and the ability to read and communicate the information found within a phylogeny has been termed “tree thinking” (Baum & Smith 2012).

Tree thinking is a skill that both students and members of the general public need to have. Media coverage of evolution often targets topics that are informed by phylogenetics, such as speciation and evolutionary relationships (Meir et al. 2007). Many museums have started using phylogenies within their displays. In addition, there are also numerous practical applications of phylogenetics, in fields from public health to agriculture to forensic sciences. Regardless of a students’ future career goals, it is imperative they have a correct understanding of phylogenetics (Novick et al. 2014).

Problems Facing Evolution Education

Despite strong support from the majority of biologists, the inclusion of evolution in biology education still faces some major issues. Many high school teachers hold a negative view of evolution and do not believe it has a place in high schools possibly due to teachers’ limited understanding of evolution and/or their religious views (Borgerding 2015). Borgerding also stated that students’ prior beliefs may not be properly addressed in class, and if evolution conflicts with these beliefs students will not accept its validity (Borgerding 2015). Whatever the cause, many students are leaving high school with a limited understanding of evolution (Olson 2012).

Similar to other concepts in evolution, students and even practicing biologists often have misconceptions about phylogenetics. Among the biology curricula that do include evolution, microevolution is often emphasized, preventing students from getting an adequate instruction on macroevolutionary topics such as phylogenetics, deep time, extinction, or speciation (Meisel 2010). Unfortunately teachers are often unable to address their students' misconceptions about phylogenetics because of the limited time they have to focus on macroevolution (Novick et al. 2014). Research also shows that teachers have misconceptions about evolution, and these can be passed to their students as "taught-and-learned misconceptions" (Yates 2014). Whatever the cause, students often leave biology classes with numerous misconceptions about evolutionary topics.

Overview of Online Learning Activities

The term "e-learning" can be used whenever an electronic device (such as the Internet or even a phone) is used in education (Faghih 2013). There are several ways that e-learning can be used, including presenting content and communicating course scheduling or online group-based activities (Mahdizadeh 2008). Instead of attempting to tackle all possible uses of e-learning, this thesis will focus on how instructors and developers can present content most effectively in online (Internet based) activities. In particular it will look at instructional design components of a summative assessment and the visual aspects of a simulation. Simulations model real-life scenarios and typically have variables students can manipulate that affect the final outcome (Merchant 2014).

Many online activities are designed to promote open learning in which students have more control over their learning. These types of activities typically allow the student to complete an assignment when and where he/she chooses and removes the time demands associated with in-class assignments (Cotton & Gresty 2006).

There is substantial research that supports the use of online learning. López-Pérez et al. (2013) found that students who completed a set of online activities had better final grades than those who did not. They concluded that students had more time with online material which helped them learn how to apply their knowledge to novel scenarios. Chen (2010) found significant positive correlations between college student use of e-learning and their higher-order thinking skills, particularly among freshman students.

Despite the popularity of using various forms of technology in education, there is still significant debate about its merits. There is a continuum of beliefs, ranging from being extremely dubious about its relative merits all the way to supporting it wholeheartedly. Furthermore, some researchers have found that many resources are effective, but only for very specific classrooms with certain instructors (Underwood 2004). As Underwood (2004) pointed out: “Islands of excellence exist, in conjunction with huge oceans of poor practice.” Therefore it is crucial that instructors develop new e-learning resources using evidence-based practices.

Development of Online Activities

Instructional Design

Instructional design refers to how a resource is developed to help students achieve a particular learning goal. Instructional design models often include learning objectives and a related assessment to determine to what degree these objectives are met. Additionally instructional design models also include teaching methods that can be used to meet these objectives (Martin 2011).

Instructors use Bloom’s taxonomy to determine the level of cognitive complexity questions or tasks require. There are six levels ranging from knowledge to evaluation with each successive level increasing the cognitive skill required (Figure 1.1). Items classified at the lowest level (knowledge) require students to recall information, while items at the highest level (evaluation) often have students evaluate research and/or data on its relative worth. Each level builds on the levels before it, so students able to answer application-level questions on population genetics should also be able to answer comprehension-level questions on population genetics (Crowe et al. 2008).

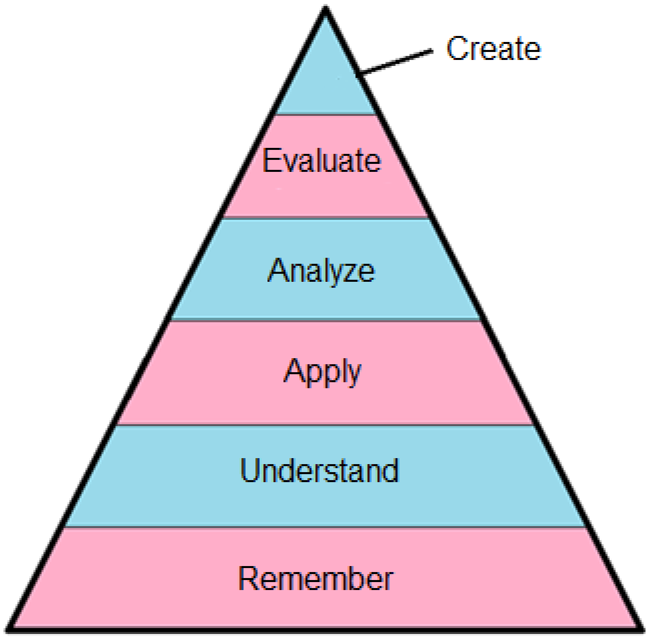

Figure 1.1 Bloom's taxonomy (drawn using Crowe 2008).

Using a variety of criteria, such as Bloom's taxonomy and usability, Foster et al. (2014) evaluated 42 online health science modules. During the primary evaluation, they found the majority of modules had knowledge- and comprehension-level questions, but fewer than 20% had questions above the analysis level. They acknowledge in their discussion that it is very difficult to quantify higher-order thinking in e-learning. Additionally, the authors believe that many of the modules might be used primarily to introduce students to content and thus lower level cognitive skills are appropriate (Foster et al. 2014).

Stephenson (2008) compared students' abilities to answer questions at different Bloom levels after they completed a traditional lecture, an interactive virtual lecture, and an e-lecture. Despite there being no significant differences in the overall performance of students, there were significant performance differences at the varying Bloom levels. Students who took online lectures performed significantly better on comprehension questions than students in traditional lectures. However, students in the traditional lecture significantly outperformed the online groups at all other Bloom levels (Stephenson 2008).

In addition to Bloom's taxonomy, activity developers should also consider how to promote inquiry. Inquiry-based learning can be used to help improve student performance academically and their attitudes towards science (D'Costa and Schluester 2008). Cunningham et al. (2006) developed an interactive online activity on gel electrophoresis and found the majority of students who completed it felt they were actively engaged in the experiment and that it made them ask additional questions about the outcomes of the experiment.

Herron (1971) described four levels of inquiry, summarized in Table 1.1. Activities at the confirmation level require students to follow a prescribed procedure in order to arrive at a solution known to instructors and students. Structured-inquiry is similar but students do not know what the solution is prior to completing the activity and have to use data and prior knowledge to describe the activity's outcome (D'Costa and Scluester 2013).

In guided-inquiry activities, students are expected to determine appropriate methods and analyses to answer a question or problem posed by the instructor. As each student might follow different methods the results of guided-inquiry activities are typically not known. Finally, open-inquiry activities involve students posing their own questions and designing an experiment to answer them. Similar to guided-inquiry activities, the results will vary among students (D'Costa and Scluester 2013).

Table 1.1 Summary of Herron's Levels of Inquiry

Level	Question generated by	Methods generated by	Solution generated by
Confirmation	Teacher	Teacher	Teachers
Structured	Teacher	Teacher	Students
Guided	Teacher	Student	Students
Open	Student	Student	Students

Inquiry-based learning is associated with critical thinking and improved academic performance. However, it can still be difficult for instructors to successfully incorporate inquiry into their curriculum. As D'Costa and Scluester (2013) noted, inquiry-based assignments often require more preparation time and increased supervision during the activity. In addition, even with guidelines (e.g., Table 1.1), instructors vary in their definitions and views of what inquiry is, making a true evaluation of inquiry-based learning extremely difficult (Cooper 2016).

To address this problem, instructors should focus less on trying to bring inquiry into their classroom and more on providing students the opportunity to engage in science inquiry practices (Cooper 2016). The Next Generation Science Standards (NGSS) includes eight science practices and describes what students should be able to do at each grade level. NGSS also purposely avoids using the word "inquiry" to describe these practices in an effort to ensure that instructors understand students' need to use both their inquiry skills *and* their content knowledge together. Many of these skills, such as analyzing and interpreting data and engaging in an argument from evidence (National Research Council 2012), are used naturally when learning phylogenetics.

Finally, the decision about the type of feedback (if any) students receive can have a significant effect on learning outcomes. Feedback provides students with an evaluation of how their current knowledge stacks up to the knowledge they are expected to have (Butler 2013). Feedback is not only important for providing additional information for students, but also serves as a method to help students develop different skills. However, there is still much to learn about how to provide appropriate feedback. There is an ongoing debate on whether feedback should be provided immediately or delayed; it appears this decision may vary based on the teacher's goals. Another significant debate is what kind of information should be included in an online feedback message (Tsai et al. 2015).

The simplest level of feedback is simply stating the correct answer. However, there is still substantial debate about how complex any additional feedback should be. Many studies have found that elaborative feedback (feedback that includes the correct answer and additional information) does not result in higher learning gains, as compared to only giving the correct answer (Butler et al. 2012). However, the questions students received feedback in these studies are often repeated on the post-test, meaning extra information is not necessary to do well on the post-test. Butler et al. (2012) found that elaborative feedback can be useful when post-test questions are different from the initial questions that served as the basis for feedback. They believed this result reflected that elaborative feedback allowed students to learn how to apply their knowledge to new situations. Therefore, elaborative feedback might be more beneficial than correct answer feedback in promoting student understanding of concepts.

Technical Aspects

Even if an online resource effectively incorporates instructional design components (e.g., Bloom's taxonomy, inquiry, and feedback), if users do not enjoy or find the resource useful, it will essentially be useless. Of particular interest to this research are two technical aspects that contribute to the overall user experience: the user interface and overall usability of the resource.

There are two parts of a user interface (UI): 1) a database that stores information (sometimes referred to as the back interface) and 2) what the user sees and can manipulate to gain access to the information (also known as the front interface; Thompson 2014). Well-designed UI's are intuitive and allow the user to achieve their goals reliably and consistently (Isaias et al. 2014).

The degree to which a user(s) can have a productive interaction with an online resource is referred to as the "usability". The usability of an online resource can be evaluated by looking at aspects such as its navigability and learnability. The usability of a resource can be very influential to the future behavior and willingness of a user to utilize of a particular resource (Isaias et al. 2014).

The effectiveness of these two aspects can be improved by incorporating the multimedia design principles outlined by Mayer and Moreno (2002). Many researchers have studied how animations affect learning, and overall it seems students learn better when animations are included simultaneous with any written/verbal instructions.

However, it is important for instructional designers to minimize material that is not directly pertinent to the tasks included in the resource. Overly complicated UI's may result in users paying too much attention to the "special effects" and not enough to the pertinent information (Mayer and Moreno 2002).

Statement of the Problem

Many evolution instructors struggle to find effective resources they can use to improve student knowledge of evolutionary topics (Friedrichsen et al. 2016). Online resources can be one way to begin to meet this need, but additional research is needed on how to develop effective online resources. While both of the studies described in this thesis provide additional resources for evolution instructors to use, they also evaluated the impact of individual factors of the resource on student performance.

The first study focused primarily on the instructional design of online activities. The importance of incorporating multiple levels of inquiry and Bloom's taxonomy have already been well-studied (see Foster et al. 2012, Stephenson 2008, Cunningham et al. 2006). However, there have been relatively few studies examining the role of feedback in an online resource at multiple levels of learners. The first study examined the effect of two types of feedback (correct-answer and elaborative) on content knowledge of novice and intermediate students. While not a focus of this study, it also incorporated many of the technical aspects (modern graphics, multimedia design principles) described above.

The second study focused on examining the effect of the user interface's appearance. Virtual Biology Lab (VBL) simulations are designed to allow students to design and conduct independent experiments on multiple ecology and evolution topics. While all of the original simulations are still available, new versions of selected simulations have been updated with more modern user interface. This allowed us to compare how the appearance of the user interface affects content knowledge and students' opinions of VBL.

Objectives

The objectives of this study are as follows:

- Develop an online activity on phylogenetics to be made available at no cost to users.
- Examine the impact of elaborative feedback versus correct-answer feedback on student performance in undergraduate biology courses.
- Examine the impact the user interface has on content understanding and self-efficacy among undergraduate students enrolled in an introductory biology course.

Hypotheses

- Elaborative feedback will improve student performance among introductory biology students and upper level evolution students.
- Students will indicate a preference for the updated user interface and will perform higher on follow-up quizzes due to an increased usability of the simulations.

CHAPTER 2

THEORETICAL FRAMEWORK

In education, a research study's theoretical framework is one of its most important qualities, and serves as a guide for the study itself. Therefore, the framework a researcher chooses (such as constructivism or post-positivism) is one of the first decisions that should be made before a study commences (Grant and Osanloo 2014). Therefore the researcher needs to select one that best reflects his/her own views and beliefs.

Following are summaries of common theoretical frameworks for educational research, including constructivism/interpretivism, post-positivism, and critical theory. As the current study is concerned the development and evaluation of an online activity, a brief discussion of how researchers from each framework views distance education (DE) is included.

Post-Positivism

Post-positivism evolved from the positivist movement, which was based on the belief that research studies should have a logical basis and empirical results. Positivists also believed that studies following the scientific method are freed from any biases caused by the researcher's culture or other influences (Treagust et al. 2014). Beginning in the second half of the 1900's this movement was modified into what is now known as post-positivism. A major motivation for the shift away from positivism was that many researchers believed that any conclusions drawn from a study's results must be affected by the social context in which the study was done. This means that there could be multiple “right” assumptions from the same data, not just one correct assumption and several wrong ones (Ryan 2006).

The following four characteristics of post-positivist research are adapted from Ryan (2006):

- Research can take a variety of forms, not just laboratory experiments
- Theory and practice are intertwined and influence each other.
- The motivation of the researcher plays a role in the study itself and will influence each step of the study. Before a researcher begins to develop a study, he/she needs to reflect on their place in the world and how their background will affect their interpretation of “facts.”
- The goal is to not only collect and analyze data, but to use that data to inform practices. Many of the founders of the post-positivist movement stated that researchers need to research how the research will benefit the study population (Devers 1999).

Most post-positivist research is designed so that results demonstrate a correlational or, preferably, a causal relationship between a teaching strategy and student performance. Therefore, most post-positivist research studies use experimental designs that allow for comparison between two or more groups. They also attempt to control for as many variables as possible so researchers can see not only what whether or not an intervention works but *why* it works. Post-positivist studies range from intervention studies involving a few classes to international studies (Treagust et al. 2014).

Post-positivism is particularly suited to studies focused on how students learn content from online activities and/or courses. Many DE researchers adapt existing technologies to accommodate their goals. This may result in a larger emphasis placed on technology rather than the educational value of the activity or course. Heinecke (2001) believed that how distance educators utilize technology is heavily influenced by their own beliefs. There are no well-defined guidelines for how to use technology in DE, so development of DE must rely on existing frameworks (Heinecke 2001).

Courses developed using post-positivist principles will have several features in common---1) content is selected by an expert in that area, 2) teaching strategies are teacher centered (independent activities, lectures, etc.), and 3) student learning is assessed through an objective assessment. The activity/course is considered effective if a student reaches a particular goal (such as a grade), and the learning progression is highly linear and directed. Because DE is aimed to reach large numbers of students from a variety of backgrounds, it makes sense to construct activities/courses that include these features. However, because these efforts may focus on transmitting content knowledge to a large audience, there may be little emphasis on developing the students' higher order cognitive skills (Heinecke 2001).

Constructivism/Interpretivism

According to constructivism, true learning requires the students to take a more active role in their education. Students approach new material using constructs built on their prior knowledge. For learning to take place, students have to modify their constructs as they receive new information or are exposed to new experiences. Modifying constructs can be a time consuming activity, and students need time and a strong support system to succeed. Constructivism is the foundation of many inquiry-based teaching methods and is gaining prominence in today's research (Hartle et al. 2012). For the purpose of this thesis, constructivism and interpretivism will be considered interchangeable, following Heinecke et al. (2001).

Hartle et al. (2012) listed four criteria that can be used to evaluate to what degree a particular activity fulfills constructivist ideals. The first criteria is that the activity requires students to engage with their prior knowledge, and allows the instructor to gauge students' current abilities. This can be accomplished by engaging students in demonstrations and/or discussions, or having students draw concept maps that reflect their current knowledge. The second criteria is that the activity causes cognitive dissonance, forcing students to question their current constructs. Using the knowledge they gained in the first step, instructors can pose problems to their students that target their misconceptions (Hartle et al. 2012).

The third criteria states that students have to be able to apply the new knowledge they receive. One of the best methods to meet this criteria is to give assessments to students that target higher levels of Bloom's taxonomy and/or allow the students to test out their new hypotheses. The most important component of this step is feedback. Students need to receive feedback on their modified constructs in order to be prepared for more advanced material. The final criteria is that students need to reflect on their learning (metacognition). By the end of an activity, students should be able to explain how the activity will influence their overall learning (Hartle et al. 2012).

Courses and activities following this framework are often built around a "core" of information all students receive, but individual students/groups can investigate different aspects of this core. Instructors often become facilitators for discussions and/or expert support for student research and presentations. Therefore learning goals/objectives are often flexible, and there are several directions the course/activity can go. Technology is often viewed as an additional resource instructors can use to promote interaction among students as well as between students and instructors. Some researchers want the full interactive capabilities of technology to be utilized so that students can connect with the larger professional community of the particular subject (Heinecke 2001). For example, students can Skype with professionals in a particular subject to get a firsthand glimpse about what they do on a daily basis.

Critical Theory

Similar to post-positivists, supporters of critical theory believe that a person's ideas and ideals are influenced by social interactions, but critical theorists also believe power is never equally distributed among the parties involved in social interactions. Critical theory research is typically focused on uncovering how these interactions are affected by the distribution of power (Treagust et al. 2014).

Critical theory research often focuses on assisting socially marginalized groups. They believe that even though research is advertised as being impartial, it often serves as a tool to elevate one group over another. Many of their research projects examine why females and minority groups are not more active in STEM fields. The researchers work with the faculty and students in at-risk schools to encourage underrepresented groups to become more involved in STEM activities (Treagust et al. 2014). Finally, critical theorists want to make learners aware of their individual situations in order to give them more control over their education (Heinecke et al. 2001).

Critical theory research is known for being highly subjective. Many critical theorists believe that listening to and collecting students' stories will provide important insight about problems minorities face. They do not put a large emphasis on empirical data as they feel it will often be viewed through the lens of the social narrative in question. As such, researchers are often transparent with their own beliefs and values to alleviate accusations of bias (Treagust et al. 2014).

Critical theorists believe that traditional forms of DE do not adequately meet the needs of many minority student groups. In response, many DE resources designed using critical theory aim to arm students with the knowledge they need to advance themselves in society and/or change society, such as through project-based learning or other community involvement programs. Unfortunately using critical theory in DE is largely understudied, so further discussion is not practical for this thesis (Heinecke et al. 2001).

Conclusion

Post-positivism was the primary theoretical framework that guided this study. This framework is particularly useful when a researcher is trying to determine what makes a particular learning activity effective. In this study the primary focus was to determine how the appearance and feedback of online activities can affect student learning. Additionally, during the development of the activity, elements of constructivism were used to allow students the opportunity to practice what they learned instead of simple recall.

CHAPTER 3

THE EFFECT OF ELABORATIVE FEEDBACK ON STUDENT PERFORMANCE

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Abstract

Phylogenetics is often described as the foundation of evolution (and by extension, biology itself), but many students and professional biologists struggle with tree thinking. One possible remedy for this problem is utilizing online learning activities. There is ample evidence that online activities can be effective learning tools for students across multiple fields and ability levels. However, how the different aspects of an activity (Bloom levels, appearance, etc.) impact student learning is still largely under-examined. Of particular interest for this study is how explanatory feedback affects student knowledge of phylogenetics. To test the effectiveness of explanatory feedback, two versions of the same activity were developed, one with correct answer feedback while the other had explanatory feedback. Students enrolled in two undergraduate biology classes were randomly assigned one of the two activity versions to complete. Pre- and post-test scores were used to calculate learning gains to determine differences between students who received explanatory feedback compared to those who received correct answer feedback. The type of feedback students received did not significantly affect their learning gain or performance on the post-test among students enrolled in the same class. However, advanced students who received explanatory feedback performed significantly better than novice students. Results from this study contribute to the body of research on online activity development as well as inform how online learning can help students gain a deeper understanding of phylogenetics.

Introduction

Phylogenetics is the study of the evolutionary relationships among different groups of organisms, and can be used to examine relationships among populations or any groups, all the way to domains (Baum and Smith 2012). It is one of the most important concepts in evolution, yet many students and even professional biologists have trouble understanding how to interpret evolutionary trees, also known as phylogenies (Meisel 2010). Phylogenetics is used across multiple biological disciplines, so it is imperative that educators have tools that can be used to further their students' understanding of this important field.

While there have been several in-class activities designed for phylogenetics, students can use online resources outside of class to further their knowledge. . Online activities are often designed to promote open learning in which students complete assignments when and where they choose, and can spend as much time as they deem necessary to complete. It is theorized that this results in a deeper understanding of the material. Cotton and Gresty (2006) pointed out that this is not always the case, and called for additional research into the development and use of online resources as educational tools.

Recently, researchers have begun to look at how the type of feedback provided to students affects their overall performance. Feedback can take several forms, but of particular interest to this study is the efficacy of correct-answer and elaborative feedback. Correct-answer feedback shows the student the correct answer but does not give any additional information. In general, it is agreed that providing the correct answer is the minimum feedback that should be given. Elaborative feedback, however, provides students with additional information beyond the correct answer (Butler et al. 2012). For an example of elaborative feedback, please see Figure 3.4.

However, as Butler and his colleagues noted, elaborative feedback itself takes several different forms. Two of the most common types are explanatory feedback, in which the student is provided with an explanation of why an answer choice is right or wrong. A related type is restudy feedback in which students get a refresher on information they learned previously (Butler et al. 2012). While feedback can be very general (such as guiding students to additional resources), feedback that is specific to the question and/or response is the most effective and results in higher student performance (Shute 2008).

The main purpose of this study was to develop an open-access online activity on phylogenetics targeted at undergraduate students. The development phase also allowed us to compare the effectiveness of the two major types of feedback: correct-answer and elaborative.

Methods and Materials

This study was completed in two main phases: activity development and evaluation of the activity itself, and assessment of correct-answer and elaborative feedback. The two phases briefly overlapped during a preliminary testing phase that allowed us to identify and remedy issues that arose in both the activity and the experimental design.

Development of the activity

Two versions of the activity were developed using the same information and questions, but one version only had elaborative feedback while the other had correct-answer feedback only (e.g., see Figure 3.4).

The activity is divided into two modules: a review and an assessment module. The review module covers basic information about phylogenetics, such as the major features of trees and the history of phylogenetics. The assessment module has ten questions split between two sections. The activity is designed to be conditionally released within a learning management system so students have to complete the review module before they are allowed access to the assessment module. This helps increase the likelihood of students knowing important vocabulary and tree-reading skills before they are expected to demonstrate their understanding of more complex skills (Hobbs et al. 2013). At the end of the assessment module there is a certificate students submit to their instructor as verification that they completed the activity. In addition, this certificate has the students' answers, and instructors can use this information to identify those questions students found difficult.

The review module contains a "map" (Figure 3.1) students can use to explore the different features of a phylogeny (indicated by stars), such as nodes and taxa. As they visit each feature, the star will lighten to indicate they have visited that feature already. Students have to visit every feature and the two links on the left side before they can begin the assessment module. They may visit the features in any order and revisit them as many times as they wish. The link at the bottom left ("Go to Activity Home") will only appear after every page has been visited.

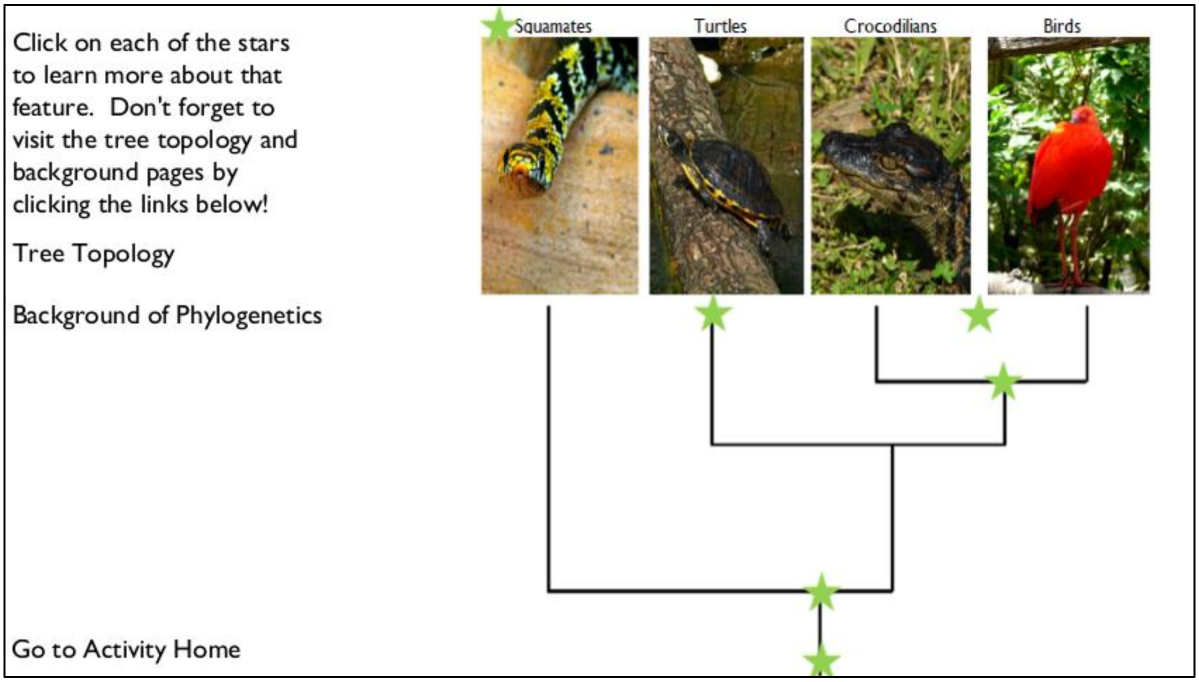

Figure 3.1. Review module navigation screen of activity

When a star is clicked, the student will be taken to a notebook page (Figure 3.2) that has basic information about that topic as well as phylogenies to help learners visualize the information. The phylogeny in Figure 3.1 is used on most pages and was designed using pictures taken by the author. Depending on the topic, the phylogeny may be modified (as in Figure 3.2) to help students visualize information contained in the text. Any additional phylogenies were taken from Wikimedia Commons to prevent copyright infringement issues. Once they are ready to go to the next feature, students can click on the arrow to go back to the navigation screen. To prevent students from clicking the arrow immediately, it is designed to remain invisible for fifteen seconds.

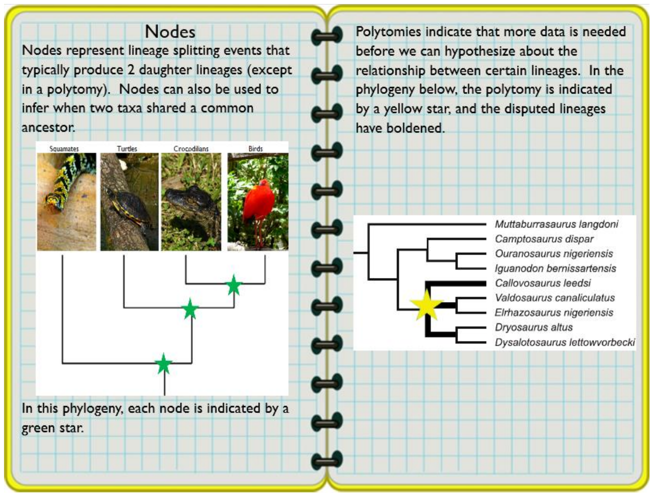

Figure 3.2. Example of review module screen demonstrating how the review information is presented and how phylogenies are incorporated.

The second module is composed of two sections with five questions each. The first section is focused on reviewing the basic features of a phylogeny while the second section concentrates on the basics of tree building. There is a mixture of short answer and multiple choice questions to minimize the amount of guessing from students. Because previous studies revealed that students differ in how they approach questions in various formats (Graff 2003), the mixture of questions forms minimizes how a student's ability to answer particular types of question affects their score. As mentioned in their review of health science modules, Foster et al. (2014) found most of the high-quality modules contained multiple levels of Bloom's taxonomy. In this application, the levels of Bloom's taxonomy vary between the two sections, with higher levels being incorporated in the second section (see Appendix A).

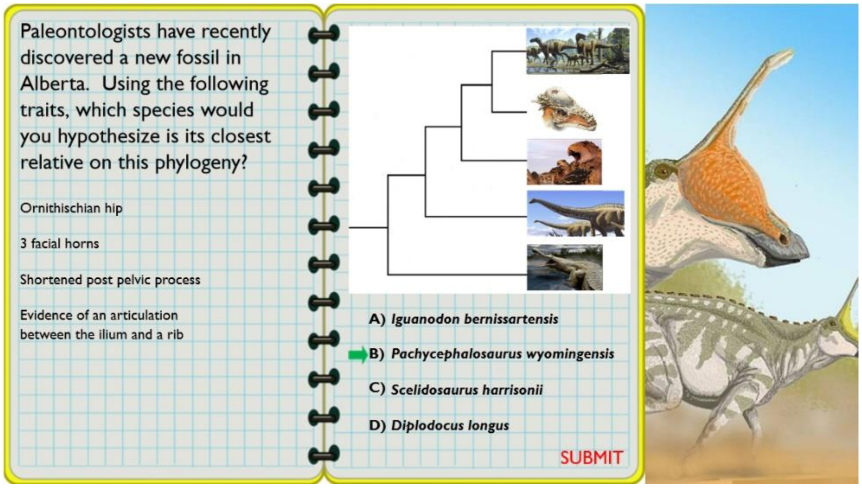

Figure 3.3. Example of how questions are presented in this activity. Each page contains one question and subsequent feedback.

Each question has a red submit button that appears after certain conditions have been met (such as clicking on a choice for multiple choice questions). When students click this button, two actions occur: 1) their answer is locked in and transferred to the certificate (see below), and 2) they get instant feedback that contains a brief explanation of the correct answer (Figure 3.4). Five seconds after submitting their answer, a green arrow appears in the bottom right hand corner of the screen for students to click to progress to the next question.

At the end of the activity, students receive a certificate (with their answers) that can be save to their computers. This certificate can be submitted to their instructors as verification of completion. Instructors are encouraged to review these certificates to identify concepts students are struggling with prior to assigning a higher-stakes assessment.

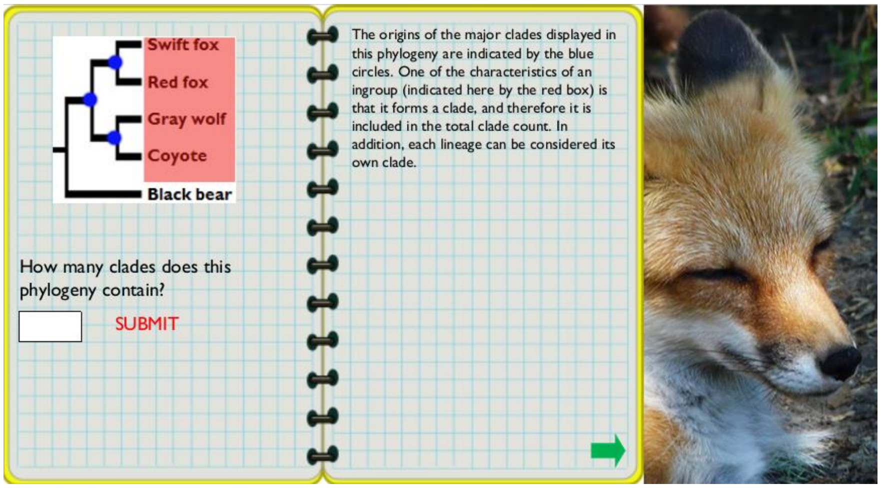

Figure 3.4. Example of how elaborative feedback is provided in this activity.

Evaluation of the activity

In order to test the effectiveness of this activity, participants were recruited from an introductory biology course and an upper-level evolution course. The introductory biology students (novice students, predominately freshman) had not yet received any explicit instruction on phylogenetics beyond what they learned in high school. The evolution students (advanced students) had been exposed to phylogenetics at least twice: once in an introductory (sophomore level) ecology/evolution class and once in the upper-level evolution class (prior to participating in this study). By using both novice and advanced students, we were able to get a better glimpse at how the activity and feedback can be used. If students completed the entire study they were awarded ten extra homework/lab points in the appropriate course. Students who did not wish to participate were offered an alternative assignment to allow them the opportunity for the same extra credit. All procedures were approved by the IRB (study c0816.15s).

The first part of the study involved a pre-test using multiple-choice questions largely adapted from a validated concept inventory on macroevolution (Nadelson and

Southerland 2010) and from a McGrawHill Biology test bank (Raven et al. 2013). Students completed the pre-test at the beginning of their class before their instructor started the day's lecture. There were also five Likert- scale questions that asked students to rate themselves on how well they feel they can engage in science and their overall understanding of phylogenetics. However, many of the responses to the Likert scale questions were incomplete and indicated students did not follow instructions appropriately, therefore these responses were not included in the final analysis.

After the pre-test was delivered, students were randomly assigned one version of the activity to complete. Students had one week to complete the activity and submit their certificate as verification of completion. Two weeks after the deadline (three weeks after the pre-test), students completed a post-test in class that was identical to the pre-test except for an additional question asking for feedback on their experience with the activity. Table 3.1 gives a brief overview of student scores on the pre- and post-tests.

Table 3.1 Scores of pre- and post-tests for each class.

Course	Pre-Test			Post-Test		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Introductory Biology	20	90	60.197	20	100	57.566
Evolution	40	100	67.143	40	100	75.714

As previously mentioned, development and evaluation phases overlapped briefly. The semester before the results discussed below were collected, we piloted this activity in the evolution and introductory biology courses, but some obstacles resulted in a low activity completion rate for both courses. An examination of this first trial allowed us to identify these obstacles and make changes that resulted in a much higher completion rate for the second semester (40% for the introductory biology class and over 80% of the evolution class). These changes included delivering the pre- and post-tests in class instead of online and conducting the study earlier in the semester before students' course loads became too heavy.

Results

152 introductory biology students and 14 Evolution students completed all parts of the study and were included in the analysis. These students were placed into one of four groups for analysis based on their class enrollment and activity version. Normalized learning gains were calculated for each student and then averaged to allow for comparisons among groups. Normalized learning gains allowed us to address the variance in pretest scores (Meltzer 2002). One evolution student who received elaborative feedback made a perfect score on the pretest and was not included in any statistical analyses of learning gains. The results of a test (Shapiro-Wilk) of the normality of learning gains and activity scores for each group revealed that the data were not normally distributed, so all analyses were nonparametric.

There were no significant differences in pre-test scores between the four analysis groups (Kruskal-Wallis; H_3=3.383, p=0.336). However, there were significant differences in the post-test scores (Kruskal Wallis, H_3= 19.532, p< 0.001). Evolution students who received elaborative feedback performed significantly higher than students in the introductory biology class who received correct answer feedback (p< 0.001) and introductory biology students who received elaborative feedback (p=0.002).

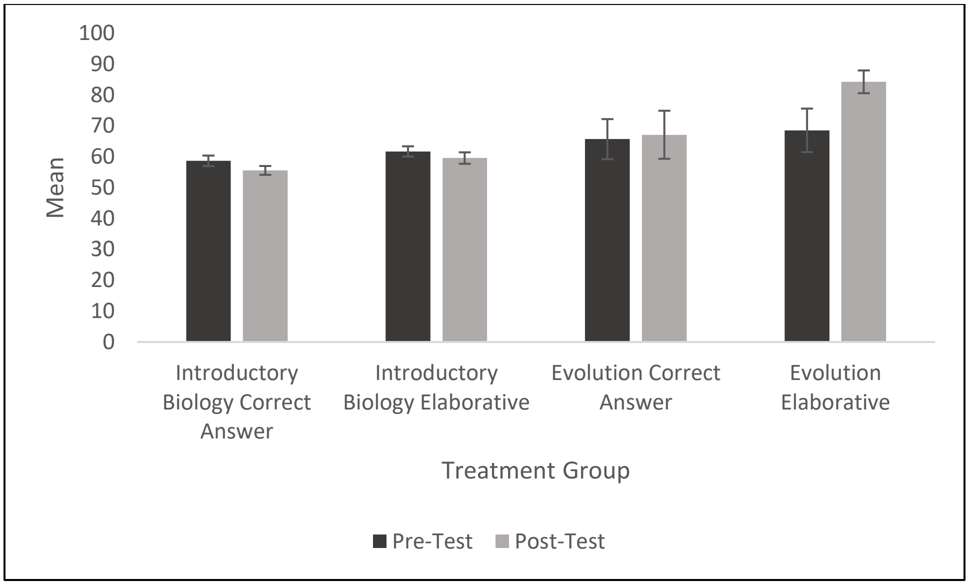

Figure 3.5 Comparison of average scores for each analysis group on pre- and post-tests. Error bars represent standard error. Asterisk above bars represent a significance of p<0.001.

There was a significant difference in learning gains across the four groups (Kruskal-Wallis; $H_3 = 13.696$, p=0.003). Pairwise comparisons revealed that learning gains among evolution students who received elaborative feedback were significantly different from both groups of introductory biology students (p=0.003 for introductory students who received correct answer and p=0.005 for those who received elaborative feedback). There were no significant differences between students in evolution who received correct-answer feedback and all other treatment groups. Figure 3.6 shows the distribution of learning gains across each treatment group. The effect sizes of feedback on the learning gains were 0.029 for introductory biology students and 0.564 for evolution students.

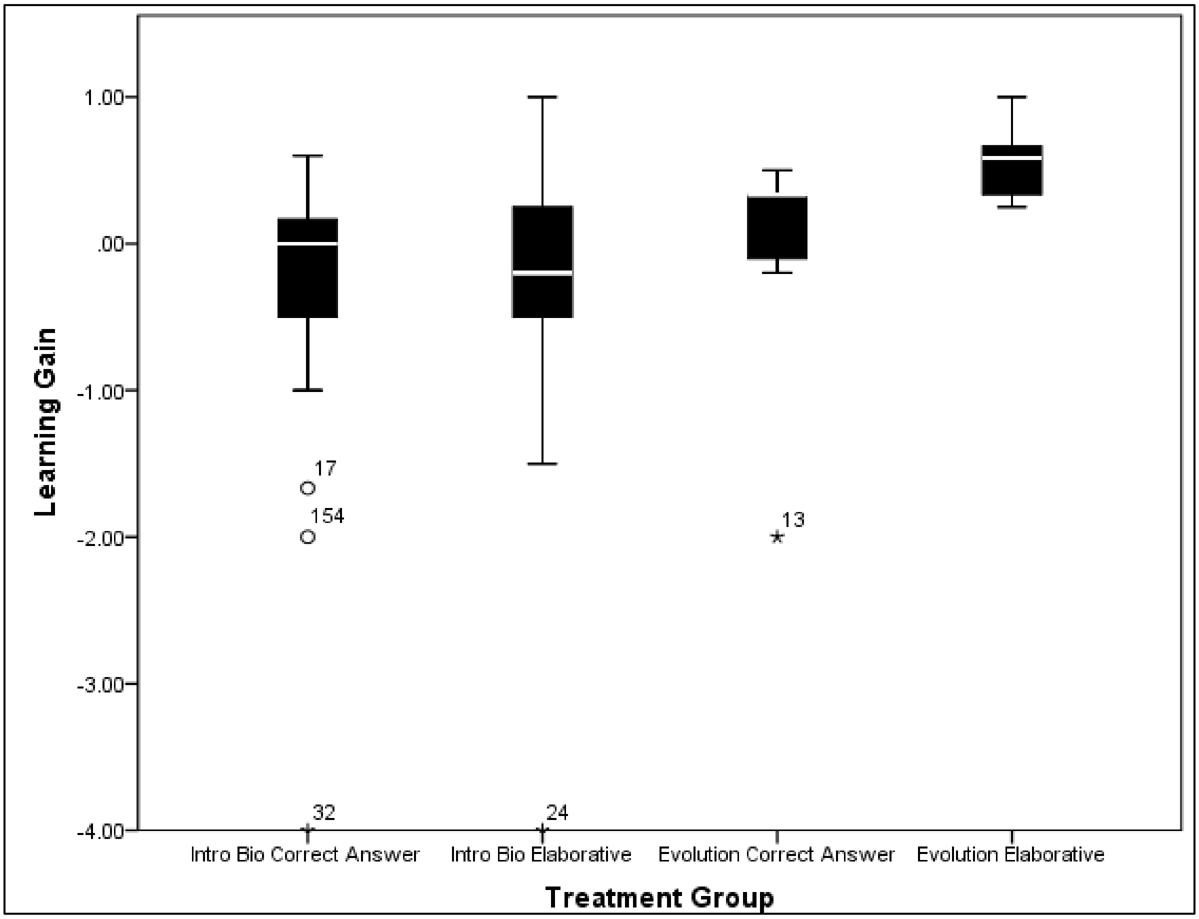

Figure 3.6. Comparison of learning gains between each treatment group. Boxes represent the interquartile range (IQR) of learning gains. The white lines within the IQR are the median learning gain. Bars above and below IQR are the range of the top 25th and bottom 25th percentiles. Outliers are indicated by open circles stars.

Table 3.2 Average and median learning gains for each treatment group

Treatment Group	Average LG	Median LG
Introductory biology correct-answer	-0.238	0.000
Introductory biology elaborative	-0.1804	-0.2
Evolution correct-answer	-0.100	0.333
Evolution elaborative	0.569	0.583

However, as Figure 3.7 shows, evolution students overall had significantly higher learning gains than introductory biology students. The medians of the evolution and introductory biology students were 0.333 and -0.167, respectively, and there was a significant effect of class enrollment (Mann-Whitney U; $p=0.001$). It is interesting to note that introductory biology students had a negative average learning gain of -0.21.

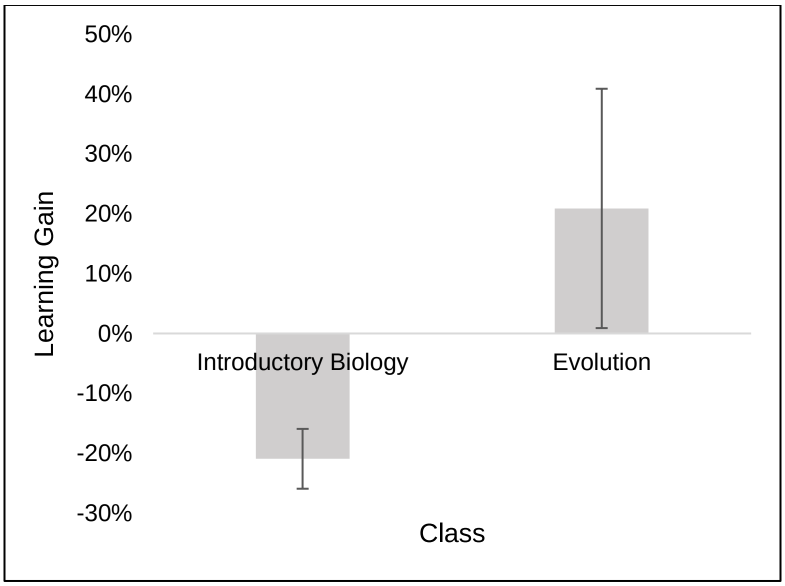

Figure 3.7. Comparison of learning gains according to class enrollment ($\bar{x}$ = -0.210 and 0.209 for introductory biology and evolution, respectively.) Error bars represent standard error.

In addition to analyses of the effectiveness of the activity as a whole, each question was analyzed to determine if any needed to be revised to make the activity a more accurate assessment. Discrimination indices were calculated for each question for both classes (Table 3.3).

Table 3.3 Discrimination index for activity questions between classes.

Question	Introductory biology	Evolution
1	0.671	0.286
2	0.572	0.286
3	0.651	0
4	0.651	0.286
5	0.434	0.857
6	0.296	0.143
7	0.177	0
8	0.316	0.429
9	0.355	0.143
10	0.316	0.857

Cronbach's alpha is commonly used to measure the internal consistency of an assessment or survey (Taber 2016). The Cronbach's alpha levels can be seen in Table 3.4. Using the range of values described in Taber (2016), the introductory biology class' value indicates very little internal consistency while the evolution class' value indicates high internal consistency. There is no consensus among science education researchers of what constitutes an "acceptable" Cronbach's alpha level, with some accepting values above 0.5, whereas others require values above 0.7 (Taber 2016).

Table 3.4 Results of reliability analysis of phylogenetics activity.

Class	Cronbach's Alpha
Introductory biology	0.534
Evolution	0.753
Evolution + Introductory biology	0.605

Finally, student responses to a short-answer question about how they view the activity and what changes they would make to it were collected, and a sample of these is shown in Table 3.5.

Table 3.5 Student responses to using the phylogenetics activity.

Class	Comment
Introductory biology	I found the activity interesting I'm just not certain of correctly interpreting all aspects of the diagram.
Introductory biology	There was very minimal teaching involved- I feel as if I only got more confused rather than more enlightened.
Evolution	Some of the wording of questions can be a little wordy and confusing.
Evolution	No, I enjoyed the activity.

Discussion

There are several important lessons learned from the results presented above. As introductory biology students had a negative learning gain after using the activity, this activity may not be the most suitable way to introduce students to phylogenetics. This finding seems contrary to the current idea of a "flipped classroom" where students interact with material prior to lecture/lab presentation. One possible reason for the negative learning gain is that the introductory biology students did not have existing constructs they could incorporate new phylogenetic terminology into. While their lecture textbooks have phylogenies in class before, they had not explicit instruction on phylogenetics yet. Therefore the terminology in the activity could have caused students to be more confused about how to interpret phylogenies than they were before completing the activity.

As Liu et al. (2012) noted, student motivation has repeatedly been demonstrated to have a positive relationship with performance on an assignment. It is therefore possible that the upper level students took the activity more seriously. While phylogenies were occasionally used in the introductory biology class, they were not explicitly tested on phylogenetics. However, students in the evolution class were expected to be able to interpret phylogenies on other assignments in their class, and thus had more incentive to take the activity seriously.

It also appears that more detailed (elaborate) feedback is most useful when students have some familiarity with the concept being presented. The evolution students in this study did not perform significantly higher on the pre-test than introductory biology students (p=0.149). However, evolution students who received elaborative feedback had significantly higher learning gains than introductory biology students. This finding may indicate that feedback can help students remember and/or connect different concepts. This could have important implications as instructors develop other online activities as they will need to consider when the activity will be completed (i.e., before or after instruction). It is possible that activities meant to introduce students to material may not need as detailed feedback as those meant to supplement instruction. However, additional research is needed to determine the validity of this hypothesis.

Finally, many students responded that additional information would have improved the usefulness of the activity. It is worth noting that the review section described above was omitted in the trials designed to test feedback types. Future studies could replicate the design presented here with and without the review section to determine how much information is best for student learning. Many students (mainly in the introductory biology course) stated that they did not learn anything from the activity because they did not know any of the definitions or concepts. It would be fascinating to see if inclusion of a review section does result in higher learning gains.

Future Directions

Perhaps one of the biggest obstacles faced in this study was the small sample size of advanced evolution students. The evolution class is a senior course and only 17 students were enrolled the semester we conducted the research. Thus, results may be heavily influenced by individual participants. As Figure 3.6 shows, one evolution student had a learning gain of -2.0, far below all other evolution students. As a result the average learning gain for the evolution class (Figure 3.7) was heavily affected by this one student. Therefore, results presented here will need to be verified in additional studies, both at our institution and others.

As the discrimination indices reveal, many of the questions should be revised to more accurately assess student knowledge of phylogenetics. As this resource is currently designed for students with some background in phylogenetics, the indices of the evolution students will be relied on more than those of the introductory biology students. However other developers could modify the activity to make it more suitable as an introductory resource.

This study was done during one semester at a single institution, so further studies of this topic are needed to examine the relationships discovered here. It would be particularly interesting to see results from students at more academic levels, such as the introductory ecology/evolution students and graduate evolution students. Additionally, it would be interesting to see whether similar studies on different concepts and/or student levels corroborate the results presented here. Phylogenetics is a difficult concept for students to grasp even with explicit instruction, so examining the role of feedback in an activity on a more straightforward topic may result in different conclusions.

This study can serve as a foundation for future research studies. Although the small sample size of advanced evolution students made drawing conclusions difficult, the methods here can be replicated in additional classes. Eye-tracking software has been used in other studies to examine how much attention users pay to different types of information, and it would be interesting to see if this software could be utilized to determine whether students read the extra feedback (Tsai 2011). This study also contributes to the existing knowledge base about how to incorporate feedback into online activities. Finally, the activity described here was developed using evidence-based instructional design principles to improve its effectiveness as a free resource.

Availability

This resource is available at https://sites.google.com/site/introtophylo/

Acknowledgements

I would like to thank the Dr.'s Anna Hiatt, Thomas Jones, and Rebecca Pyles for all of their assistance during this project. Another big thank you to the students who participated in this study; your participation is greatly appreciated.

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CHAPTER 4

HOW DOES AN UPDATED USER INTERFACES ON VIRTUAL BIOLOGY LAB SIMULATIONS AFFECT STUDENT LEARNING

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Note to Thesis Reader

The following chapter was written in the format required for the Journal of Microbiology and Biology Education's (JMBE) 'Curriculum Section'. It is recommended that readers familiarize themselves with this format prior to reading this chapter. For more information on this format, please visit http://jmbesubmissions.asm.org/asm/pages/files/JMBE%20Curriculum%20Section%20Author%20Guidelines.pdf.

Abstract

Virtual Biology Lab (VBL) is a freely available online resource that contains interactive simulations on ecology and evolution. Since its inception (2010), VBL has become a popular learning tool in a variety of classes, but technology is beginning to render its current design obsolete. To remedy this, the coding for simulations are being updated to operate on a variety of mobile devices and computers. The need for new coding presented the opportunity to enhance the graphics and animations of the simulations, which also provided the opportunity to investigate whether an updated user interface affects student learning. Students in an introductory biology course at East Tennessee State University were randomly assigned to complete one original and one updated simulation on different topics. After completion of the assignment, students took a short quiz that included questions on content and their opinions about online learning activities. Scores from the quizzes were analyzed to determine the impact of the updated user interface on students learning. Overall, there were no differences in

content or affective scores, but many students commented that the simulations did help them better understand the material as compared to lectures.

Introduction

Many topics in ecology and evolution can be difficult to demonstrate in a traditional undergraduate course. Instructors are faced with time, space, and financial constraints that prevent them from incorporating lab experiments in these fields. Most evolutionary mechanisms take place over very long time scales and therefore cannot be readily demonstrated in the classroom. Evolutionary mechanisms that can be demonstrated in laboratories often require significant resources and/or specialized equipment that cannot be provided by many universities (1).

Incorporating online simulations that model real-life processes into lab exercises is one way to combat these problems. Simulations typically include several independent variables that students can manipulate to see how they affect the outcome of a particular scenario (2). For example, within the space of one lab period, students can plan and conduct a virtual experiment on barnacle competition to see how manipulating variables such as sea level and predator density affects the relationship among barnacle species. Simulations generate realistic data that students can analyze to further their understanding of the concept(s) being portrayed, as well as the processes of analysis and interpretation.

One of the key components of simulations (and online resources in general) is their user interface (UI). The UI is what users see and interact with while they are using the resource. The arrangement of the different features of an activity (such as the control panel or pictures) affects how easily a particular resource can be used. The UI of a resource therefore has a very strong influence on how users perceive the resource, so it is imperative that developers understand the basic principles of UI design to maximize the likelihood of the resource being a useful learning tool (3).

Virtual Biology Lab (VBL, available at www.virtualbiologylab.org) is a freely available suite of twenty-one simulations that cover ecology, evolution, and cell biology. Each simulation has several parameters students can adjust to examine effects on a model biological system. The previously mentioned simulation on barnacle competition allows students to manipulate the sea level and beginning population densities to examine how they affect competition between two species of barnacles. Equally important, each simulation can also be used to engage students in science practices as outlined by the Next Generation Science Standards (4).

Since VBL went online in 2010, advances in technology and computer graphics have rendered existing VBL simulations outdated, both in aesthetics and programming. Existing VBL simulations were recoded into HTML5 (a versatile computer coding language), incorporating new graphics and a more modern UI. The update also provided us opportunity to determine how these components affect student learning. The focus of this study was to examine how the new interface affected students' confidence in acquiring knowledge and engaging in the process of science. Data was also collected on how students view the effectiveness of these simulations. It was expected that the increased usability of the simulations will result in higher self-efficacy and content scores.

Intended audience and pre-requisite knowledge

While originally designed for undergraduate courses, VBL has also been successfully implemented in high school courses. The simulations discussed here are completed in an introductory ecology and evolution course in which students enroll in concurrent lecture and laboratory. Students are required to have completed two introductory courses (one on cell biology, one on organismal biology). In the ecology and evolution course, students are assigned two VBL simulations over the course of the semester, assigned in laboratory shortly after the topic is presented in lecture.

The first simulation students complete in this course is PopGen Fishbowl. This simulation allows students to examine how violating the assumptions of the Hardy-Weinberg equilibrium affects the population genetics of a population of fish. Students can affect parameters such as population size, the relative fitness of each genotype, and the migration rate. Students can also access real-time data on the population size and allele/genotype proportions.

Students also complete an island biodiversity simulation based on MacArthur and Wilson's model of equilibrium of biodiversity on islands (5). Students compare how different taxa (birds, reptiles, arthropods, and mammals) colonize islands of varying sizes, distances from the mainland, and habitat types. Data on the diversity and abundance of species on each island is continually updated on the data collection page.

Learning time

Each lab activity is designed to be completed within a three-hour lab period, and includes hypothesis development, setting up and running the experiment, and analyzing data. Actual time can vary depending on how the instructor utilizes simulations (e.g., in class or homework, lab or lecture activity).

Learning objectives

Each simulation is associated with specific learning objectives for each content area. However, every VBL simulation aims to help improve students' abilities to use biological modeling to further their understanding of both the process of science and the biological concept portrayed by each simulation.

Procedure

Materials

Each student (or group of students) needs to have access to an Internet-enabled device such as a computer, tablet, or smartphone. All simulations can be accessed at http://virtualbiologylab.org/.

Student instructions

There are no set instructions for student use of VBL. Instructors can develop these resources as needed.

Faculty instructions

It is recommended that faculty cover appropriate topics prior to using any of the VBL simulations. VBL simulations can be used in a variety of ways, including independent homework assignments, group laboratory activities, or in-class demonstrations. As every class is different instructors are encouraged to review the tutorial (included with each simulation) and experiment with the different features of each simulation prior to deciding how to incorporate VBL into their course.

Suggestions for determining student learning

Students took a five-question quiz after completing each simulation that covered the concept demonstrated (Appendices B and C). In addition, students were assigned homework that required them to use the simulation to answer hypothetical scenarios developed by the instructor.

Sample data

Below are screenshots from the two simulations analyzed during the field tests. Information on student learning outcomes can be found under “Field Testing.”

Figure 4.1. Screenshots of PopGen Fishpond user interfaces (old on left, new on right) (6). Copyright VBL 2017.

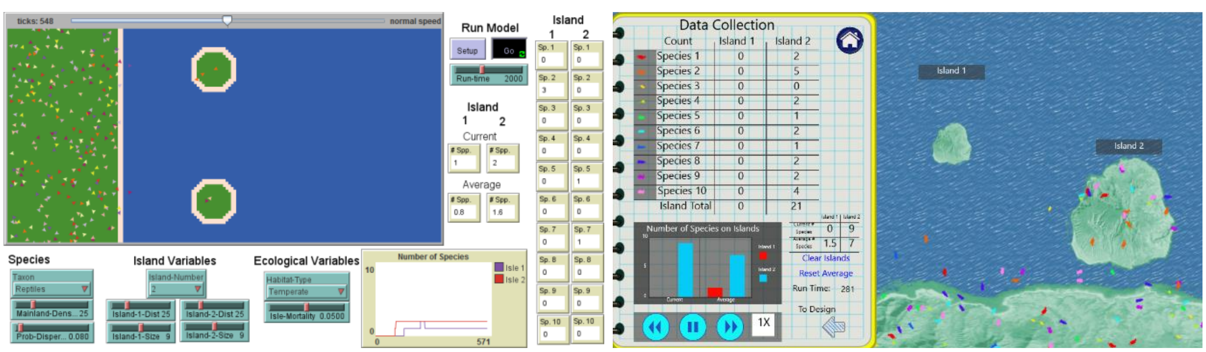

Figure 4.2. Screenshots of Island Biogeography user interface (old on left, new on right) (6). Copyright VBL 2017.

Safety issues

There are no safety concerns associated with VBL.

Discussion

Field testing

The user interfaces (old and new) of two simulations were examined in this study: PopGen Fishpond (Figure 4.1) and Island Biogeography (Figure 4.2). Data were collected from 128 students in the Fall 2016 class and 31 students during Spring 2017. This difference in sample sizes is due to course progressions, as students typically take this class during the fall semester. Participants were divided into groups by lab section. According to lab section, students completed either the OLD PopGen FishPond simulation followed by the NEW Island Biogeography, or the NEW Popgen Fishpond followed by the OLD Island Biogeography. All students use PopGen Fishpond first and Island Biogeography a few weeks later. After completing each simulation students took an in-class quiz (Appendices B and C) that had five content questions and five questions on how they feel the simulation helped them learn the particular topic.

Evidence of student learning

The results did not reveal any significant differences in content scores based on which simulation version they completed (Mann-Whitney U tests; all significance values above 0.05). Overall, students generally performed better on the Island Biogeography quizzes than the PopGen Fishpond quizzes.

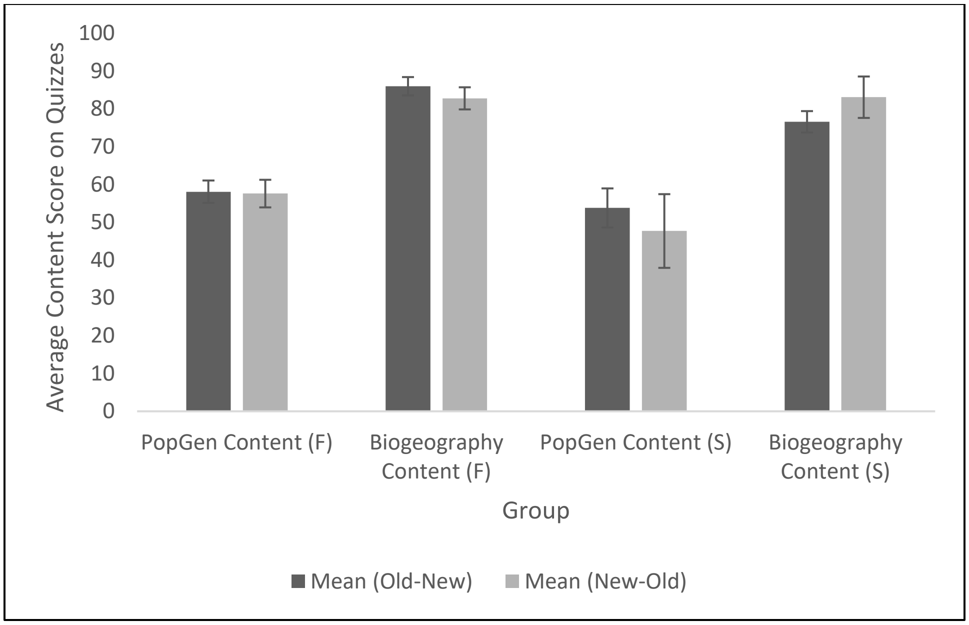

Figure 4.3. Mean content scores for each treatment group. Error bars represent standard error. (F) indicate the scores of participants from the fall semester, while (S) are participants in the spring semester.

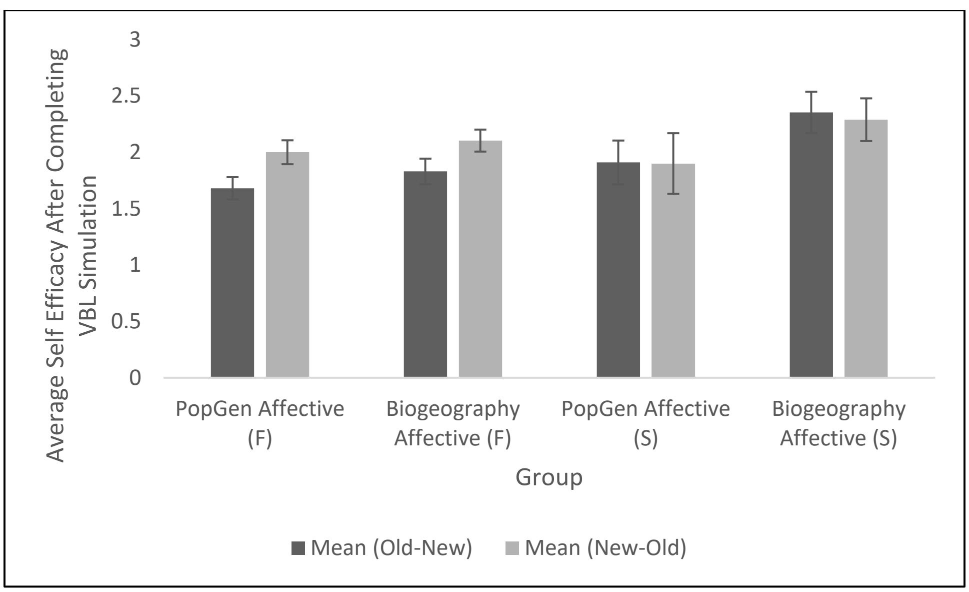

Figure 4.4. Mean self-efficacy scores for each treatment group after completing each simulation. Error bars represent standard error. (F) indicate the scores of participants

from the fall semester, while (S) are participants in the spring semester. Responses ranged from 0 (no gain) to 4 (great gain). Refer to Appendices B and C for more details.

As shown in Figure 4.4, students generally felt that they had gains in their understanding of the process of science and their content understanding. To calculate the scores shown in Figure 4.4, the responses of the last four quiz questions were ranked on a scale of 0-4 and averaged for each student.

Although there were no significant differences in performance, over 75% of students indicated that the simulations helped them visualize what they were learning in lecture. Additionally, students recognized that these simulations were beneficial in demonstrating processes that take place over extremely long time scales. Below are student responses to using VBL.

- *"It helps by allowing me to see process that would either take too long or too many resources to study in the real world."*
- *"The simulations helped to see how changing certain aspects of a population can greatly change the outcomes of the popuations size, genotype frequencies, etc."*
- *"The simulations showed generations of change in a few minutes. It gave me a visual example to something that is normally hypothetical."*
- *"Biological modeling or simulations help to visualize the experiment on a small scale. It can also be accelerated without inputing the results. Therefore a lot of information can be learned in a hands on short amount of time."*

Possible modifications

Given proper support the activities outlined here can be modified as out-of-class assignments.

Supplemental Materials

Appendix B: PopGen Fishbowl Quiz

Appendix C: Island Biogeography Quiz

Acknowledgements

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CHAPTER 5

IMPLICATIONS FOR EDUCATORS

The research study described in Chapter 3 aimed to examine the importance of feedback in online learning activities across novice and advanced students. Overall advanced students appeared to be able to use elaborative feedback more effectively than novice students, though this could also be a result of the complexity of the material in the activity. The second study looked at how updating the user interface of online simulations affected student understanding of two evolutionary models. The result of the analyses showed that students performed roughly the same after completing old versus updated simulations. However, additional studies looking at these specific activities will need to be done to determine if the trends discussed above hold true for other populations of students.

Elaborative Feedback in a Phylogenetics Activity

Selecting Material to Include in Online Resources

Learning progressions are hypothetical pathways students take as they gain more complex knowledge about a particular concept, and can be used to help educators plan their lessons (Furtak 2014). As (Tomlinson, 2016) pointed out, educators should identify where a student is in a given learning progression and provide appropriate feedback to help that student advance to that next level. Learning progression could also be used to inform the development of online activities, particularly in regards to selecting information to be included in feedback messages. While this will require the developer to do additional research into what the target audience should have been exposed to, it could result in more effective learning resources and is an avenue worth exploring.

While many online activities are designed to introduce students to new material (Foster et al. 2014), they may not be the most effective way to introduce phylogenetics. Indeed, many researchers have found that it is imperative that students receive direct instruction on tree thinking before they interact with phylogenies on their own (Dees et al. 2014).

Impact of User Interface

Developing Online Resources

It is imperative that instructors have access to research-backed resources and know how to use them effectively. This can include simply advertising about them, but will likely require us to revise existing activities and/or develop new ones using evidence-based practices. A good starting point for this would be to review existing resources across every discipline, similar to the 2014 review of health science modules by Foster et al. This will allow us to see how many high quality resources are available and let us know how much work would need to be done to update the remaining resources or if new ones need to be created.

The user interfaces of online resources should be designed to ensure students with disabilities (such as visual impairments) can still achieve the same level of interaction as other students (Laabidi et al. 2014). As these simulations become more widely used it may be necessary to include additional components (such as audio instructions) to maximize their accessibility for all students.

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APPENDICES

Appendix A: Table of specifications for online phylogenetics activity

Written by W. David Ford (2017)

Table 1. Spec table for activity questions used in study.

	Remember	Understand	Apply	Analyze	Evaluate	Create	Questions
Tree Anatomy	1, 3, 7						1, 3, 7
Tree Reading			2, 6	5			2,5,6
Tree Building					8, 10	9	8, 9, 10
Character analysis					8, 10	9	8, 9, 10
Clades	1						1
Common ancestry			6				6
Evolutionary Advancement	4						4
Nodes	3		2				2, 3
Outgroup	7			5			5, 7
Shape of phylogeny				5			5
Tip placement			6	5			5, 6
Tree topology			2	5			2, 5

Table 2. Spec table for questions in the final activity version.

	Remember	Understand	Apply	Analyze	Evaluate	Create	Questions
Tree Anatomy	1, 3						1, 3
Tree Reading			2, 6	5			2, 5, 6
Tree Building				8, 9	7, 10		7, 8, 9, 10
Character analysis				9	7, 10		7, 9, 10
Clades	1						1
Common ancestry			6				6
Evolutionary Advancement	4						4
Nodes	3		2				2, 3
Outgroup				5, 8			5, 8
Shape of phylogeny				5			5
Tip placement			6	5			5, 6
Tree topology			2	5			2 ,5

Appendix B. PopGen Fishbowl Follow Up Quiz

Written by Thomas C. Jones, Anna C. Hiatt, and W. David Ford

Biology III **Population Genetics II Lab Quiz** **Name ________________________________**

Lab Section Time ______________________________

Questions 1-5 have one correct answer.

1. Which of the following effects is most likely when a population size becomes very small?
   a) The dominant allele will rapidly increase in frequency.
   b) The dominant allele will rapidly decrease in frequency.
   c) The recessive allele will rapidly increase in frequency.
   d) The recessive allele will rapidly decrease in frequency.
   e) The dominant and recessive alleles have equal probability of decreasing in frequency.

2. Which of the following outcomes is most likely when, in a population of very small size, there is selection against the heterozygous genotype?
   a) The dominant allele will rapidly increase in frequency.
   b) The dominant allele will rapidly decrease in frequency.
   c) The recessive allele will rapidly increase in frequency.
   d) The recessive allele will rapidly decrease in frequency.
   e) The dominant and recessive alleles have equal probability of decreasing in frequency.

3. What is the most likely outcome in an observed population if a large number of migrants are entering the population from a second population where the recessive allele frequency is half that of the observed population?
   a) The dominant allele will decline to zero.
   b) The recessive allele will decline to zero.
   c) The dominant allele will decline in frequency somewhat.
   d) The recessive allele will decline in frequency somewhat.
   e) The dominant and recessive alleles have equal probability of decreasing in frequency.

4. What is the most likely outcome in a population over a large number of generations, if a recessive allele is produced by a forward mutation rate of $1x10^{-6}$ and has a back mutation rate of $5x10^{-7}$?
   a) The recessive allele will decline to zero.
   b) The homozygous recessive genotype will decline to zero.
   c) The recessive allele will have an equilibrium frequency of 1.0.
   d) The recessive allele will have an equilibrium frequency between 0 and 1.0.
   e) The dominant and recessive alleles will have equal equilibrium frequencies.

5. In a large population in which p and q are both equal to 0.5, and where positive assortment (inbreeding) subsequently becomes very high, which of the following is most likely?
   a) The dominant allele will decline to zero.
   b) The recessive allele will decline to zero.
   c) The dominant allele will increase to a frequency of 0.6.
   d) The receive allele will increase to a frequency of 0.6.
   e) The frequencies of the dominant and recessive alleles will not change.

Part 2: The following questions do not have a correct answer. To receive credit, just answer them honestly.

6. How do you feel about using simulations (similar to Virtual Biology Lab) as learning aides?
   a) Extremely negative
   b) Slightly negative
   c) Indifferent
   d) Slightly positive
   e) Extremely positive

7. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in understanding the general concepts being illustrate?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

8. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in the relationship between the illustrated concepts and the rest of the course material?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

9. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in your confidence in formulating and testing hypotheses?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

10. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in your confidence in interpreting biological data?
    a) No gain
    b) Little gain
    c) Moderate gain
    d) Good gain
    e) Great gain

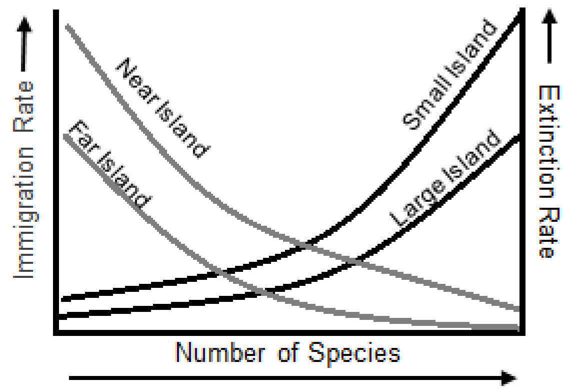
Appendix C: Island Biogeography Follow Up Quiz

Written by Thomas C. Jones, Anna C. Hiatt, and W. David Ford

Biology III   Island Biogeography Lab Quiz   Name ________________________________

Lab Section Time ____________________________

Questions 1-5 have one correct answer.



1. What do the four intersecting points in this graph represent?
   a) Minimum biodiversity of an island
   b) Biodiversity equilibrium of an island
   c) Maximum biodiversity of an island
   d) Expected rates of extinction on an island
   e) Expected rates of colonization of an island

2. Using this graph, which island would have the highest extinction rate?
   a) Small island with 50 species
   b) Large island with 50 species
   c) Small island with 100 species
   d) Large island with 100 species
   e) All would have the same extinction rate

3. Which taxa would most likely be the first to colonize an island 300 kilometers from the mainland?
   a) Arthropods or birds
   b) Arthropods or mammals
   c) Birds or mammals
   d) Birds or reptiles
   e) Reptiles or mammals

4. According to MacArthur and Wilson's (1963) Island Biogeography model, what factor <u>increases</u> the number of species you would find on an island?
   a) Loss of habitat diversity
   b) Colonization from the mainland
   c) Local speciation
   d) Spontaneous generation
   e) All of the above are factors in the model.

5. According to MacArthur and Wilson's (1963) Island Biogeography model, which island would have the <u>most</u> biodiversity?
   a) Rainforest, close to the mainland
   b) Rainforest, far from the mainland
   c) Tundra, close to the mainland
   d) Temperate forest, close to the mainland
   e) Temperate forest, far from the mainland

Part 2: The following questions do not have a correct answer. To receive credit, just answer them honestly.

6. How do you feel about using simulations (similar to Virtual Biology Lab) as learning aides?
   a) Extremely negative
   b) Slightly negative
   c) Indifferent
   d) Slightly positive
   e) Extremely positive

7. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in understanding the general concepts being illustrate?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

8. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in the relationship between the illustrated concepts and the rest of the course material?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

9. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in your confidence in formulating and testing hypotheses?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

10. As a result of working with the Virtual Biology Lab simulation model, what GAINS DID YOU MAKE in your confidence in interpreting biological data?
   a) No gain
   b) Little gain
   c) Moderate gain
   d) Good gain
   e) Great gain

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