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Biology Laboratories at a Distance: A Case Study and Experiment of Ecology and Evolution Labs with Community College Students

Beverly E. Ranney

UNIVERSITY OF NORTHERN COLORADO

Greeley, Colorado

The Graduate School

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Beverly E. Ranney

College of Natural and Health Sciences
School of Biological Sciences
Biological Education

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Accepted by the Doctoral Committee

Susan Keenan, Ph.D., Research Advisor Co-Chair

Lauryn Benedict, Ph.D., Committee Member

Teresa Higgins, Ph.D., Committee Member

Robert Reinsvold, Ph.D., Committee Member

Richard Jurin, Ph.D., Faculty Representative

Date of Dissertation Defense____

Accepted by the Graduate School

Linda L. Black, Ed.D.
Associate Provost and Dean
Graduate School and International Admissions

ABSTRACT

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Community colleges deliver more courses online; laboratory-based courses face challenges in how to do this. This study examined how ecology and evolution laboratories could effectively be delivered in an online biology community college course. Virtual simulations and hands-on, at-home kits were used in two groups. Results showed that students using the virtual simulations had higher learning gains and more positive perceptions towards their laboratory experiences than those students using at-home kits. By evaluating learning gains on a pretest/posttest and utilizing interviews and focus groups, this research concluded that virtual simulations offered a superior learning experience for online learners.

The results suggest that laboratory experiences offered students important advantages: course engagement, opportunities to think about the processes of science, and opportunities to engage with difficult or abstract content. Students expected laboratories to be streamlined. The results of this research suggest that instructors and administrators at community colleges critically examine the use of virtual simulations for abstract or difficult content as virtual simulations provided opportunities for greater student success than traditional, hands-on labs when delivered online. Virtual simulations provide viable alternatives to traditional laboratories for online students.

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TABLE OF CONTENTS

CHAPTER

I. INTRODUCTION……………………………………………. 1

Community Colleges and Online Education
Rationale for Study
Statement of the Problem
Purpose Statement
Study Site Description
Research Questions
Significance of the Study
Researcher Stance
Summary

II. LITERATURE REVIEW…………………………………….. 17

Chapter Overview
Research Approach
Theoretical Framework
Community Colleges
Summary

III. METHODOLOGY…………………………………………… 57

Chapter Overview
Research Design

IV. RESULTS…………………………………………………….. 106

Chapter Overview
Research Q1
Research Q2

V. DISCUSSION………………………………………………… 164

CHAPTER

V. continued

Chapter Overview
Community Colleges and Online Biology
Discussion of Q1
Discussion of Q2
Conclusion

REFERENCES …...………………………………………………………… 195

APPENDIX A IRB MATERIALS…….………………………………………. 226

APPENDIX B SYLLABUS…………………………………………………..... 231

APPENDIX C INSTRUMENTS………………..……………………………. 236

APPENDIX D LAB EXAMPLES…………………………………………….. 257

APPENDIX E INTERVIEW QUESTIONS..…………………………………. 300

LIST OF TABLES

TABLE

1. Instructional Approach Assumptions………...................................... 32

2. Online Biology Timeline………………………………………… 67

3. Virtual Simulation Lab Alignment…………………………………. 68

4. At-Home Kit Lab Alignment……………………………………….. 69

5. Student Characteristics……………………………………………... 108

6. Pretest Data…………………………………………………………. 109

7. Midterm Data……………………………………………………….. 110

8. Assessment Statistics……………………………………………….. 111

9. Learning Gains……………………………………………………… 113

10. Ecology Simulation Frequencies…………………………………… 122

11. Evolution Simulation Frequencies…………………………………. 129

12. Overall Simulation Frequencies……………………………………. 136

13. Ecology Hands-On Frequencies……………………………………. 143

14. Evolution Hands-On Frequencies…………………………………... 150

15. Overall Hands-On Frequencies……………………………………... 156

LIST OF FIGURES

FIGURE

1. Moodle course screenshot………………………………………….. 62
2. Data analysis flowchart……………………………………………. 86
3. "Evolutionary Evidence" screenshot……………………………... 95
4. "Organizing Organisms"……………………………………………. 96
5. "Designing Lizards"………………………………………………… 96
6. "Evolving Lizards"………………………………………………….. 97
7. "Predicting Patterns"………………………………………………... 98
8. Workbook page from "Evolutionary Evidence"……………………. 98
9. "Finches and Evolution" screenshot……………………………….. 99
10. "Isle Royale" screenshot……………….…………………………… 100
11. "Keystone Predator" screenshot……….……………………………. 101
12. Handout from "Man's Best Friend?"…….………………………….. 102
13. Handout from "Island Biogeography and Evolution"……………… 102
14. Natural selection hands-on set-up……………..……………………. 103
15. Nutrient pollution hands-on set-up………………………………….. 104
16. Nutrient pollution testing hands-on set-up………………………….. 104
17. Polymer clay caterpillars……………………………………………. 105
18. Student learning gains comparison…………...…………………….. 112

FIGURE

19. Initial ecology simulation word cloud……….....…………………….. 118

20. Ecology simulation word cloud………………...…………………… 121

21. Initial evolution simulation word cloud…………...………………... 125

22. Evolution simulation word cloud………………..………………….. 128

23. Overall feelings about virtual simulations…………………..………. 130

24. Final virtual simulation word cloud………………………………… 135

25. Initial ecology hands-on word cloud………………………………... 139

26. Ecology hands-on word cloud………………………………………. 142

27. Initial evolution hands-on word cloud……………………………… 147

28. Evolution hands-on word cloud……......…………………………… 149

29. Overall hands-on word cloud…....…………………………………... 151

30. Final hands-on word cloud….………………………………………. 155

CHAPTER I

INTRODUCTION

Community Colleges and Online Education

Community colleges are essential for ensuring access to higher education opportunities. In 2010-2011, 45% of all undergraduate students were enrolled at community colleges, translating to 3.1 million full-time students and 4.6 million part-time students (Knapp, Kelly-Reid, & Ginder, 2012). Students enroll at a community college for a host of reasons. These reasons include: exploring potential academic programs; increasing earning power by earning a college degree; spending less on college costs including tuition, room and board; taking the most direct route to employment via certification; finding classes that fit into their schedules; learning in smaller classes; and strengthening their academic skills for transfer to four-year schools (Hoachlander, Sikora, Horn, & Carroll, 2003).

As the 21st century advances, new ways of reaching students through the use of online educational opportunities have developed, granting entry to more students, in more places, at more times, than ever before. In fall 2012, approximately 7 million undergraduate college students took at least one online course (Allen & Seaman, 2014). Compared to other disciplines, the number of online laboratory science courses was low (Allen & Seaman, 2014). One reason for the relatively lower number of online laboratory science courses is the laboratory portion of such classes. How to offer a traditionally hands-on, on-campus experience online is a novel challenge for science departments. This is problematic not only for students seeking science content, but also for instructors seeking to meet student needs.

Rationale for Study

The American Association for the Advancement of Science (AAAS) proposed to make all Americans scientifically literate by 2061 (AAAS, 1993). This goal requires that science courses be more accessible to learners than they have been to previous generations. One way to increase accessibility is to increase the availability of online science courses offered through community colleges. Community colleges tend to have open-access enrollment for students. While traditional on-campus science courses are still essential, expanding biology courses into the online milieu through accredited college course offerings makes science content and processes more accessible to a myriad of learners while holding that content to academically rigorous standards. Laboratory experiences are quintessential components of science education; the challenge is how to incorporate the essence of that element into an online educational opportunity.

Biology is a particularly important science because it is foundational to a scientific understanding of the world around us. Understanding some basic biological principles allows a person to describe, explain, and predict biological phenomena. Everyone has experience with biology, ranging from as simply as existing as living being to sophisticated observations of the natural world. Having an understanding of how biology operates is an important component of science literacy. Biology is also a core component of a liberal arts education (Schwab, 1982). Community colleges are essential to providing college-educated students the general education requirements that form a foundation of a liberal arts education (Zeszotarski, 2001).

At community colleges, online education is an important way to make core components of education available to students. As part of many community colleges' missions, distance-learning opportunities have grown for constituents. The expansion of course delivery to include online classes has expanded opportunities to serve students, regardless of location (Stumpf, McCrimon, & Davis, 2005). Nearly one-half of college students in the United States attend a community college (Juszkiewicz, 2015). More online courses are available at community colleges than four-year institutions and online enrollment continues to grow (Allen & Seaman, 2010). Approximately 6.7 million students, or 32 percent of all students in higher education, were taking at least one online course in 2012 (Allen & Seaman, 2013). The lowest online enrollment growth rate in the last decade was recorded in 2011, the last year for which data are currently available, but it was 9.3 percent (Allen & Seaman, 2013). The annual growth rate for all higher education institutions was -0.1% in 2011 even as the online segment grew (Allen & Seaman, 2013). Initial estimates for annual growth in enrollment in higher education indicate the greatest gains were made in online classes for fall 2012 (Allen & Seaman, 2013). It is critical for institutions to prepare for the changes to teaching and learning as online classes continue to increase in demand (Paulsen & Smart, 2001).

Most of the research in online biology delivery in science education has focused on student or instructor perceptions of the course (Gess-Newsome & Lederman, 1995; Riffell & Sibley, 2005; Stuckey-Mickell & Stuckey-Danner, 2007; Stuckey-Mickell, Stuckey-Danner, & Taylor, 2007). Some research has been done on learning gains of biology content delivered online, though the research specifically examined learning gains in hybrid format courses at four-year institutions (McDaniel, Lister, Hanna, & Roy, 2007; Riffell & Sibley, 2005) or teacher preparation courses (Lebec, 2003). Using virtual simulations as a teaching tool in on-campus biology courses has been briefly explored (Perry, Meir, Herron, Maruca, & Stal, 2008; Toth, Brem, & Erdos, 2009) while learning gains in biology laboratories delivered at a distance have been less researched. The majority of published work on online biology education is on student perception of online courses and these tend to describe useful case studies but not the efficacy of laboratory experiences.

Historically, laboratory experiences were incorporated into United States college curriculum in conjunction with a growing adoption by high schools to integrate laboratory experiences into college preparatory courses (Blosser, 1980; NEA, 1893, p. 26, 139-141). Organized in 1893, a group known as the Committee of Ten recommended that biology courses be placed first in the sequence of high school science classes, that approximately 60% of class time be devoted to laboratory work, and laboratory work focus on helping students become better observers of the natural world. The Committee of Ten also included a list of experiments to be done in a high school biology classroom. These laboratory experiences were based on lists of experiments that college professors expected their students to master before the students investigated other areas (NEA, 1893). The focus for students was on mastering procedural techniques and understanding basic principles, rather than original inquiry or memorization of facts. The professors who composed the list for the Committee of 10 were primarily chemists and physicists.

On this foundation, laboratory instruction became widely incorporated into secondary and post-secondary education.

Laboratory instruction has transitioned from students completing lists of defined experiments with expected outcomes to students performing complex inquiries. The National Academies of Science recommends that students no longer perform expository exercises in laboratories but rather understand science concepts by doing science in inquiry-based exercises (Olson & Loucks-Horsley (Eds.), 2000). Biology courses currently may use a range of laboratory exercises, from expository to inquiry-based for student instruction. Translating these exercises into an online experience is critical to developing quality online biology instruction. An improved understanding of how virtual simulations and at-home kits are used in online biology instruction, when one pedagogy or another yield higher learning gains, and how students perceive these laboratory exercises, would add to our understanding of how to construct online biology learning opportunities.

Statement of the Problem

Delivering general biology online to students has not kept pace with other non-laboratory general education courses. Research has not examined the extent to which distance-delivered laboratories help online students make sense of biology content and how those instructional approaches are perceived by students, though many researchers have found that inquiry-guided experiments enhance laboratory instruction (Anderson, 2002; Haury, 1993; Hofstein & Lunetta, 1982; Lord & Orkwiszewki, 2006; Wallace, Tsoi, Calkin & Darley, 2003). Researching if and how distance-delivered laboratory activities help students understand biology content is of particular interest because understanding which laboratory activities can successfully help students learn biology content may help biology programs develop and deliver more online biology course options for students.

Research on the use of virtual simulations in biology classes may lead to better use of simulations by biology instructors; this in turn, may lead to an increase in the availability of online biology courses. Once we understand in greater detail if, how, and why virtual simulations are useful, and once we explore in more detail how students use virtual simulations, instructors may have a more useful tool to help students understand and process complex biological concepts.

Purpose Statement

The purpose of the study was to investigate if there was a correlation between the effectiveness of two distance-delivered laboratory methods and biology content learned by online students. The methods included virtual simulations and at-home, hands-on activities, referred to as "at-home kits." The scope of the research was limited by focusing on two units in an online general biology course's laboratory: evolution and ecology. The scope of the research was focused on these two units because they represented the best developed laboratory activities for both instructional approaches in online general biology.

The specific virtual simulations examined included ecology and evolution simulations developed by SimBio Corporation and at-home kits developed by the instructor. A multi-phase concurrent mixed methods design was employed to carry out the research (Creswell, 2002). The core phase included an experimental design, assessing students' learning gains through a pre-test, multiple assessments, and an online survey to analyze students' attitudes towards laboratory delivery methods. A second phase utilized an instrumental case study to elaborate upon and more fully describe how students used laboratory exercises in an online biology course.

Study Site Description

In the fall of 2006, Cotton College, a pseudonym for a Midwestern community college where this research took place, implemented an administrator's proposal for an online general biology course. The impetus was a desire to create courses that would allow students to earn an associate's degree online. I was the faculty member assigned to develop and teach this course; I conducted this research while an online faculty member concurrently pursuing my doctorate at University of Northern Colorado in 2012-2013. The online general biology course was asynchronous, required no campus attendance, was transferable to the in-state four-year universities, and as economical to students as possible. It is important to note that the most commonly offered type of undergraduate biology course offered within this state's community college system was a single course designed to be rigorous enough to satisfy an introduction to the major and broad enough to serve as a survey course for the non-major. The four-year universities offered the same course labeled "General Biology." Cotton College sought to increase student enrollment by having a degree program that allowed students to earn their degrees online without coming to campus.

The online general biology course used in this study was offered in a 16-week format, consisting of lecture and laboratory. Lectures included PowerPoint slides, links to videos and animations, and discussion boards. There were two laboratory sections of the online general biology course in which students were randomly assigned. In one, the students used only virtual simulations for their laboratory experience. In the other, the students used only at-home kit activities for their laboratory experience. My research goal was to assess if there was a relationship between the laboratory experiences and course grades.

Cotton College administrators and the newly created Institutional Review Board agreed for me to conduct this research on investigating the relationship between laboratory experiences and course grades if I agreed to keep the identity of the college anonymous. Their concerns regarding naming the college in my study were based on an accreditation issue the college was facing. Cotton College offered several online classes which used an intense four-week format and those classes had caused concern with the accreditation association. They were also concerned that I was both instructor and researcher, potentially placing pressure on the students' privacy, although the informed consent students signed when agreeing to participate in the study relieved much of this concern and the institution declined to have a third-party collect the consent so as to verify students' willingness to participate.

Research Questions

One of an instructor's responsibilities to students is to use instructional methods that direct and facilitate student learning (Janeksela, 2014). I was interested in knowing if virtual simulations were as effective as the conventional hands-on approach. Using my background in teaching at Cotton College, I knew that the evolution and ecology laboratory activities were the most difficult for students. Therefore, the following questions guided this study:

Q1 What is the relationship between the type of laboratory instructional approaches and the ecology and evolution content mastered in an online general biology course?

H1 There was no significant difference between the pretest-posttest learning gains of online general biology students using two types of laboratory instructional approaches.

H2 There was no significant difference in learning gains between ecology/evolution questions in the pretest-posttest and non-ecology/evolution questions in the pretest-posttest using two types of laboratory instructional approaches.

H3 There were no significant differences between the final course grades of online general biology students using two types of laboratory instructional approaches.

H4 There were no significant differences between the laboratory grades of online general biology students using two types of laboratory instructional approaches.

Q2 What are the perceptions of community college students towards ecology and evolution laboratory experiences in online general biology?

Significance of the Study

Online education continues to expand, offering a staggering breadth of online course offerings through community colleges. However, laboratory-based science classes have been slow to adopt online delivery methods for a number of reasons, primarily based on concerns over how laboratory experiences could be delivered at a distance (Bialek & Botstein, 2004; Volery & Lord, 2000). Coupled with the concern of laboratory delivery, is concern over the online environment being potentially isolating for students (Russo & Benson, 2005). As science does not take place in a void and would stagnate without the interchange of ideas and information (Driver, Asoko, Leach, Scott, & Mortimer, 1994), concerned biology educators have questioned the validity of offering science classes online because of a perception that such online classes would isolate students from the larger community of learners (Bolliger & Wasilik, 2009; McInnerney & Roberts, 2004). Scientific knowledge is constructed within the scientific community and then transmitted to others within the community and to learners (Driver, et al., 1994). The rise of technologies with instant communication capabilities contributes to the rise of online course offerings and impacts the way science is transmitted and taught (Peat, 2000; Shim, Park, Kim, Kim, Park & Ryu, 2003). Science education researchers must therefore be aware not only of content advances and evolving instructional strategies but also how technology advances change the way science education is learned.

Limitations of the Study

As an instrumental case study, this research intended to describe students' experiences with distance laboratory methods in an online general biology course as richly and completely as possible. Stake (1995) defined an instrumental case study as one that "examined mainly to provide insight into an issue or to redraw a generalization. The case is of secondary interest, it plays a supportive role, and it facilitates our understanding of something else" (p. 437). The "something else" that I sought to explore in this research was what instructional strategies are useful to deliver biology laboratory experiences online to a broader audience than a single community college. The study setting is highly contextualized to a single community college; the limitations imposed by the college may or may not be reflective of limitations other community college instructors face when implementing an online biology course. These limitations restrict the ability to generalize to other higher education institutions (Leedy & Ormrod, 2005). However, findings from the experimental portion of the research may have applicability if used with caution. The study is limited in scope to the laboratory instruction of two topics: evolution and ecology, within a general education biology course.

The quantitative Question 1 with its null hypotheses allowed me to use statistical significance testing to draw conclusions if the two treatments were equally effective but statistical significance testing by itself is of limited practical use to instructors (Fan, 2001; Thompson, 1993). The effect size statistic, Cohen's *d*, helped to clarify if the statistical significance testing had practical application for students (Fan, 2001). Cohen's *d* is used because, "In research situations in which two groups are involved and the comparison of the group means is the primary interest, *d* has become the measure of choice for effect size" (Fan, 2001, p. 277). The qualitative Question 2 informed why students may have been successful with a particular laboratory delivery method. Semi-structured individual interviews, focus groups, and laboratory reports provided multiple opportunities to discuss specific laboratory experiences with students.

Self-selection of students into an online course represents another potential source of error. While approximately one-third of college students take an online course each year (Allen & Seaman, 2010), why a student chooses a particular online course is a limitation to this study. To address this limitation, students were randomly assigned a laboratory delivery method and all students in the study completed a pretest.

Additional limitations may have emerged with the semi-structured interviews and focus groups if students found it difficult to recall particular laboratory experiences. To address these limitations, examples were used in the interviews and focus groups to prompt them to recall their experiences. Additionally, students were encouraged to email further reflections to the researcher. As the instructor-researcher, students may have felt that they needed to give socially acceptable responses or similar “right answers” in conversation with me. To address this limitation, students were reminded that participation was voluntary, what they said to me would in no way impact their grade and their responses would help shape future courses. Also as the instructor-researcher, my view of correlation of laboratory activities to instrument questions for data analysis could have been subjective. To ensure an objective analysis of the data, former colleagues from Cotton College reviewed the laboratory assignments and their correlation to the selected instruments.

Definitions

Virtual Simulation: A computer-based software program that is used for a student’s laboratory experience. A student downloads the program from the Internet and completes it off-line.

At-Home Kit: A hands-on experience a student completes with physical materials in an environment of their choosing.

Expository Instruction: Termed “verification” or “traditional”, instruction in which the instructor is viewed as the source of knowledge who then tells students what is important (Domin, 1999).

Inquiry-Based Instruction: Also termed “discovery-based learning”, instruction in which students identify and pose questions, design an experiment, analyze data, and draw conclusions (Keys & Bryan, 2001).

Scientific Literacy: “Scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity. It also includes specific types of abilities" (National Research Council, 1996, p. 22).

Researcher Stance

I was both the researcher of this project and the instructor of the course. At all times I sought to do what was best for the students. As an instructor, I used instructional tools I thought would help my students learn biology content, protected their privacy, and listened to them when we talked about the course so that I could help them. As a researcher, I protected the students' identities, critically examined the instructional tools under consideration, and sought to hear what the students meant from our conversations.

From both perspectives of researcher and instructor, constructionism was a sound framework with which to engage my students and the data. Constructionism is built upon the foundations of constructivism and posits that learners have to engage in unknown situations as an essential part of learning (Ackermann, 2001). Constructionism allowed the learners to take their prior knowledge and investigate the content, while developing an understanding of phenomenon. When course material is presented as a set of facts to be memorized, learners often become overwhelmed and disengaged. One solution is to present the content as a process to understanding phenomena, just as happens in a research setting. In a research setting, prior knowledge is used to investigate poorly understood or unknown phenomena. Research is not memorization but application of observations, which engage researchers into looking deeper into phenomena. This is often not the case in introductory survey courses, where breadth is often valued over depth of material. The glaring disconnect between research and lecture does little to attract students to the discipline or retain them once they are sampling majors-level courses (Walczyk & Ramsey, 2003). Therefore, I approached this research by understanding that knowledge is constructed as our understanding of phenomena is constructed, by engaging with materials, and wanting my students to construct their own understanding of biology content.

I taught online general biology for 7 years. I created the class in 2006 and was responsible for the transition from an instructor-driven course, heavy with passive lectures and cookbook laboratory experiences to a more student-centered course, focused more on discussions with students and inquiry-type laboratory experiences. Teaching online biology classes in this era of advancing technological improvements is pioneering work that I am grateful to be a part of as I foresee online general biology education replacing most face-to-face general biology within a generation at community colleges. Community college students need flexible learning options and online courses offer that flexibility.

In any research, it is possible for the researcher to influence the results. For the experimental portion of this research, those items addressed in Questions 1, I attempted to reduce bias by randomly distributing students into one of two treatment sections of online general biology. This created some level of frustration for several of the participants, who were aware of previous online biology classes that their spouse, child or friend had taken, and they were experiencing a "different" class than had their spouse, child, or friend. This may have biased their efforts, motivation, or responses.

One of the design biases inherent in this study is students self-selected into an online course. While many students take an online course each semester, not all students do. Those who do enroll in online courses may not be representative of all students in higher education, in community colleges, or who take general biology courses. Another design bias stems from the institution used in the study: a single, rural, community college in an agricultural portion of the Bible Belt. Institutions fitting this description are not representative of all community colleges in the United States. Inclusive bias, or the use of the online general biology course which I taught, limits the way the results can be used: they cannot be extrapolated to fit all community college online general biology courses.

There were other facets of bias that may have influenced data and my analysis. Procedural bias, where an unfair amount of pressure is applied to participants, was minimized because students were not rewarded with course points for participation. I assume had that been the case, I would have had many more interviews and a greater degree of these next forms of bias present. While the additional data would have been welcomed, the danger of having students give answers they assumed I wanted to hear, or been reluctant to express what they truly thought of the laboratory experiences, would have reduced the value of the data. Measurement bias may have existed because participants may have been reluctant to give what they perceived to be socially unacceptable answers in interviews or focus groups. By alerting students that should they opt in to the research, their grades were being studied may have influenced how students studied, how much time they devoted to their work, and how much effort they put into various laboratory assignments. To minimize interviewer bias, where I may have subconsciously given the participants clues towards my own opinions, prejudices, or values, I asked the interviewee to verify their word clouds, clarify any statement, and encouraged participants to contact me via email or phone if they changed their minds about a response or wanted to add to a response. Response bias, the converse of interviewer bias, where participants may have given responses they thought I wanted to hear was minimized by asking students to discuss their likes and dislikes, the pros and cons, of laboratory experiences. It would have been helpful to have had an additional researcher conduct the interviews and focus groups to minimize any bias that I personally introduced. By using multiple data points (interviews, focus groups, laboratory reports, and scores on various exams) I hoped to minimize the methodological bias inherent in this research.

Summary

Online education is expanding in the 21st century and biology courses have been slow to adapt to this method of instruction. However, access to quality science courses is a fundamental component of a liberal arts education (Schwab, 1982) and necessary to advance scientific literacy. If distance delivery methods of laboratory experiences are better understood, biology courses may expand more rapidly into online course offerings, giving students access to a richer education and greater access to ways to increase scientific literacy.

CHAPTER II

LITERATURE REVIEW

Chapter Overview

Online biology instruction challenges present opportunities for biology educators to engage in dialogue about the role of laboratory instruction in the 21st century. This chapter presents the research approach taken by discussing the research paradigm, ontology, epistemology, and theoretical framework used. Within the theoretical framework, constructivism as a learning theory, andragogy, and how and why biology courses may be delivered online by community colleges are discussed. Finally, this chapter reviews the literature related to the community college environment, online education trends, and instructional goals and approaches for laboratory courses.

Research Approach

Research Paradigm

Crotty (1998) suggests that before embarking on research, two questions need answers. The first question address what methods and methodologies will be used; the second addresses the justification for the first's answers. I am using a mixed-model (Johnson & Onwuegbuzie, 2004), collecting quantitative and qualitative data to address two overarching research questions because both types of methods were necessary to understand how instructional practices could be leveraged to help students succeed in an online biology course. A mixed model approach is one in which qualitative and quantitative data were collected within or across the phases of research as opposed to a mixed-method where there are distinct phases of qualitative and quantitative data collection (Johnson & Onweugbuzie, 2004). The quantitative data include learning gains between pre- and posttests, grades for the laboratory, final course grades, and attrition rates. The qualitative data include interviews, focus groups, and researcher observations. I find I follow Peirce (1878), James (1907), and Dewey (1920) in wanting to examine the practical consequences of the research; in this research that translates to the instructional approaches a general biology course uses, therefore I am a pragmatist when I examine my research paradigm (Johnson & Onweugbuzie, 2004).

Research methods are tools which allow researchers to glean understanding of a phenomenon (Onwuegbuzie & Leech, 2005). As a researcher, I want to use those tools which will best allow me to understand how students learn laboratory biology online and how that translates into overall learning in the whole course. As a pragmatist, my research questions drive the methods I use, as Miles & Huberman (1994) advocated. Both qualitative and quantitative methods rely on observations as a starting point. Sechrest and Sidani (1995) noted that both qualitative and quantitative methodologies "describe their data, construct explanatory arguments from their data, and speculate about why the outcomes they observed happened as they did" (p. 78). Sieber (1973) contended that qualitative and quantitative methods have inherent strengths and to better understand phenomena, both should be utilized. Creswell (2002) advocated integrating multiple methods within a single case to more richly describe the phenomenon. The "pragmatic rule or maxim or method states that the current meaning …is to be determined by the experiences or practical consequences of belief" in the research findings (Johnson &

Onwuegbuzie, 2004, p. 16). Being a pragmatist means that I reject a strict dichotomy between qualitative and quantitative approaches and embrace a mix of methods to understand the phenomenon (Johnson & Onwuegbuzie, 2004; Newman & Benz, 1998). This allows me to evaluate how effective different distance laboratory experiences were for students based on consequences, meaning in this research, student grade outcomes and perceptions of laboratory experiences (Johnson & Onwuegbuzie, 2004).

Ontology

Crotty defined ontology as "the study of being," concerned with "what kind of world we are investigating, with the nature of existence, with the structure of reality as such" (Crotty, 1998, p. 10). He also posited that ontology and epistemology merge together (1998). Guba and Lincoln (1989) describe ontological assumptions as responses to "what is there to be known?" or "what is the nature of reality?" (p. 83). Johnson and Onwuegbuzie (2004) keep ontological assumptions separate from epistemological assumptions. In order to clearly state my position, the ontology used to guide this research is soft relativism (Johnson & Onwuegbuzie, 2004). Soft relativism should be understood to mean that the researcher respects the views and opinions of the participants, understanding that the researcher has an "interest in understanding and depicting individual and social group differences" (Johnson & Onweugbuzie, 2004, p. 16) rather than a purist relativist, who would insist on all understanding being constructed by the individual to a local and specific reality and knowledge only existing relative to other constructed understandings (Guba & Lincoln, 1994). I am also not a hard relativist. Hard relativism is portrayed as having two points: truth is a function of framework and all frameworks are equally valid (Alexander, 1986). Soft relativism rejects Guba and

Lincoln's (1994) purist definition of relativism and Alexander's (1986) depiction of hard relativism and embraces instead a pragmatic understanding that while there may be a "truth" that is knowable and measurable, its meaning is created by the participant.

Epistemology

In an effort to ensure a strong research design, I chose a research epistemology congruent with my beliefs about the nature of how students learn biology and in keeping with my pragmatic stance. Epistemology is "how we know what we know" (Crotty, 1998, p. 8) and "the nature of the relationship between the knower or would-be knower and what can be known" (Guba & Lincoln, 1989, p. 201). Identifying the epistemology used in the research allowed me to understand what kinds of knowledge are possible and how I know that knowledge is adequate and legitimate (Maynard, 1994).

Two linked epistemological frameworks, constructivism and constructionism, guided this research. Both were used because the former encompasses the individual's engagement with material and the latter because it encompasses the social building of knowledge through discourse based on empirical data (Crotty, 1998; Papert & Harel, 1991; Schwandt, 2000). Papert, a proponent of constructionism, based his work on Piaget's constructivism and defines constructionism as: "Constructionism—the N word as opposed to the V word—share's constructivism's view of learning as 'building knowledge structures' through progressive internalization of actions… it then adds the idea that this happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sand castle on the beach or a theory of the universe" (Papert & Harel, 1991, p. 1). Constructionism focuses on the building and transformation of ideas when worked out with artifacts and the expression of these ideas, grounded in context, and is “more situated, more pragmatic than Piaget’s constructivism [or Vygotsky’s socio-constructivism]” (Ackermann, 2001, p.5). Constructionism is also concerned with the arriving at “truth” through community discourse and empirical data (Schwandt, 2000). Therefore, as a pragmatist, constructionism was a logical epistemology as it guided my interpretation of student-participant interactions and artifacts: I looked at laboratory summaries and responses to questions in the context of general biology and looked for the building blocks that students used to build understanding. The understanding that biology students needed to be building to be successful in the class (i.e., earn their desired grade) would be based on the scientific community’s understanding of the phenomena under consideration.

Crotty defines constructionism as the view that, “all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between human beings and their world, and developed and transmitted within an essentially social context” (Crotty, 1998, p. 42). This definition of constructionism is used in understanding how science content is created as it recapitulates the scientific method of observation, testing, verification, publication. Crotty delineates between constructionism and constructivism this way: “reserve the term *constructivism* for epistemological considerations focusing exclusively on the ‘the meaning-making activity of the individual mind’ and to use *constructionism* where the focus includes ‘the collective generation [and transmission] of meaning’” (Crotty, 1998, p. 58). This is a variation from Papert and Harel’s (1991) definitions of constructionism and constructivism, where the delineation between the two was based more on an individual manipulating an artifact, either mentally or physically, than the conveyance of understanding of phenomena from individual to collective. Papert and Harel's definition fits with a pragmatic stance and Crotty's definition helps to keep the researcher focused on the inclusion of discourse within a community to arrive at understanding. Based on Papert and Harel's (1991) and Crotty's (1998) definitions, biology education could understand constructionism to deal with the transmission of understanding between the scientific community and learners where participants are engaged in manipulating models and using critical discourse to arrive at a consensus understanding of phenomena.

The social, authentic language aspect of constructionism is important to biology education. Learning any discipline requires learning the language of that discipline (Lemke, 1990). It is within the construction of language that biological phenomena are understood and the language used to describe phenomena unites the scientific community. Learners construct meaning of phenomena by incorporating that understanding into their schema, not inventing their own explanation (Crotty, 1998). Language is essential to construct meaning (Wittgenstein, 1969); therefore, biology learners must learn a culturally relevant language to make sense of scientific constructions of understanding. Grasping the nuances of the language requires that learners practice it through activities such as reading, writing, and discussing (Michael, 2006; Yore & Treagust, 2006). Language acquisition, construction, and usage is therefore central to the constructionist epistemological position.

Constructivism is defined as knowledge constructed by learners in a social environment that incorporates learner experiences (Driscoll, 1994). It can also be thought of as an epistemology in which learners create their own understandings of material based on an interaction between their prior knowledge and believes and the new ideas and knowledge with which they contact (Resnick, 1989). Construction of meaning is a human endeavor; biologists seek to construct meaning of biological phenomenon and students seek to construct understanding of biology content. Biology education can define constructivism as the socially negotiated understanding of phenomena, as recognized by the scientific community, and constructed by learners (Davis, Jo McCarty, Shaw, & Sidani-Tabbaa, 1993). I view constructivism as the learner's struggle to arrive at understanding of phenomena through constructing their understanding of socially negotiated conceptualizations of phenomena.

As a pragmatist, what mattered to me in selecting an epistemology was identifying one that acknowledged learners have to incorporate the ideas they encounter with their previously held beliefs and ideas to create meaning out of what is presented. Students need to re-make ideas in their own ways, confront their ideas that do not hold up to scientific meaning of phenomena and reconcile the differences. The social aspects of learning: discussions, peer-to-peer interactions, student-instructor interactions, engaging with the scientific literature, needed to be present in the epistemology. Constructivism and constructionism allow for the individual mean-making and the social building of knowledge. As Crotty (1998) recognized, there is much inconsistency in terminology though understanding the ideas to be similar but distinct.

Given my pragmatic stance, I embrace the idea that "in the natural sciences many properties of objects can be measured with near-perfect reliability" (Onwuegbuzie & Leech, 2005, p. 377) and recognize that in education, many measures may have a degree of unreliability. This unreliability stems from the abstract nature of the measures, such as achievement and motivation, that are measured indirectly (Onwegbuzie & Daniel, 2002;

Onwegbuzie & Leech, 2005). Indirect measures are without 100% score reliability, meaning that error and hence subjectivity in interpretation is introduced (Onwuegbuzie & Leech, 2005). As an instructor, I recognized that there is content that must be covered in a college-level biology class; as a researcher, my interest lay in how students made sense of laboratory content in an asynchronous, online environment. Crotty (1998) noted that realism (ontological position) postulates reality exists outside the mind and objectivism is its epistemological complement, asserting that meaning exists in objects independent of consciousness. This understanding complements the biology content I teach but not the reality of learners grappling with understanding the content. Therefore, I selected constructionism and constructivism as the lenses through which to conduct my research because through years of teaching biology, I have observed students wrestling with building understanding of content and transmitting their understanding to others.

Theoretical Framework

The journey to find the framework used in this research began with evaluating how I view knowledge. When I was studying fish distribution in tributaries in the Palouse drainage system in eastern Washington, I took for granted that science objectively measured items. After all, the three-spine stickleback, fathead minnows, and speckled dace were all real, slime-coated fish I measured in millimeters before releasing back into the streams. The idea that knowledge could be viewed as relative was still a foreign concept. As I began teaching, it became apparent that not all students hold the same understanding of science content and this was especially true when I began teaching in Oklahoma. Teaching opened my eyes that science, and our understanding of it, may not be a black-or-white world as I had been taught.

One of the first books I picked out of the stacks in the University of Northern Colorado Michener Library was *On Becoming a Biologist* by John Janovy, Jr. (1995). The following passage from the book struck me as illuminating the problem of teaching versus learning biology, the disconnect between the sage on the stage, wishing to pass on knowledge of a subject with "endless forms most beautiful" (Darwin, 1859), with the audience struggling to place foreign bodies in their proper context.

> Inherently and by definition, a broad education demands a person think by the laws of reality which operate in different domains. A student should at least be exposed to the rules and practices of the social sciences and artists, as well as those of normal science. Why is such exposure critical? Because the actual human experience of teaching and learning crosses into multiple domains… lectures, seminars, and symposia are forms of theatrical productions, and so result in the transfer of information according to the laws which operate in the domain of drama…
>
> The most effective pedagogy involves the use of several learning modes—for example, lecture, demonstration, experimentation, and role playing—to reinforce a given idea. Such methods rely on the use of operating rules from several domains to convey a concept that is intended to apply in a single realm. Imagine that we enter a darkened room to teach landlocked Midwestern freshmen, 4-H still coursing through their blood, something of the architecture of sponges. We choose the most beautiful and dramatic pictures of spicules, relate the secretion of species-specific skeletal elements to the aging and sexing of hominid fossils, discuss evolution of body type in parallel with the embryology of a pig's lung to illustrate folding, and in the end generalize, using the rhetorical devices of an actor, by asking how a principle of development derived from sponges could be applicable to our lives, how often the true nature of something is obscured until we study its ontogeny. In the silence, we spread the leuconoid principles across individual lives, across history: How did we get into this condition? We got here through a progressive series of changes. No one in the class has seen touched, measured, or chemically analyzed a sponge, yet all feel they've learned. Given the fact that they can't walk directly from the lecture hall to the ocean, they have. The subject is biology. (p. 100)

Science education constructivism posits that students are responsible for constructing meaning of course content and is the bedrock for student-centered learning practices. As the quote from Janovy illustrates, biologists commonly transmit information to students in a lecture hall, feeling as though learning will occur if elegant illustrations and linkages to other areas of biology are provided for students to absorb. If the goal of biology instructors is for those Midwestern freshmen (and all other biology students) to understand how we got "into this condition" then it is necessary for those students to construct meaning of that information that links into and changes *their* prior knowledge.

Constructivism

Understanding constructivism as applied to biology education research is essential for informing sound pedagogical practices in a discipline struggling to retain students (Lord, 1997). Colburn (2000) defines constructivism in science education as "trying to help students *change their beliefs* to be more in line with those held by the scientific community" (p. 42). The beliefs of students matter because "there are extensive sets of attitudes and beliefs about science that are taught to our students. How we conduct our class sends messages about how, why, and by whom science is learned" (Perkins, Adams, Pollock, Finkelstein, & Wiemann, 2005, p. 61). Further, it is through changing student beliefs about the nature of science that meaningful learning about science occurs (Perkins et al., 2005). Lambert & McCombs (1998) reference a 1991 study by Goldenberg to characterize learner-centered constructivism as a way "in which students try to make sense of their experience by constructing knowledge, meaning and understanding" (p. 11). These definitions provide guidance for a framework of science education constructivism.

Student-centered learning, relying on the theoretical underpinnings of constructivism, removes the instructor as the “sage on the stage” and centers studying on learners, making the instructor the “guide on the side” (King, 1993). Such student-centered learning instructional practice is a common paradigm used to address science education research questions (Clement, 1993; Driver, Asoko, Leach, Scott, & Mortimer, 1994; Galili & Hazan, 2000). Clement (1993) reported that students with alternative views in introductory physics benefited from student-centered learning strategies involving discussions and analogies to understand central concepts. Driver et al. (1994) posited that learners have to not only construct meaning but also understand the symbolic world of science through accessing the knowledge systems of science and discussing these with a more experienced person. Introduction to biological concepts would be introduced through discourse on relevant tasks, such as laboratory activities. Galili & Hazan (2000) reported that challenging students’ prior knowledge allowed those students to construct more correct scientific understandings and such challenges take place in student-centered learning because of the fundamental ways in which people construct understanding.

Constructivism as an educational theory has a rich history with names such as Piaget, Bruner, and Vygotsky shaping the paradigm while others such as Knight, Wood, and Lord expanded the educational theory to explicitly explain its application to scientific knowledge and biology education. Constructivism as a modern learning theory appears to date to John Dewey who advocated for students to grapple with situations in which they must draw out meaningful experiences (Dewey, 1930). Dewey did not believe that learning occurred in a vacuum but rather that manipulation of ideas in a social context was necessary for learners to construct knowledge together. Application of concepts in meaningful ways is central to Dewey's understanding of learning. Piaget (1964) and Bruner (1996) were also central to the development of constructivism. Piaget's constructivism, based on children's psychological development, is the basis of discovery learning and is readily applicable to science education (Piaget, 1964). Learners progress through stages in which they discover and accept ideas that may later be discarded as wrong, meaning that understanding of ideas is built slowly over time through inquiry-based learning. Bruner's ideas of learning centered on student discovery of new principles in a spiral manner so that students built upon prior knowledge based on their readiness to learn, ability to extrapolate, and organization of material (1996).

Research suggests that students need to build upon their prior knowledge and reconcile alternative conceptions with conceptions advanced by the scientific community. Yet Lord (1997), Hofstein & Lunetta (2004) and Wood (2009) argue that many general biology courses are still taught in a manner in which instructors transmit knowledge, rather than have students construct their understanding. The disconnect between research and teaching is glaring and does little to attract students to the discipline or retain them once they are sampling majors-level courses (Walczyk & Ramsey 2003). In light of this, over the past two decades more content specialists, those whose primary research has been content-focused, have recognized a need to evaluate how biology courses are being taught in higher education. The nature of science and structure of science have long been questioned by philosophers of science (Herron, 1969) yet there is still a lack of awareness among community college faculty that how we understand the nature of knowledge fundamentally impacts the way we view education. In a traditional scientific view of knowledge, Kuhn describes scientific knowledge changing through revolutions (2012) and those revolutions creating paradigm shifts. Such a shift is needed for biology educators to shift from a view of knowledge that exists "out there" to being constructed by learners (McComas, Clough, & Almazroa, 1998).

Lord (1997, 1998) posits that education focused on a learner's prior knowledge, aspirations, and interests increase student motivation. Lord (1997) reported lecture classes structured around constructivist learning principles had learners who performed better on standardized, departmental exams and maintained more positive attitudes about biology than students whose instructor used traditional, instructor-driven methods. Studies after Lord's continued to support these findings (Knight & Wood, 2005; Zumbach, Schmitt, Reimann, & Starkloff, 2006) yet most biology courses appear to be taught with traditional, instructor-driven pedagogy (Wood, 2009). There is reason to believe that online education can change this paradigm; online education gravitates towards learner-centered approaches (Koohang, Riley, Smith, Schreurs, 2009; Wang, 2010; Wang & Kang 2006).

Biology education espouses constructivism in online biology courses. Online instruction fosters a greater use of learner-centered constructivism principles in course design than in traditional face-to-face classrooms, encouraging engagement in participant-driven discussions where articulation and reflection of scientific principles promotes metacognition (Asbell-Clarke, Rowe, Leibowitz, & Hubbard, 2007; Pyatt & Sims, 2007). Such an embrace may influence traditional lecture halls, influencing instructors to change from instructor-driven methods to methods with students constructing their own knowledge. As more students take online biology courses and are in turn influenced by such instructional methods, the next generation of biology instructors will be better trained in constructivism than preceding generations.

Much can be said for focusing education on a learner's aspirations and interests yet even with such a focus, there is also content that must be mastered and assessed for understanding. The National Research Council perceives science education fitting within four overlapping ways-of-learning domains: learner-centered, knowledge-centered, assessment-centered, and community-centered (NRC, 2005). Rather than be exclusive, these domains are inclusive of each other and support constructivism instructional strategies. Scaffolding content so that learners are supported in the discovery and construction of knowledge is essential for successful education in all fields. The overlap of knowledge-centered and learner-centered instructional strategies where specific content is mastered by the learner by building on their previous knowledge, gains meaning and expands their understanding of the living world is when students construct understanding.

Constructivism fits well within biology education research; it may be the "grand unifying theory" of biology education as Colburn (2000) postulated. The challenge appears to be having more instructors adopt the use of this grand unifying theory. Just as Darwinian evolution faced an uphill battle for acceptance among all scientists until there was a scientific revolution standing the old paradigm of creationism on its head, biology education research faces an uphill battle today in getting biology instructors to understand the need for theoretical frameworks. The focus of instructors needs to be on nurturing student learning rather than trying to cover all the content that is deemed "biology." It is possible that the expansion of online education opportunities will foster greater use of learner-centered instructional strategies in biology education to the benefit of all biology instructors and their students.

Andragogy

Higher education traditionally operates within a continuum of teaching methods with lecture being the predominant mode for knowledge transfer (Brookfield, 1986; Cross, 1981; Knowles, 1980, 1990; Merriam & Caffarella, 1999). This continuum can be thought of as ranging from teacher-centered methods, embodied by pedagogical approaches, and student-centered methods, embodied by andragogical approaches. Defined as “the art and science of teaching children” (Knowles, 1990) pedagogy practices in higher education replicate environments where learners are expected to be passive recipients of knowledge. The classic example of pedagogical approaches is the lecture. Contrast pedagogy with andragogy: “the art and science of teaching adults” (Knowles, Holton, & Swanson, 1998). Andragogy in higher education posits that student-centered activities produce engaged learners. Both pedagogy and andragogy have sets of assumptions that guide instructors on how to best design classes for learners. While it may seem that contrasting pedagogical approaches and andragogical approaches is semantic hairsplitting, the differences in the two sets of assumptions should be examined and understood by education researchers (Table 1). Both models make six assumptions about learners: the learner’s need to know, self-concept, experience, readiness to learn, orientation to learning, and motivation (Knowles, Holton, & Swanson, 1998).

Table 1

Instructional Approach Assumptions. Adapted from Knowles, Holton & Swanson, 1998.

Aspect	Andragogical Model	Pedagogical Model
Need to Know	Learner needs to know why something is important prior to learning it.	Learner needs to know what the teacher tells them.
The Learner's Self-Concept	Learners are responsible for their own decisions.	Learners are dependent on the teacher.
Role of the Learner's Experience	The learner's experiences have great importance.	The learner's experience is of little worth.
Readiness to Learn	Learners become ready to learn when they see content as relevant to their lives.	Learners become ready to learn when the teacher requires.
Orientation to Learning	Learners expect life-centered content.	Learners expect subject-centered content.
Motivation	Learners are motivated primarily by internal forces.	Learners are motivated by external forces.

Needs and goals of community college learners are different than the needs and goals of learners in the K-12 system (Knowles, 1980; Cross, 1981; Brookfield, 1986; Merriam & Caffarella, 1999). Online instruction offers an opportunity to reach adult learners using new methodologies based on andragogical principles. Community college instructors should consider andragogical principles when designing online content delivery for adults. Merriam & Caffarella (1999) recommend that higher education instructors consider blending pedagogical methodology with principles of andragogy to help learners achieve success with content.

Student-Centered Classrooms

Researchers have been evaluating the effectiveness of learner or student-centered classrooms compared to instructor or teacher-centered classrooms for many years (Baviskar, Hartle, & Whitney, 2009; Burrowes, 2003; Feldman, 1976; Huba & Freed, 2000; Fata-Hartley, 2011; Knowlton, 2000; Lord, 1999; Weimer, 2006). Student-centered classrooms stem from a constructivist perspective held by the instructor (Lord, 1997). The activity in any given classroom may fall on a continuum of student-centered to instructor-centered, depending on the epistemological position of the instructor and the subject content (Lord, 1997). Generally, student-centered classrooms or student-centered activities produced higher levels of student success, motivation to learn, and satisfaction (Lord, 1997; Huba & Freed, 2000).

Learner-centered classrooms also facilitate the movement towards expert from novice on a learning continuum. Faculty can be thought of as anchoring the expert end of the continuum while non-majors biology students can be thought of as anchoring the novice end of the continuum. In *How People Learn* (Bransford, Brown, & Cocking, 1999), the idea of expertise is explained as field-dependent, organized knowledge supporting understanding. Through their organization schemas, experts recognize and rely on patterns of relationships to recall and understand information. Students in introductory courses have difficulty identifying such patterns because they typically do not know much about biology or have deep-seated alternative conceptions about biology. Alternative conceptions can be thought of as "existing mental models that are at variance with accepted scientific knowledge (even when the faulty mental model has some demonstrable utility in the student's life)" (Michael & Modell, 2003, p. 11). Novice students have little prior knowledge to relate the new knowledge they are learning so that retaining and constructing meaning with the new knowledge is difficult. This means that instructors need an understanding of the knowledge level of students as it will shape what students learn.

Student-centered classrooms generally have lower attrition rates and higher success rates when compared to instructor-centered classrooms. Lasry, Mazur, & Watkins (2008) reported lower attrition rates in student-centered physics courses at two-year institutions compared to instructor-centered physics courses. Freeman, Haak, & Wenderoth (2011) reported higher success rates for students in student-centered majors' introductory biology courses compared to instructor-centered majors' introductory biology courses at a top-tier, four-year research university. Wood (2009) reported a decrease in attrition rates in student-centered introductory biology courses and argued that such methods do more to prepare students for a globally competitive world.

Community colleges typically include some aspect of preparing their students for the global workforce in their mission; understanding student-centered classes may help instructors meet that goal. Understanding what student-centered (also referred to as "learner-centered") instruction looks like is necessary. Felder and Brent (1996) characterize it as:

> Student-centered instruction is a broad teaching approach that includes substituting active learning for lectures, hold students responsible for their learning, and using self-pace and/or cooperative (team-based) learning. Other ways to center our teaching on students include assigning open-ended problems and those requiring critical or creative thinking, reflective writing exercises, and involving students in simulations and role-plays. (p.43)

Student-centered learning in an online class allows students and the instructor to introduce materials, such as texts, questions, and outside resources, and discuss the implications these have on learning (Gibbons & Wentworth, 2001). Student-centered learning encourages collaboration and discussion between students and between students and instructor (Gibbons & Wentworth, 2001). In a student-centered laboratory class, instructors understand that students construct their understanding of content and need opportunities to discuss with peers and the instructor their understanding (Winters, Lemons, Bookman, & Hoese, 2012). When student-centered instruction is poorly done, instructors may be too quick to provide answers to students (Winters, et al, 2012).

One way to address student attrition rates is for instructors to adopt learner-centered instruction including active learning methods (Braxton, Milem, & Sullivan, 2000). Learner-centered instruction includes four domains into which instructional principles and activities can be grouped: cognitive and metacognitive factors, motivational and affective factors, developmental and social factors, and individual differences factors (McCombs & Vakili, 2005). Learner-centered instruction is defined as that which focuses learning on an individual student's background, including experiences and perspectives, interests and needs, to effectively promote motivation, learning, and achievement (McCombs & Whisler, 1997). Active learning "involves students in doing things and thinking about the things they are doing" (Bonwell & Eison, 1991, p. 2). Examples of active learning include: discussions, instructor-posed questions, peer-to-peer questions, reflective writing assignments, and test questions (Braxton, Milem, & Sullivan, 2000). Those students who experience active learning believe they have enhanced knowledge and course content and feel more positive about their college experiences (Braxton, Milem, & Sullivan, 2000). Learner-centered active learning may also appeal more to non-traditional students because these students voluntarily returned to higher education and tend to be responsible learners (Miller & Lu, 2003); such approaches may increase retention.

Student-centered teaching in an online course is an area in need of further research in science education. Because student-centered practices increase retention in face-to-face settings, it is logical that student-centered practices would increase retention in online courses. Increasing retention may help online science education gain acceptance by community college instructors but is not the only concern such instructors have in expanding online science education opportunities. Other instructor concerns include administrative support, student readiness, student isolation and frustration, technology, bandwidth availability, and questions of effectiveness (Appana, 2008; Downes, 2000; Smart & Cappel, 2006). In short, online learning has its limitations (Appana, 2008). Overcoming these limitations requires institutional support for instructors and students (Appana, 2008) and instructional design that engages learners (Smart & Cappel, 2006).

Grounded Theory

As grounded theory uncovers relevant conditions by determining how participant respond to conditions under investigation, this method was useful in seeing how students perceived their laboratory experiences without letting my preconceived notions of the superiority of hands-on activities detract from the data (Strauss & Corbin, 1990). The data, as is true in grounded theory methodology, came from a variety of sources (Strauss & Corbin, 1990). These sources included lab summaries, interviews, and focus groups. Analysis began as data were collected (Strauss & Corbin, 1990) by reading and re-reading the data and generating word clouds. This allowed the examination of multiple data points simultaneously and the discovery of how students perceived their laboratory experiences, keeping with grounded theory methods (Glaser & Strauss, 1967). Through comparing lab summaries and naming similar experiences with the same term, categories emerged. Categories are descriptions that pertain to the same phenomenon as defined by the actions used by the participants to describe their laboratory experiences, thus giving explanatory power to how students perceive online laboratory experiences (Corbin & Strauss, 1990). To give a more robust description of student perceptions towards distance laboratory work, observing the completion of laboratory activities of online students would be an area of fruitful inquiry.

Community Colleges

Missions Define Community Colleges

Community colleges offer learners a distinct higher education experience. "Community colleges are centers of educational opportunity…inclusive institutions that welcome all who desire to learn, regardless of wealth, heritage, or previous academic experience" (Dougherty & Townsend, 2006, p. 1). A community college strives to meet many diverse needs under an open admissions policy. In doing so, compromises regarding areas of emphasis are often made (Brint & Karabel, 1989; Dougherty, 1994; Dougherty & Townsend, 2006). What educational opportunities a community college ends up focusing on can be directly tied to the mission of a particular community college (Dougherty & Townsend, 2006). The mission of Cotton College is to "provide high quality education, support student success, and empower individuals to become productive members of local, regional, and global communities." As it relates to general education classes for transfer to four-year institutions, Cotton College's planning documents state it exists to provide: "a quality and affordable general education for all students; and a rigorous education in several basic fields of university-parallel study for those students who plan to transfer to a senior institution and complete a bachelor's degree" (Cotton College, 2011).

The mission of community colleges encompasses three broad directives under an open admissions policy: general education courses as part of associates degrees or transfer to four-year institutions, technical workforce training, and continuing education opportunities for lifelong learning in the community (Vaughn, 2006). Focused primarily on teaching (Kane & Rouse, 1999), community colleges use mission statements to direct the focus of their campuses, especially in a rapidly changing world with new opportunities (Dougherty & Townsend, 2006). Educational opportunities developed by community colleges, include collegiate and transfer education, occupational education, remedial education, and adult and community education (Cohen & Brawer, 2003). The mission of a community college is therefore designed to act as a guide for a college's administrators and faculty in deciding how to best serve the needs of their students (Baily & Averianova, 1998). With mission statements directing administrators and faculty to meet the educational needs of the diverse students they serve, community colleges began an extensive foray into online educational opportunities in the early 2000's to meet student need (Allen & Seaman, 2010).

Community Colleges and Online Education

Community colleges offer higher education opportunities to an array of learners. One characteristic many of these learners have in common is a desire for flexible scheduling of classes (Miller, Pope, & Steinmann, 2005). To meet student demand for flexible scheduling, colleges and universities nationwide expanded online course offerings (Bourne, Harris, Mayadas, 2005; Frith & Kee, 2003; Schrum & Hong, 2002), Cotton College began expanding online educational opportunities for general education classes in 2006-2007. With working adults comprising a substantial proportion of students, community colleges met their students' needs with online asynchronous instruction (Mayadas, Bourne, & Bacsich, 2009). Institutions also saw online education as a way to meet increased student enrollment while working within constraints of limited facilities and instructors (Vaughan, 2006). One of the driving factors for Cotton College's expansion into online general biology was to be able to serve an increasing student enrollment with flexible scheduling options without having to expand the physical capabilities of the campus. Such physical expansion was logistically and fiscally unmanageable to handle in a timely manner to meet student demand. This reflected other campus' solutions to meet demand when physical expansion was an unavailable option (Crawford & Persaud, 2013). Online educational opportunities became the answer to meet increasing student enrollment.

Students seek flexible paths to degree attainment, as evidenced with 1 out of 3 college students enrolled in at least one online class, (Allen & Seaman, 2010). In 2013, the number of college students taking online classes was 7.1 million and 70.8% of administrators surveyed viewed online education as critical to their long-term success (Allen & Seaman, 2013). Students cited flexibility as the number one reason they took an online class (Crawford & Persaud, 2013). The laboratory component of science courses offers unique opportunities for instructors to provide flexible learning opportunities, including ones that can be accessed at the students' convenience.

As online education became a central component for the majority of the nation's community colleges, many disciples offered courses and programs online (Allen &

Seaman, 2010). In 2010, 65 percent of higher education institutions reported that online courses were critical to their long-term strategy (Allen & Seaman, 2011). The health profession disciplines, including allied health fields, were the fastest growing in online program offerings (Allen & Seaman, 2010). However, data on the total number of online science courses or programs was limited while the scarcity of courses was noted by researchers and instructors (Jeschofnig & Jeschofnig, 2011). The scarcity of science courses was likely due to the laboratory component and faculty being unwilling, unable, or uncertain of how to deliver laboratory experiences at a distance (Jeschofnig & Jeschofnig, 2011). For instance, at Cotton College, eleven sections of general biology were offered over the course of a year: eight in a traditional face-to-face on-campus setting and three sections online. Comparatively, Cotton College's child development courses offered ten online courses and two face-to-face courses; English, mathematics, history, and art offered an even split of their on-campus and online offerings. Such low availability of online courses is problematic for science content. Science courses represent a critical component of general education requirements and to a liberal arts education (Cech, 1999; Schwab, 1982).

While flexibility for students was a driving factor in the expansion of online courses, the continuation of online course offerings is driven by student success as measured by the number of students completing courses. Cotton College's online programs, like that of many other community colleges nationwide, faced retention issues. Addressing retention is of critical importance in designing and implementing online courses (Angelino, Williams, & Natvig, 2007; Aragon & Johnson, 2008). In some science disciplines, more than 50% of the students starting an online science course fail to complete it (Freeman et al., 2014). One way to address retention rates is for instructors to adopt learner-centered instructional modes (Braxton, Milem, & Sullivan, 2000; Freeman et al., 2014).

Community College Learners

One of the distinguishing characteristics of community college learners is that non-traditional students make up a large percentage of the population (Kim, 2002). Non-traditional students are defined in literature as between the ages of 25 and 50, entering post-secondary education with a high school diploma or GED (Kenner & Weinerman, 2011). Non-traditional students may also be financially independent whereas traditional students are not (Levin, 2007). This financial independence means that non-traditional students tend to work full-time to support themselves, their families, and their educational aspirations, placing them at greater risk for not completing their education (Ely, 1997). Non-traditional students also have one semester or less of college credit (Kenner & Weinerman, 2011). Traditional students are between 18-24 years of age and attending school on a full-time basis (Miller & Lu, 2003). These students started college within one year of completing high school and are learning to balance multiple responsibilities outside of school, facing multiple stressors outside the classroom (Kim, 2002; Dill & Henley, 1998). Community college learners tend to have family responsibilities, job responsibilities, and community commitments (Miller, Pope, & Steinmann, 2005). The community college students involved in this study typically had family obligations as parents, caregivers to aging parents, a job requiring more than 30 hours per week, church commitments of approximately 5 hours a week, and were carrying an average of 12 credits. A further description of student-participants is provided in Chapter III.

Traditionally higher education has served the needs of a student population typified as 18-22 years of age, white, and of upper socioeconomic status (Cross, 1981). Such students, and the faculty who teach them, value broad educational exposure (e.g., general education), counseling and advising services, intellectual orientation to college, career preparation, personal development, and a sense of college community (Cross, 1981). Historically, the needs of students were often unmet (Bowl, 2001). Students, especially non-traditional students, can be characterized as “frustrated participants” (Bowl, 2001, p. 152), and struggle to balance financial and academic stability, lack of time, indifference, and institutional marginalization (Bowl, 2001, p. 152). Between 1986 and 1992, enrollment in higher education increased 17 percent (National Center for Education Statistics, 1996). Between 1996 and 2010, higher education enrollment of students ages 25-34 increased 45 percent and enrollment of students ages 35 and over increased 32 percent. In 2013, an estimated 17.5 million students enrolled in higher education programs which represents a 46% increase from 1996 (NCES, 1996; NCES, 2015). An additional two million students began undergraduate studies in 2014 (NCES, 2015). Approximately 41% of those students are learners over the age of 25 (NCES, 2015). Many of these students today face struggles similar to Bowl’s (2001) “frustrated participant” in that students are motivated to succeed academically but lack the infrastructure supports to do so (Handel & Williams, 2012).

Community college campuses often have different learners compared to four-year colleges and universities. Community colleges are typically more ethnically heterogeneous with older students who are less academically prepared, may have limited English proficiency, and are first generation college students (Fike & Fike, 2008).

Community college students also typically have first-hand experience with financial hardship: lower socioeconomic status, job loss, or job retraining have driven these students to seek higher education opportunities (NCES, 2003). If students older than 22 are going to enter higher education, they typically enroll in a community college (NCES, 2003).

An important distinguishing feature of community college students is that they are adult learners. This is important because adult learners typically have different learning styles (Felder & Brent, 2005). As opposed to younger students who tend to be subject-oriented, adult learners seek for their learning to be task and goal-oriented (Knowles, 1984). Such students want to see an immediate benefit to themselves for the learning strategies used by an instructor (Kenner & Weinerman, 2011). Many of the metacognitive strategies (ways in which they think about their learning) that adult learners have adopted and used successfully in their everyday and professional lives may not be beneficial to collegiate learning (Sternberg & Caruso, 1985). This challenges instructors to present new learning strategies to adult learners and show them how such strategies will be of benefit to them in successfully completing college classes.

Cotton College recognized the non-academic responsibilities students typically had and honored students' desires to complete degrees or work training programs and launched an aggressive foray into online education in 2006-2007. This expansion was mirrored in community colleges across the nation (Allen & Seaman, 2010). Cotton College's online education program, like that of other community colleges nationwide, faced a retention issue. While not the focus of this research, addressing retention is of critical importance when designing and implementing science online courses if the failure and retention rates mentioned previously are to be addressed. Given the responsibilities students have outside of academics, it was apparent that classes could become simply another item on a long to-do list for a number so students who have other responsibilities or were inadequately prepared for college-level work (Fike & Fike, 2008).

Learning Outcomes for General Biology

Common goals for science courses include teaching critical thinking skills and problem-solving abilities (Hofstein & Lunetta, 2004). Teaching critical thinking skills entails students learning how to understand and evaluate content (Schafersman, 1991). The laboratory component of science courses offers unique opportunities for instructors to provide flexible learning opportunities, including ones that can be accessed at the students' convenience. The emphasis on placing the learning of laboratory experiences in the hands of the learner is done because of community colleges' focus on creating student-centered learning environments (Huba & Freed, 2000).

Instructional challenges require that researchers investigate what students will learn in a laboratory experience given different student backgrounds, needs, and instructors' expectations for college laboratory courses. Researchers also need to investigate the options to deliver that experience when instructors face the realities of decreased budgets, increased demand for classes, and a more diversified student body. Recognizing that students with different backgrounds, preparation, and abilities have different levels of success, instructors have found that instructional choices matter for students to be engaged with the course (Jegede & Okebukola, 1991). The current literature review suggests that it is important to understand the instructional uses of laboratory experiences, evaluate the effectiveness of laboratory experiences using quantifiable methods, and understand student and instructor perceptions of the use of laboratory experiences through qualitative methods. Quantitatively evaluating the effectiveness of distance-delivery methods is a necessary step for their expanded and accepted use. Understanding how students and instructors perceive distance-delivered laboratory experiences is important to promote sound instructional practices and student learning in the advancing world of online science education.

The purpose of this research was to investigate how effective two distance-delivered laboratory methods were as instructional tools in an online general biology course. Instructional tools must serve the needs of the learning outcomes. Therefore, knowing what the learning outcomes of a course are is essential in determining if the instructional tool is appropriate. The learning outcomes for the general biology course used in this study were:

1. Demonstrate knowledge and understanding of basic biological concepts and principles, including comprehension of life and living systems, various biological laws and theories, and their importance.
2. Solve problems and reach tenable solutions that require abstract and analytical reasoning.
3. Collect data, analyze it, and submit reports demonstrating comprehension of the principles involved.
4. Apply the habits of critical thinking as demonstrated by descriptions of how science is relevant to their daily lives and use this understanding to make responsible decisions about the impact of human activities on the environment.

These learning outcomes were determined by a committee of full-time science faculty at Cotton College. Cotton College's Curriculum Committee, composed of faculty and administrators, approved these learning outcomes in the fall of 2006 to be used as the learning outcomes in all sections of general biology offered by the institution.

Laboratory experiences are intrinsic to laboratory-based science courses; this has been a contributing reason for the slow expansion of such courses into the online academic arena. Laboratory instruction in the United States dates to the 19^{th} century (Tamir, 1976). For over a hundred years, instructors have struggled with finding meaningful ways to address and include laboratory instruction in the classroom (Anderson, 1976; Kirschner & Meester, 1988; Hofstein & Lunetta, 1982; 2004). With emphasis today on students' active learning in the science classroom, the purpose of laboratory instruction is again being debated.

While national reports such as *Bio2010* (National Research Council, 2003), *A New Biology for the 21st Century* (National Research Council, 2009), and *Vision and Change* (American Association for the Advancement of Science, 2011) have outlined preparing students for 21^{st}-century biology learning, the focus has not been on community college learners. Nor has there been consensus on the objectives of the laboratory at any level (Tobin, 1990; Hofstein & Lunetta, 2004; Hodson, 2005). *Bio2010* was aimed at future biomedical researchers and focused on creating research-focused laboratory experiences, while recognizing the interdisciplinary nature of biology (Kennedy & Gentile, 2003). The *New Biology* report (NRC, 2009) focused on the interdisciplinary nature of biology, the need for the next generation of biologists to have strong quantitative skills, and for all undergraduate students to engage in independent research as soon as possible in their respective educational plans. *Vision and Change* (2011) encouraged laboratory work to take a prominent position in introductory courses and focused on evaluating a student's ability to apply new information and think critically. *Vision and Change* (2011) encouraged the development of process skills, including experimental design, data analysis and communication of results (Schmidt, 2013). These reports advocated an apprenticeship model (i.e., working in a faculty member's active research laboratory) to highlight the call for engaging students in research as well as encouraging the use of inquiry-based laboratory instruction. This call for undergraduate research is an expansion of previous calls for inquiry-based laboratory instruction (Hofstein & Lunetta, 1982; 2004).

The Boyer Commission Report (Kenny et al., 1998) offered suggestions for improving undergraduate biology education through constructivism principles of inquiry-based education, primarily through the involvement of all undergraduates in research laboratories. While the focus of the Commission was the improvement of biology education at R1 universities, the message involving students in research opportunities is applicable to all institutions, regardless of size. However, one limitation of institutions is limited access to research projects. To overcome that limitation, Wood (2003) argued that transforming large lecture classes into inquiry-based, interactive sessions where students questioned processes and solved problems constituted inquiry-based learning.

Expanding the apprenticeship model at community colleges may be difficult, given the institutional focus on teaching and community college faculty perceptions of the value of undergraduate research opportunities. Interestingly, 60% of community college life science faculty believe that a student's ability to design an experiment is the least important skill for students to master as undergraduates while approximately 50% of instructors at R1 universities and nearly 70% of instructors at non-R1 universities believe that the least important skill a student masters as an undergraduate is being able to effectively monitor their own learning (Coil, Wenderworth, Cunningham, and Dirks, 2010). There is more agreement regarding the most important skill for undergraduates to master, with faculty of R1 universities, non-R1 universities, liberal arts colleges, and community colleges perceiving that problem solving/critical thinking is the most important skill to develop as an undergraduate (Coil et al., 2010). This is followed by interpreting data and developing communication skills (Coil et al., 2010).

Examining the three most important skills that faculty agree should be developed as an undergraduate: critical thinking, interpreting data, and communication, suggests that laboratory instruction does not require the physical manipulation of apparatus. While learning in the laboratory may ideally include manual manipulation, the ability to problem solve is of greater priority according to faculty (Coil et al., 2010). If alternative instructional methods, such as simulations, meet many of the goals of laboratory instruction, they should be evaluated for instructional use.

Finding ways in which to include learning experiences fulfilling the laboratory learning experience that meet general biology learning outcomes in online courses is necessary to provide access to general education science classes, particularly at community colleges. Eli Meir, founder of SimBio, a leading virtual simulation software company, observed, “Students, and much of the general public, have trouble understanding what makes a good scientific experiment, and changing that is a major goal of introductory science classes. But to learn, students must practice designing their own experiments…there are too few opportunities for that in the introductory biology classes…" (Meir, 2012). Couple this observation with the realities community college instructors have with perennially underfunded budgets, the need for research to investigate distance-delivered laboratory instruction methods becomes more readily apparent. The current literature review suggests that it is important to understand the instructional uses of virtual simulations and at-home kits, the effectiveness of biological simulations via quantifiable methods, and qualitatively understand stakeholder perceptions of the use of distance-delivered laboratory methods.

Online Biology

Online education has grown rapidly in the last ten years (Allen & Seaman, 2010). Today, online course offerings are plentiful and students have numerous choices in advancing their education. Laboratory-based science classes have been slow to adopt online delivery methods for a number of reasons, primarily based on concerns over how to deliver the laboratory experience.

Biology education has multiple options for moving into an online milieu. One interesting proposal is the use of Power Labs, regional centers for online laboratory development based on physical laboratory work using remote instrumentation and brief, intensive face-to-face contact (Albon, Cancilla, & Hubball, 2006; Cancilla & Albon, 2008; Çepni, Taş, & Köse, 2006). Power Labs could be associated with a hybrid format of online learning but rather than have a weekly laboratory meeting, a weeklong laboratory experience would be scheduled, after extensive preparation via case studies, orientation, and remote instrumentation work (Cancilla & Albon, 2014). Another option is web-based simulations re-creating classic biology experiments while giving learners the ability to change the variables (Ayala, 1999). It is not necessary or desirable for virtual simulations to replace all traditional laboratory components. As Windschitl (1998) argues, if physical laboratory space is equipped, available, and practical for student use, a simulation should not be used. These conditions are often unmet, necessitating examination of alternatives. Researchers investigating the use of computer simulations to deliver laboratory experiences found faculty reserved over the replacement of a hands-on experience with a computer simulation (Bialek & Botstein, 2004). Other faculty concerns have included the potentially isolating online environment learners encounter, the validity of laboratory exercises not done under the supervision of an expert, and the transferability of the laboratory component (Volery & Lord, 2000).

It is to be hoped when conditions for students are not suitable to employ a traditional laboratory experience, other options, such as the ones mentioned here, will influence instructors to change from instructor-driven, face-to-face based options to student-centered, virtual options. When physics courses at a large university in New York needed more space for student learning, researchers designed and evaluated virtual simulations and found that students benefitted by constructing their understanding of physics concepts (Bhargava, Antonakakis, Cunningham, & Zehnder, 2006). Additionally, researchers found that these virtual simulations reduced equipment needs, met student need for flexible scheduling, offered rich information not readily available in traditional labs, and students were able to self-pace their learning (Bhargava, et al., 2006). This prompted the department to integrate more such student-centered methods into classes. As more students take online biology courses and are in turn influenced by such instructional methods, the next generation of biology instructors will be better trained in student-centered learning methods than previous generations (Davis, Petish, & Smithey, 2006).

Previous researchers' findings suggest that online education is a valuable experience for students of the digital age and it is a practice that continues to expand (Asbell-Clarke et al., 2007). As more students begin the journey of higher education, more demand will be created for quality, flexible general education classes, including laboratory-based sciences. An expansion of online general biology classes is therefore likely. However, there is limited research on the effectiveness of virtual biology simulations to teach concepts in general biology. Likewise, there is little research on the value students and instructors perceive virtual science experiments offer in place of traditional face-to-face settings.

The use of virtual simulations to teach science content is not new. As computers have evolved from behemoth-sized to mouse-sized, software applications have been changing too. While the first computer simulations were little more than an algorithm to play with different scenarios, today's simulations are more sophisticated, with interactive graphics, elaborate or life-based scenarios, and are more easily available to a wider audience. Early research using microcomputer simulations found that community college students using problem-based simulations in environmental education increased their problem-solving abilities with gains lasting at least five weeks after participating in the simulation (Faryniarz & Lockwood, 1992). Microcomputer simulations were tools that helped students learn skills to process scientific concepts (Berge, 1990; Chiu, 1999). Other researchers found that using virtual simulations helped students obtain higher-order thinking skills, such as interpretation of graphs, which benefited the students' study of content material (Jackson, Berger, & Edwards, 1992).

Research on the current generation of virtual biology simulations does not do a good job of separating out the effects virtual simulations have on student learning compared to effective teaching of the material by an instructor or other outside sources of learning, such as textbooks (Abraham et al, 2009; Maldarelli, Hartmann, Cummings, Horner, Obom, Shingles, & Pearlman, 2009; Swan & O'Donnell, 2009). Researchers either do whole class analysis and create treatment groups "naturalistically" by allowing students to self-select treatment groups and rely on self-reporting with an honor system (Swan & O'Donnell, 2009) or researchers create special focus groups drawn from populations of college students (Abraham et al., 2009; Meir, Perry, Herron, & Kingsolver, 2007). Another challenge with this research is that the results of effectiveness of virtual simulations are reported as a whole and not individually, so that the effectiveness of a virtual microscopy simulation is compared with the effectiveness of a virtual evolution simulation (Swan & O'Donnell, 2009; Maldarelli, et al., 2009) so while a study may speak to the generalities of virtual biology simulations, they are not addressing specific simulations.

The strength of the research discussed above is that the researchers are recognizing that virtual simulations have a place in college and university classrooms. Swan and O'Donnell (2009) focused on the impact virtual biology simulations had as supplemental instruction tools for motivated biology students. They found that students who used virtual biology simulations performed significantly better on laboratory practical examinations but the gains did not transfer to lecture exams, including the final exam. This raises the question if the virtual biology simulations being vetted were too specific for laboratory techniques and not specific enough for “big picture” concepts. If the purpose of laboratory is to explore the concepts introduced in lecture, it is curious that students who performed significantly better on laboratory exams were not able to transfer knowledge to lecture exams.

Virtual biology simulations used as instructional support tools have been shown to help introductory biology students master concepts (Bell, 1999). One limitation of introductory biology laboratory sessions is time. By using virtual biology simulations that are housed on the World Wide Web or on software stored with the student, instructors can by-pass this limitation and provide students with a means for understanding biology (Bell, 1999). One challenge with using virtual biology simulations stored on the Web is the maintenance of the website where the simulations are located; the simulations described by Bell (1999) are no longer available on-line.

Virtual laboratories that create virtual realties in which to work show promise for virtual biology simulations. One research group has focused on creating virtual laboratories as preparation tools for biology students in traditional, face-to-face laboratory sections (Subramanian and Marsic, 2001). By taking advantage of technological advances, these researchers hope to motivate a wide variety of students. However, as with Bell’s (1999) research, Subramanian and Marsic (2001) relied on future administrations housing the virtual laboratories on-line, in this case, the university server. It appears that the virtual laboratories are currently used in software engineering education and used for demonstration purposes for biology education. Subramanian and Marsic (2001) reported students had positive feedback for the use of virtual laboratories to enhance their understanding of material but the researchers did not examine quantitatively any gains students may have made on course material by using the virtual laboratories. A set of virtual laboratories maintained by a researcher in Hong Kong found that students who participated in virtual laboratory work enjoyed the experience, were more actively engaged in learning material than students in traditional face-to-face classes, and apparently motivated the students to learn the material (Chan & Fok, 2009). These results were also found by researchers in the US, where students positively responded to completing virtual laboratory assignments in an online human biology course (Stuckey-Mickell and Stuckey-Danner, 2007; Stuckey-Mickell et al., 2007).

The future of virtual laboratories may be into the transformation of games for science education; Mayo (2007) offered a compelling look at the role video games can play to enhance student understanding of science concepts. There is a growing movement in physical education gaining acceptance to incorporate interactive video games in physical education (P.E.) classes (Trout and Christie, 2007). Physics classes, health classes, and engineering classes are adapting to delivering content through virtual simulations played as games (Mayo, 2007); perhaps this is a part of online biology education's future.

Scientists grappled with the role of simulations in science so it is not surprising that the value of simulations in education is still debated. Complex systems modeled in a simulation provide ways for researchers to conduct ecological experiments when those experiments would be prohibitive in nature (Clement, 2000; Peck, 2004). Simulations provide scientists and educators with ways to manipulate models that would otherwise be unavailable. Philosopher of science Eric Winsberg argues that model simulations can provide scientists with the means to grapple with questions that cannot be studied in other ways, provided that the simulations are derived from well-understood theories, empirical data and from the modeling of systems in other contexts (Winsberg, 2003). Further, Winsberg cautions against using models in the absence of data as model creation should be guided by theory informed by data (Winsberg, 2006). Applying Winsberg's arguments to education, when simulations are data-driven and are good representations of the systems, they may be appropriate for general education students to use to understand basic principles. Students at community colleges electing to take a general biology course to fulfill a general education requirement are unlikely to self-identify as wanting to major in biology and so, an exposure to and awareness of basic principles is sufficient for these students.

A group of researchers associated with SimBiotic Software has done several studies evaluating the effectiveness virtual evolution simulations provide students in learning evolution concepts (Abraham et al., 2009; Perry et al., 2008; Meir et al., 2007). These researchers have a financial stake in the success of SimBiotic Software so it is not surprising their studies show students' test scores improve after using the virtual simulations. One feature of their studies is that both multiple choice and open-response questions are used to assess students before and after use of the virtual simulations. Students score higher on multiple choice questions after using the virtual simulations and it is important to note that while answers to the open-response questions improve, students still do not completely understand evolutionary concepts after completing virtual evolution simulations. Virtual simulations are not a magic bullet. They are a useful tool in helping students visualize otherwise abstract processes (Perry et al., 2008).

Summary

Community colleges respond to the needs of their communities as outlined through their mission statements; the study site's mission statement was the driving purpose for the creation of an online biology course. Online education increasingly plays a significant role in helping learners achieve their educational degrees through the flexibility of on-demand learning in an online setting. Science courses, as critical components of a college education, must find ways in which to adapt to an online environment to deliver content to students. Laboratory instruction presents an unique opportunity for faculty to find innovative solutions. Student-centered instructional practices hold promise for addressing challenges faced by community colleges, including retention issues. Virtual simulation software has a role to play in the online delivery of biology; researchers are still investigating best practice methods. Using student-centered teaching will allow science instructors to better position themselves to fully participate in online education for the benefit of students.

CHAPTER III

METHODOLOGY

Chapter Overview

The following research questions guided this study:

Q1 What is the relationship between the type of laboratory instructional approaches and the ecology and evolution content mastered in an online general biology course?

H1 There was no significant difference between the pretest-posttest learning gains of online general biology students using two types of laboratory instructional approaches.

H2 There was no significant difference in learning gains between ecology/evolution questions in the pretest-posttest and non-ecology/evolution questions in the pretest-posttest using two types of laboratory instructional approaches.

H3 There were no significant differences between the final course grades of online general biology students using two types of laboratory instructional approaches.

H4 There were no significant differences between the laboratory grades of online general biology students using two types of laboratory instructional approaches.

Q2 What are the perceptions of community college students towards ecology and evolution laboratory experiences in online general biology?

This study served to identify which laboratory instructional delivery method, virtual simulations or at-home kits, resulted in higher student performance in ecology and evolution laboratory activities through the measurement of learning gains, laboratory grades, and final grades for online community college students and in the investigation of those students' perceptions towards laboratory treatments.

Research Design

IRB Process

Approval for the research was granted by both Cotton College and University of Northern Colorado. Students signed a consent form to participate in the research. A copy of the consent form and the Institutional Review Board approval letters are in Appendix A.

Course and Sample Population

Cotton College was an open-enrollment community college in the southwestern United States. The administration asked that pseudonyms be used for the College and student-participants in this research. The researcher, in conjunction with an administrator, selected a pseudonym for the study site and participants selected the pseudonym they wanted used in research findings. Cotton College served rural communities and offered A.A., A.S, and A.A.S. degrees and a certificate of mastery in childhood development. Cotton College served over 5,200 students in the fall of 2012, of which 84% were part-time, 62% were male, and 52% were white. Approximately 73% of the students Cotton College served in Fall 2012 were enrolled only in online classes while 12% were enrolled in some online classes, and 15% were not enrolled in any online classes.

The annual enrollment in general biology courses was approximately 535 students. Of those, approximately 100 to 150 students annually enrolled in the fall and spring semesters in online general biology. Online general biology was an asynchronous, online course and did not require students to come to campus at any point during the semester.

There were five sections of traditional campus-based general biology offered in the fall semester and four sections in the spring semester. Campus-based sections were capped at 24 students due to laboratory space constraints; online sections were capped at 65 students, though the administration reserved the right to override the online cap providing the instructor was compensated. The campus-based sections varied in instructors and the number of times sections met per week: one section met once per week in the evening for five hours; one section met twice per week in the morning for two and half hours per meeting; and two sections met four times a week with the breakdown of those class sessions being three 50-minute lectures and one two-hour laboratory session.

The population (N = 116) for this study was comprised of students enrolled in online general biology during Fall 2012 and Spring 2013 through Cotton College. Each semester, one section of online general biology was offered. The section had two pedagogical subgroups for laboratory experiences: virtual simulations and at-home kits. Students were randomly assigned to an instructional treatment after registering for the course. One subgroup used virtual simulations for the laboratory component and the other used hands-on experiences students assembled in at-home kits for the laboratory component. The subgroups used their assigned instructional treatment for the entire semester for laboratory exercises, which included 14 laboratory exercises. Each week, students completed one laboratory exercise. Students submitted electronic copies of their work and those were kept for qualitative analysis. Lecture materials, discussion prompts, and homework assignments were the same in both subgroups.

Non-traditional students comprised approximately 55% (n=64) of the students enrolled in online general biology over both semesters. Students were asked during the first week of the semester, as one of my normal procedures with students, for any information the student wished the instructor to be aware that might impact their performance in the course. Topics identified by students included personal issues such as: pregnancy and expected childbirth during the course (n = 6), military deployments (n = 3) or rotations during the course (n = 2), family-life situations such as the addition of children through foster placement (n = 1), sheltering family members (n = 2), and pending divorce (n= 2). Also identified by students were work schedules, course loads, and child care issues. Approximately 55% of the students in the course (n= 64) over two semesters self-identified as working more than 40 hours per week, often in multiple jobs. Eighty-one students in the course shared they were taking the course online because of time restraints in their personal lives due to child care issues or work hours. Nearly all non-traditional students privately expressed to me through emails, virtual chats, or telephone calls some degree of trepidation about taking a science course online; the trepidation appeared primarily to be driven by students lacking confidence in their educational skills.

The general biology course was the course recommended for biology majors and non-biology majors, including early childhood majors and pre-nursing students. The course considered fundamental principles of ecology, evolution, cell biology, genetics, and science and society. Appendix B contains the syllabus, with research participation solicitation.

Cotton College’s general biology courses operated on a 16-week semester schedule, including one week for finals. When a student logged into online general biology they saw on the left-hand side of their Moodle page course links to contact the instructor through email, chat, phone, and video chat, virtual office hours, the syllabus, a link to Cotton College's Technical Help Desk, and the grade book. The center of their screen was divided into 17 blocks based on weeks. The top block, or course header, contained a Frequently Asked Questions discussion board, Instructor Announcement discussion board, tips for successfully studying biology, links to virtual microscopes, science dictionaries, and the textbook's student companion webpage. Each subsequent center block held information, hyperlinks, discussion boards, and assignments for that week. Blocks for the semester were open and available to students beginning on the first day of class. On the right-hand side of the screen was a course calendar highlighting assignment due dates. All students in online general biology saw this general layout. The difference between the two sections was in the weekly laboratory assignment content, consisting of one link in the weekly center blocks. Cotton College has now moved to Canvas, a different learning management system but Figure 1 provides a screen shot of one a Moodle course, allowing readers to visualize how information was laid out for students in online general biology.

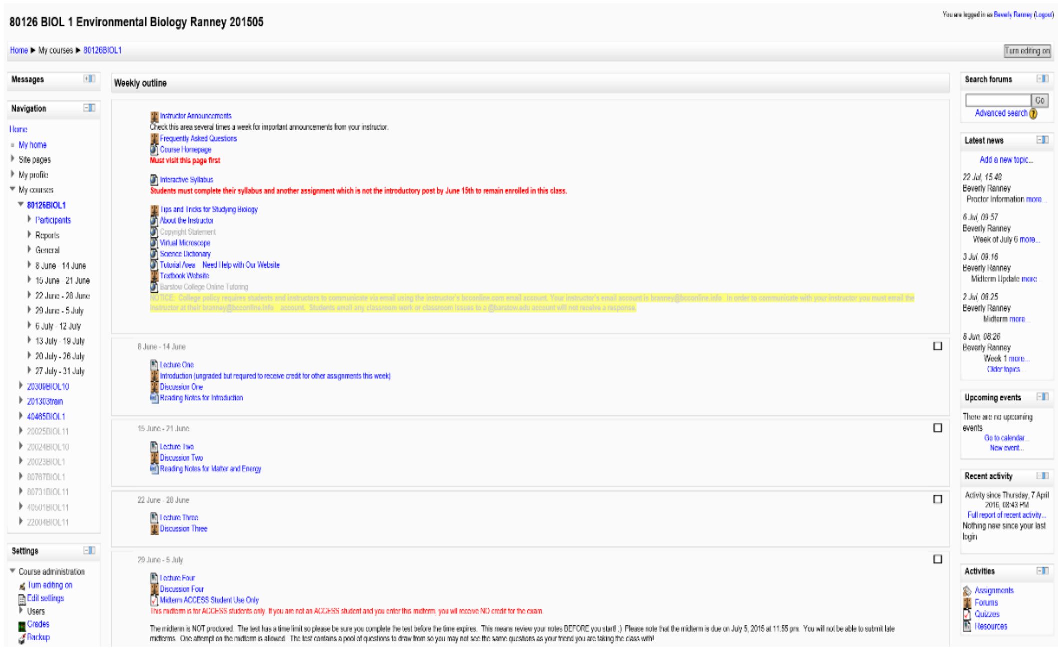


Figure 1. Moodle course screenshot.

The syllabus included information on research participation and students were directed to view a discussion board posting for more information or to contact the instructor. Participation in the study was solicited through a posting describing the study on the class discussion board; the consent form was an attachment to the post that interested students downloaded. The post also contained instructions on how to return the consent form. The consent form included volunteering rights, procedures to ensure confidentiality, and the nature of the activities involved in the study. Participation in the study was high: 94% of students participated in the study.

Research Design for Q1

The experimental design followed the outline of Campbell & Stanley's Pretest-Posttest Control Group Design (1963) using a comparison groups. Literature discusses the use of the term "comparison" group for educational research where no control exists in the context of non-randomized studies (NRC, 2002). Equivalent groups were achieved by randomly assigning students to sections of online general biology. Students were assigned numbers on slips of paper. These slips were placed in a bowl and the numbers drawn. The assignment to treatment rotated from virtual simulation experience to at-home kit assignment thereby preserving equivalent numbers of students in each treatment.

Campbell & Stanley (1963) list history, maturation, testing, instrumentation, statistical regression, selection, experimental mortality, and selection-maturation interaction as main events that are relevant to the internal validity of education research. The threats to internal validity for quantitative education research are minimized by using this experimental design (Campbell & Stanley, 1963). The factors are controlled in the sense that they should be manifested equally in the course sections because of the random assignment of students to treatments.

Campbell & Stanley (1963) list interaction effect of testing, interaction effects of selection biases and the experimental variable, reactive effects of experimental arrangements, and multiple-treatment interference as threats to the external validity of education research. The threats to external validity cannot be neatly controlled because researchers cannot generalize with statistical certainty to other populations (Campbell & Stanley, 1963). Because in the realm of educational research, researchers and instructors may want to be able to generalize findings from research where testing was a regular phenomenon, the interaction effect of testing is not present. The possibility exists that there is an interaction effect of selection biases because of the students who self-select into an online course may represent a unique population.

Data Collection for Q1

Q1 What is the relationship between the type of laboratory instructional approaches and the ecology and evolution content mastered in an online general biology course?

H1 There was no significant difference between the pretest-posttest learning gains of online general biology students using two types of laboratory instructional approaches.

H2 There was no significant difference in learning gains between ecology/evolution questions in the pretest-posttest and non-ecology/evolution questions in the pretest-posttest using two types of laboratory instructional approaches.

H3 There were no significant differences between the final course grades of online general biology students using two types of laboratory instructional approaches.

H4 There were no significant differences between the laboratory grades of online general biology students using two types of laboratory instructional approaches.

The data collected for evaluating H1 learning gains consisted of responses to a pretest, midterm, and posttest which also served as the department-wide final exam. Learning gains were calculated with the pretest and posttest. The midterm served as a comparison point but learning gains were not calculated from midterm data as the pretest test items did not match the midterm test items. The data collected for evaluating H2 compared a subset of ecology and evolution questions from the pretest/posttest to non-ecology/evolution questions from the pretest/posttest. The questions were divided based on if the question directly asked an evolution or ecology content question; questions contributing to a content field, such as genetics questions, were included in the non-ecology/evolution question set. The data collected for evaluating H3 compared the final course grades of the two groups using the types of laboratory instruction. Laboratory grades were collected to evaluate the H4 hypothesis regarding instructional approach and laboratory grades.

Frequency data for test completion, laboratory assignment completion, gender, and student classification were collected with data so that differences in student groups could be compared; gender and student classification were self-reported by students as part of the routine data I collect every semester about my students in a beginning semester questionnaire. Test completion data and laboratory assignment completion data were collected to eliminate students from the study who did not complete the class, failed to complete laboratory assignments, or failed to complete one of the test instruments. Students who agreed to participate in the research, completed the laboratory assignments, and completed the course were included in the data collection.

The pretest and posttest were the same instruments: the Biology Concept Inventory or BCI (Garvin-Doxas & Klymkowsky, 2008) and the Conceptual Inventory of Natural Selection or CINS (Anderson, Fisher, & Norman, 2002). Cotton College's Biology Department updated department-wide pre and post-testing in 2009; the department had previously used uniform post-testing from 1990-2004 through a department created final exam composed of instructor written questions. A department-wide pre-test and final consisting of questions from the BCI and CINS would be given for all sections of general biology, including online general biology. The subset of ecology/evolution questions used to evaluate RQ1B The midterm was a collection of fifty questions that came from the publisher-provided test bank correlated to the textbook the students used in the course. All instructors at the study site used these assessments to evaluate the content knowledge in ecology and evolution of students. The midterm exam covered the ecology and evolution units of the textbook. The test bank allowed questions to be sorted based on ranking of Bloom's taxonomy with classification levels of: Recall, Understand, Apply, Analyze, and Evaluate. The midterm consisted of 15 Recall questions, 20 Understand questions, 8 Apply questions, and 7 Analyze/Evaluate questions. Students had 60 minutes to complete the midterm. All sections of Cotton College general biology used the print version of *Biology* 10^{th} edition (Mader & Windelspecht, 2010). The department agreed that all courses would use publisher-provided test bank questions on objective midterm assessments.

A timeline for online general biology (Table 2) sets out when events happened in chronological sequence; the same schedule was followed both semesters. An alignment of the laboratory activities to the assessments used is presented in Tables 3 and 4. Table 3 provides an alignment of the laboratory activities to the assessments used in the virtual simulation laboratory group and Table 4 provides an alignment of the laboratory activities used in the at-home kit laboratory group. Colleagues at Cotton College reviewed the alignment of laboratory activities to the assessments.

Table 2

Online Biology Timeline

Week	Events	Lecture Topic	Virtual Lab Assignment	At-Home Kit Lab Assignment	Assessments
1	Class Begins	Introduction to Biology: Studying Life, Darwin and Evolution	Setting Up Your Lab	Setting Up Your Lab	Pre-Test CLASS-BIO Survey
2		How Populations Evolve Speciation	Evolutionary Evidence*	Evidence of Evolution*	
3		Taxonomy, Systematics, Phylogeny	Finches & Evolution*	Mechanisms of Evolution*	
4		Evolution of Plants, Invertebrates & Vertebrates	Keystone Predator*	Sampling Ecosystems*	
5		Behavioral Ecology	Isle Royale*	Nutrient Pollution*	
6		Population & Community Ecology	Diffusion	Diffusion	
7		Ecosystems & Conservation	Osmosis	Eggs 4 Osmosis!	Midterm opened at end of week
8		Basic Chemistry Organic Molecules	Cellular Respiration Explored	Kitchen Chemistry	
9	Interviews Begin	Cell Structure and Function	DNA & Genes	Strawberry DNA	
10	Focus Groups Begin	Cell Cycle, Mitosis, Meiosis	Mitosis Explored	Mitosis & Meiosis on the Table	
11		Mendelian Genetics	Meiosis Explored	Punnett Squares	
12	Interviews End	Genetics	Punnett Squares	The Sex (-Linked) Talk	
13	Focus Groups End	Diversity of Microorganisms	Classifying Using Biotechnology	Understanding HIV	
14		Plants & Animal Structure & Organization	Virtual Plant Dissection	Dissecting Flowers	
15		Human Systems	Nutrition	“Sweet Truth” Exercise	
16	Class Ends	Catch-Up/Review			Post-Test CLASS-BIO Survey

*Denotes lab used in current study.

Table 3

Virtual Simulation Lab Alignment

Week	Lab Assignment	Lab Objectives	Assessment Alignment
1	Setting Up Your Lab	Familiarize Student with Lab Procedures	Not Applicable
2	Evolutionary Evidence*	Understand evidence used by biologists to understand evolution Test hypotheses	BCI Items 4, 6, 7, 8, 9, 12, 14, 26 CINS Items 4, 6, 7, 8, 9, 13, 16, 17, 19, 20 Midterm Items 1, 5, 6, 8-16, 23
3	Finches & Evolution*	Understand how natural selection works Test hypotheses	BCI Items 4, 5, 6, 7, 8, 9, 12, 14, 15, 26, 29 CINS Items 2, 3, 4, 5, 7, 9, 10 Midterm Items 2, 3, 4, 7, 17-22, 24-29
4	Keystone Predator*	Understand competition, character displacement, resource partitioning, food webs, and make and test predictions	BCI Items 2, 3, 8, 9, 17, 18 CINS Items 1, 2, 3, 4, 5, 10, 11, 12, 13, 14, 15, 18 Midterm Items 30, 32, 34, 39, 41-45, 49, 50
5	Isle Royale*	Understand predator-prey dynamics, carrying capacity, energy transfers in an ecosystem, exponential and logistical growth	BCI Items BCI Items 2, 3, 8, 9, 13, 17, 18 CINS Items 1, 2, 3, 4, 5, 10, 11, 12, 13, 14, 15, 18 Midterm Items 31, 32, 33, 34, 47, 49, 50
6	Diffusion	Perform simulated molecular-level experiments to understand equilibrium and randomness	BCI Items 1, 13, 25 CINS Items NA Midterm Items NA
7	Osmosis	Understand underlying molecular mechanisms of osmosis and osmotic pressure	BCI Items 1, 13, 20, 25 CINS Items NA Midterm Items NA
8	Cellular Respiration Explored	Understand enzymes, acids and bases, redox reactions, concentration gradients and the steps in aerobic and anaerobic respiration	BCI Items 2, 3, 13, 17, 18, 20 CINS Items NA
9	DNA & Genes	Understand what DNA and genes are made of, what mutations are and what effects mutations can have on an organism and a population	BCI Items 10, 11, 19, 27 CINS Items 7, 17
10	Mitosis Explored	Understand the cell cycle, cell division, the mechanics of mitosis including the stages/phases of mitosis, and understand how cancer relates to mitosis and the cell cycle	BCI Items 7, 16, 21, 24 CINS Items NA
11	Meiosis Explored	Understand the mechanics of meiosis, including gamete formation, the connection between meiosis and genetics, understand crossing over and independent segregation. Compare and contrast mitosis and meiosis.	BCI Items 15, 22, 28 CINS Items 4, 7, 9, 13, 16, 17
12	Punnett Squares	Understand how to complete a Punnett Square, laws of probability, understand alleles and variation in a population and understand dominant and recessive traits	BCI Items 21, 24 CINS Items 4, 7, 9, 13, 16, 17

Table 3 Continued

Week	Lab Assignment	Lab Objectives	Assessment Alignment
13	Classifying Using Biotechnology	Understand that bacteria can be identified using various technologies; describe the lines of evolutionary descent through a phylogenetic tree	BCI Items 10, 13, 20 CINS Items 8, 20
14	Virtual Plant Dissection	Understand the parts of plants, including flower structure	BCI Items 2, 3 CINS Items NA
15	Nutrition	Understand what food labels tell a consumer, identify the daily amounts of specific nutrients, understand the basic building blocks of a healthy diet	BCI Items 10, 11, 19, 20, 27 CINS Items NA
16	Catch Up/Review	No lab assignment	N.A.

Table 4

At-Home Kit Lab Alignment

Week	Lab Assignment	Lab Objectives	Assessment Alignment
1	Setting Up Your Lab	Familiarize Student with Lab Procedures	Not Applicable
2	Evidence of Evolution*	Understand evidence used by biologists to understand evolution Test hypotheses	BCI Items: 4, 6, 7, 8, 9, 12, 14, 26 CINS Items 4, 6, 7, 8, 9, 13, 16, 17, 19, 20 Midterm Items 1, 5, 6, 8-16, 23
3	Mechanics of Evolution*	Understand how natural selection works Test hypotheses	BCI Items: 4, 5, 6, 7, 8, 9, 12, 14, 15, 26, 29 CINS Items 2, 3, 4, 5, 7, 9, 10 Midterm Items 2, 3, 4, 7, 17-22, 24-29
4	Sampling Ecosystems*	Understand competition, character displacement, resource partitioning, food webs, predator-prey dynamics, and make and test predictions	BCI Items 2, 3, 8, 9, 17, 18 CINS Items 1, 2, 3, 4, 5, 10, 11, 12, 13, 14, 15, 18 Midterm Items 30, 31, 32, 34, 39, 41-45, 49, 50
5	Nutrient Pollution*	Understand energy transfers in an ecosystem, carrying capacity, exponential and logistical growth; understand water cycle and solar energy inputs in systems	BCI Items 2, 3, 8, 9, 13, 17, 18 CINS Items 1, 2, 3, 4, 5, 10, 11, 12, 13, 14, 15, 18 Midterm Items 31-35, 40, 47, 48, 49, 50
6	Diffusion	Complete the case study to understand equilibrium and randomness	BCI Items 1, 13, 25 CINS Items NA Midterm Items NA
7	Eggs 4 Osmosis!	Observe eggs in different solutions to understand osmosis and osmotic pressure	BCI Items 1, 8, 9, 13, 20, 25 CINS Items NA Midterm Items NA
8	Kitchen Chemistry	Understand enzymes, acids and bases, redox reactions, concentration gradients and the steps in aerobic and anaerobic respiration	BCI Items 2, 3, 8, 9, 13, 17, 18, 20 CINS Items NA

Table 4 Continued

Week	Lab Assignment	Lab Objectives	Assessment Alignment
9	Strawberry DNA	Understand what DNA and genes are made of, what mutations are and what effects mutations can have on an organism and a population	BCI Items 10, 11, 19, 27 CINS Items 6, 19
10	Mitosis & Meiosis on the Table	Understand the cell cycle, cell division, the mechanics of mitosis and meiosis, including the stages/phases, and understand how cancer relates to mitosis and the cell cycle; how mechanics of meiosis, including gamete formation, connection to genetics, crossing over and independent segregation. Compare and contrast mitosis/meiosis.	BCI Items 7, 15, 16, 21, 22, 24, 28 CINS Items 4, 7, 9, 13, 16, 17
11	Punnett Squares	Understand how to complete a Punnett Square, laws of probability, understand alleles and variation in a population and understand dominant and recessive traits	BCI Items 21, 24 CINS Items 4, 7, 9, 13, 16, 17
12	The Sex(-Linked) Talk	Understand what a sex-linked trait is, how to read a pedigree, and give examples of human sex-linked conditions.	BCI Items 22, 28 CINS Items 7, 17
13	Understanding HIV	Understand the life cycle of HIV, how scientists can track mutations in HIV RNA and use it as a molecular clock	BCI Items 10, CINS Items 9, 10, 16, 18
14	Dissecting Flowers	Understand the parts of plants, including flower structure	BCI Items 2, 3 CINS Items NA
15	“Sweet Truth”	Understand what food labels tell a consumer, identify the daily amounts of specific nutrients, understand the basic building blocks of a healthy diet	BCI Items 10, 11, 13, 19, 20, 27 CINS Items NA
16	Catch Up/Review	No lab assignment	N.A.

Student motivation was not measured directly. A limitation of this research is that students earned the participation credit for the pretest by completing the pretest, not based on choosing correct answers. The midterm and final (posttest) were worth approximately 10% and 15% of a student’s grade, respectively. All students were under the same point distribution so the limitation that arises is that there may be a larger increase in learning gains shown by all participants than there would have been had the pretest been a graded exam as the midterm and posttest were.

In June 2012, I inputted all objective assessment questions into the course management system, Moodle. Questions from the BCI and CINS were typed into the quiz feature of the Moodle course and grading parameters were set. Each question was worth one point. Questions from the publisher provided test bank were uploaded in the same manner to Moodle. Instructions to students were set. For the pretest, students were to read these instructions:

Things You Should Know:

- You should complete this pretest during the first week of class, preferably before you start reading your textbook.
- You have 75 minutes to take the pretest. It will be submitted automatically after 75 minutes whether you are finished or not.
- To receive participation credit for the pretest (remember, the pretest is this week's participation grade!) I must have either your completed pretest submission or an email explaining difficulties you were having. The email must be received during the times the pretest is due.
- Remember, the pretest is NOT a test score. No stressing! ☺
- Please email me if you have questions or concerns. Have a great week and I'll see you on the discussion board!

For the midterm, students were given these instructions:

Things You Should Know:

- You must complete this test during this week of class, preferably AFTER you have read your textbook, done your assignments, and completed your laboratory exercise ☺

- You have 75 minutes to take the test. It will be submitted automatically after 75 minutes whether you are finished or not.
- START WITH PLENTY OF TIME TO FINISH BEFORE THE DEADLINE!!!
- You can only open the test ONCE so be sure you have 75 minutes of quality time to yourself!
- Answer the questions you know for sure first. You can review your answers and the questions before submitting but you can only submit your test ONCE.
- To receive credit for the test I must have either your completed test submission or an email explaining difficulties you were having. The email must be received during the times the test is due. IT will verify your computer-related difficulties if you are testing on campus.
- Please email me if you have questions or concerns. Have a great week and I'll see you on the discussion board!

For the posttest, which was also the final, these instructions were the instructions, which students were to read before taking the assessment:

Things You Should Know:

- You must complete this test during this final week of class ☺
- You have 75 minutes to take the test. It will be submitted automatically after 75 minutes whether you are finished or not.
- START WITH PLENTY OF TIME TO FINISH BEFORE THE DEADLINE!!!

- You can only open the test ONCE so be sure you have 75 minutes of quality time to yourself!
- Answer the questions you know for sure first. You can review your answers and the questions before submitting but you can only submit your test ONCE.
- To receive credit for the test I must have either your completed test submission or an email explaining difficulties you were having. The email must be received during the times the test is due. IT will verify your computer-related difficulties if you are testing on campus.
- Please email me if you have questions or concerns. Have a great week and congratulations on a great semester!

Correct answers were scored at 1.0 point each and no credit was assigned for incorrect answers. The assessments were set to be automatically corrected through the Moodle platform via the answer key inputted in June, 2012.

All objective assessments in online biology were administered online, through the course management system Moodle in a secure browser. The secure browser prevented additional windows or tabs being opened in the browser but did not prevent students from having a second screen on another device from which to look up answers nor did it prevent a separate browser being opened. Tests were not proctored per Cotton College standard online course policies but were limited to 75 minutes. The time limit was also a standard Cotton College policy. Students had to solicit and receive a password for each exam from the instructor prior to taking each assessment. Students could pick which day and time they took the assessments during a specific window of time within the course;

this was a condition of online classes offered at Cotton College. These testing conditions were beyond my scope to manipulate. The pretest had to be taken during the first week of the course, the midterm had to be taken in the seventh week of the course and the final had to be taken during finals week. During the weeks the assessments were available to students, they could decide when to take the exams. Coupled with the standard policy at the college not to have exams proctored, students could hypothetically take the exams together on separate computers and verbally share answers. Multiple questions appeared on each screen, varying depending on the length of the question from 3-4 questions per screen after which the student would select the “Next Page” button at the bottom of their screen to proceed to the next set of questions. To answer a question, students would select a button next to their desired answer, akin to filling in the circle on a Scantron form. Moodle would record which answer the student selected and automatically score the assessments based on answers the instructor had inputted when loading the assessment questions. Students would receive their scores on assessments 1 hour after the assessment closed for the class. Students could not review questions after submission and had no access to the assessment after submission. For the pretest, no feedback other than total score was given to the students. For the midterm and posttest, detailed feedback was provided to students who selected incorrect answers. The feedback included the correct answer, why the answer was correct, and for the midterm, what portion of the textbook the assessment question came from. The order of the questions was not randomized on the pretest or posttest but was on the midterm assessment.

When students took the BCI and CINS pretest/posttest, the questions and answer selections appeared in the same order each time. Administered first were questions from the BCI, followed by questions from the CINS. Students took the pretest in the first week of class and the posttest in the final week of a 16-week semester. In week seven of the course, students took the midterm. Appendix C has copies of the instruments used. Students who completed the three assessments were included in the analysis.

Objective Instruments for Q1

The Biology Concept Inventory (Garvin-Doxas & Klymkowsky, 2008) was a 29-item multiple-choice instrument developed through qualitative and quantitative methods. During development of the BCI, thousands of students responded to essay questions from which themes emerged when coded by the researchers. This was followed up with think-aloud interviews with approximately 60 students. These interviews provided the data used to create “distracter” answers on the multiple-choice instrument. The BCI focuses on three areas of conceptual understanding: biological processes (*n*= 9) biological structures (*n*= 12), and randomness (*n*= 7). These areas of conceptual understanding correspond to content areas in a typical introductory biology course including evolutionary processes, genetic traits, molecules, DNA, and diffusion. In the original study of the BCI (Garvin-Doxas, Klymkosky, & Elrod, 2007), the multiple-choice instrument was administered first with 539 students and then a modified version with 4441 students. The BCI has a Cronbach’s alpha of 0.83 (Garvin-Doxas, Klymkosky, & Elrod, 2007). The Cronbach’s alpha measures the internal consistency, as a scale of reliability, of the BCI instrument (Garvin-Doxas, Klymkosky, & Elrod, 2007). While the BCI is not a normed standardized summative assessment tool (Klymkowsky, Underwood, & Garvin-Doxas, 2010) it is a useful instrument for assessing student understanding of biological concepts.

The Conceptual Inventory of Natural Selection is a 20 item multiple-choice instrument developed through field testing with over two hundred students in a nonmajors' general biology course. The CINS had a Kuder-Richardson 20 of 0.64, which is above the threshold for a classroom assessment of 0.60 KR20 (Anderson, Fisher, & Norman, 2002). Measuring learning gains with a concept inventory may allow instructors in different settings to compare their results with this research. The use of concept inventories is advocated by some in the biology education research community so that faculty can identify the ideas students hold (D'Avanzo, 2008; Libarkin, 2008). Student perceptions of a pedagogical tool are important considerations because their perceptions are indications of their approach to learning and to the effectiveness of teaching (Entwistle & Ramsden, 1982).

Biology Colorado Learning Attitudes about Science Survey (Adams, et al., 2006) was administered to online general biology students to collect affective data to determine if students' attitudes regarding biology shifted following instruction. In previous research using the CLASS-BIO, students' attitudes shifted towards more novice-like attitudes following instruction rather than shifting towards more expert-like attitudes (Adams, et al., 2006). Expert-like attitudes were defined by Semsar, Knight, Birol, & Smith (2011) as those attitudes that more closely resembled university-level Ph.D. biology faculty. Demographic information on students including gender and class standing was collected to allow analysis of differences in learning gains for different subsets of students within each treatment. The students followed an active link from the course's Moodle page to a survey delivered via Qualtrics. The survey was confidential, not anonymous, and provided information on changes in student attitudes over the course of the semester.

Surveyed during the first and last weeks of the semesters; students earned participation points for completing the surveys.

The Colorado Learning About Science Survey-Biology was used to assess students' epistemological beliefs about learning biology and is a tool used to evaluate the impacts of instructional approaches on student growth in expertise in scientific thinking (Semsar, et al., 2011). Based on the work of the original Colorado Learning About Science Survey-Physics and the modified Colorado Learning About Science Survey-Chemistry, the biology version modified the previous instruments. The final instrument consisted of 31 Likert-scale items and measures novice-to-expert-like perceptions in seven categories (Semsar, et al., 2011). As students moved from novice-like to expert-like in their understanding of content, they moved from believing that knowledge was absolute and teacher-provided to understanding that knowledge was relative to perspective and therefore consistent with a constructivist model of knowing (Hammer, 1994). Students' beliefs can influence their conceptual learning by affecting how they approach learning (House, 1994; 2000). Semsar et al. (2011) asserted that because students' beliefs, perceptions, and prior knowledge affect the ability of students to make learning gains in the course of a semester, "it is critical that we learn how our educational practices impact the underlying perceptions students have about biology" (p 269). For these reasons, the CLASS-BIO instrument was selected to assess students' perceptions of learning in their online general biology course.

The CLASS-BIO was open to students during the first (pre-assessment) and last (post-assessment) weeks of the class. Students received class participation points for completing the CLASS-BIO survey and they had to complete it both in the first week and last week of the class. The CLASS-BIO survey has seven categories derived from extensive studies detailed in Semsar et al., 2011. The seven categories included: Real World Connection, Problem Solving Difficulty, Enjoyment, Problem Solving Effort, Conceptual Connections, Problem Solving Strategies, and Reasoning. CLASS-BIO uses a 5-point Likert scale from strong agree to strongly disagree. Response rejection criteria followed Semsar et al (2011) criteria. Survey responses were not included if they met these criteria: less than three minutes to complete the survey, the same response (e.g., “strong disagree”) for more than 90% of the items, and incorrectly responding to the statement “We use this statement to discard the survey of people who are not reading the questions. Please select agree (not strongly agree) for this question to preserve your answers.” Only the first set of acceptable responses per student was scored and only surveys meeting all survey criteria response requirements were included in analysis. There were three sets of student responses where the individual submitted multiple responses to the CLASS-BIO and following Semsar, et al (2011) criteria, only the first set of responses meeting the criteria were used. The response set used for those three individuals were the response that took longer than three minutes to complete, fewer than 90% of the items had the same response, and correctly responding to the “We use this statement to discard the survey of people who are not reading the questions” item. Students had to answer the CLASS-BIO survey twice, once in the first week and once in the last week of the course, to be included in the analysis.

Student data of gender and student classification (i.e., traditional or non-traditional) were gathered from students to include in analysis to determine if there was a difference between characteristics in laboratory exercises. These data were gathered during the first week of the class as part of a routine questionnaire I give to students to help us understand each other in an online class. Demographic information was also included as part of the CLASS-BIO data collection, serving as a verification of the data students provided within the routine questionnaire. Inclusion of such data allowed data analysis to be more robust by asking questions such as the following: Did females perform differently than males using virtual simulations or at-home kits? Did traditional students perform differently than non-traditional student using virtual simulations or at-home kits?

Data Analysis for Q1

Learning gains comparisons between online general biology students using different laboratory delivery methods used a pretest-posttest equivalent group design with random assignment to treatments. Learning gains were calculated based on the method presented in Hake, 1998. Hake stated that learning gains were defined as, "the ratio of the actual average gain (%[post]-%[pre]) to the maximum possible average gain (100-%[pre])" (p. 64). Learning gains have been used in previous studies (Knight & Wood, 2005; Udovic, Morris, Dickman, Postlethwait, Wetherwax, 2002) to show how students' understanding changes with instruction. An increase in learning gains suggested movement from novice to expert in understanding (McDaniel, Lister, Hanna, Roy, 2007). Learning gain differences between groups were assessed with a student t-test. Based on the randomization of student into treatments each semester, students were grouped based on their laboratory treatment, increasing statistical power for subsequent analysis. Additionally, how women did with virtual simulations compared to at-home kits was compared as well as how men did with virtual simulations compared to at-home kits was compared with t-tests.

The effect size (Cohen's *d*) of the learning gains was calculated for statistically significant findings (Robinson & Levin, 1997). Cohen's *d* is important for interpreting educational research findings which aim to evaluate instructional approaches because they help instructors understand the strength of the relationship between the learning gains and the instructional approach (Sullivan & Feinn, 2012; Trusty, Thompson, & Petrocelli, 2004). A small effect size, whose values range from 0.2 to 0.49, suggests that a person from the experimental group will have a higher score from the comparison group between 56%-63% of the time; a medium effect size, whose values range from 0.5-0.79, suggests a person from the experimental group will have a higher score from the comparison group between 64%-70% of the time; a large effect size, whose values range from 0.8-1.0, suggests a person from the experimental group will have a higher score than a person from the comparison group between 71%-76% of the time (Coe, 2002). Statistical analyses were done in SPSS 20 and Microsoft Excel. The software program G*Power was used for the effect size analysis. A power analysis done in G*Power showed that the optimal sample size for 95% power with α error probability of 0.05 ranged between 111 students and 1073 students when Cohen's *d* is between 0.3 (small effect) and 0.8 (large effect). The sample size of the research was too low to permit factorial analysis with appropriate statistical power.

To address if there were significant differences between the laboratory instructional approach and the final course grades, a student t-test was used to compare the final course grade percentages and the laboratory instructional approach. To address if there were significant differences between the laboratory instructional approach and the laboratory grades, a student t-test was used to compare the overall laboratory grades and the instructional approach. Effect sizes were also calculated for statistically significant findings as described above.

The scoring of the CLASS-BIO followed the protocols laid out by Semsar et al. (2011) and included collapsing the five-point Likert scale to a three-point scale: neutral, agree, or disagree. The collapse was done because the difference between agree/strongly agree and disagree/strongly disagree was not necessarily equal (Semsar, et al., 2011). Responses were scored in relation to agreement with expert consensus: favorable, neutral, or unfavorable. The average overall percent-favorable response score, representing the percentage of student responses identical to expert consensus, is reported. Also reported are the percent-favorable response scores for each category (e.g., Real World Connections, Problem Solving Difficulty) for student populations.

Research Design for Q2

The purpose of a case study is to "…maximize what we can learn" (Stake, 1995, p. 4) about a contemporary phenomenon. Information is situational and the methods employed should reflect the nature of the research questions (Fitzpatrick, James, & Worthen, 2004). Research in instructional strategies derives from literature on classroom research and the Scholarship of Teaching and Learning (SoTL) in higher education (Boyer, 1990; Cross & Steadman, 1996; McKinney, 2010; Weimer, 2006).

This instrumental case has embedded units. Both laboratory instruction methods are embedded units, situated within the larger case of online general biology. This distinction is made based on the work of Yin (2003). After the tradition of Stake (1995), this research is considered an instrumental case study in that the student achievement results were of primary interest to Cotton College. The perceptions of the students to the delivery methods was considered by Cotton College administration to be of secondary importance, though such perceptions are essential to understanding the treatment results in context.

Case study research requires that boundaries of the case be determined prior to research (Stake, 1995; Yin, 2003). "Boundaries" of a case allow a researcher to define what it is that will be studied in detail and allows the breadth, depth, and sample of the research to be described (Baxter & Jack, 2008). Several qualitative research methodologists have defined what constructs set boundaries for case study research. Each case is bound by time and place (Creswell, 2002), activity (Stake, 1995), and context (Miles & Huberman, 1994). Setting the boundaries of the case in this manner allows an in-depth exploration of the community of learners.

The learners in this case were students in online general biology at a rural community college in the southwestern United States. The case was bound by the time of two academic semesters: Fall 2012 and Spring 2013, the study site, and the context of a fully online, general biology course. The length of the case was set by the Institutional Review Board of Cotton College through the restriction of time to two semesters, during which the study could take place. The focus of the case study was on understanding the learning gains made by the students using either virtual simulations or at-home kits for their laboratory experiences and then understanding their perceptions towards those laboratory experiences. The case study relied on several sources of data: learning gains from assessments, semi-structured interviews, focus groups, and laboratory reports.

These data capture a holistic description of learners' experiences with online general biology (Swanborn, 2010).

Data Collection and Analysis for Q2

> Q2 What are the perceptions of community college students towards ecology and evolution laboratory experiences in online general biology?

As Semsar et al. (2011) noted, understanding student perceptions is critical to improving educational methods. Research Q2 sought to identify the perceptions of students towards laboratory experiences that assisted in the construction of understanding. Perceptions of community college students towards laboratory experience were explored through laboratory reports and video chats with either semi-structured interviews or focus groups.

Laboratory reports were part of weekly assignments and included a summary of laboratory procedures, a paragraph on what a student felt they learned from the experience, and how that learning and experience tied into the larger picture of biology the class was studying. Laboratory reports were to be a minimum of 500 words, written in 5- paragraph essay form, use complete sentences, and proper English grammar. Additionally, for full credit, students had to include at least 3 screen shots (virtual simulation users) or 3 photographs (at-home kit users) of their laboratory experience. Students self-reported time on task for the lab experience; through the Moodle link I could verify that a student had opened the virtual simulation, how long they had used a simulation, and if they had repeated it. As the at-home kits were instructions loaded into a downloadable file, I could not obtain the same information for that treatment. Students were encouraged but not required to cite information beyond their textbook when making connections to the wider ideas in biology. All reports were to be submitted through the

Moodle system as a Word document, rich text format file, or PDF. Students uploaded one file each per laboratory report. The laboratory reports were the beginning of data analysis for Question 2; as is the norm in qualitative studies, data analysis began with data collection and did not end until the final report was written.

A theme in this research is a group of responses that informs the research question (Braun & Clarke, 2006). In this research, I was interested in better understanding students' perceptions towards their laboratory experiences so I could address student success in online general biology. Thematic analysis was done to identify and describe the themes that were important to understanding the phenomenon (Daly, Kellehear, & Gliksman, 1997). To identify and describe the themes, categories were identified and then grouped together (Green, Willis, Hughes, Small, Welch, Gibbs, Daly, 2007). Word clouds were used to help triangulate the categories (McNaught & Lam, 2010). Constructivism, or the theoretical framework of Crotty (1998) which states that individuals have to interact with the world to build their understanding of it, underlie all assumptions in the data analysis process with grounded theory guiding the findings.

Themes can be identified primarily in one of two ways: bottom up (inductive) or top down (deductive) where the inductive approach links themes to data via grounded theory (Braun & Clarke, 2006). The themes were not driven by my interests nor was data coded with pre-existing frames. By using a grounded theory approach to code data, the data were read and re-read for themes related to laboratory perceptions without linking the categories a priori to literature. Using a semantic approach (Braun & Clarke, 2006), I identified categories within the "surface meaning of data" (Braun & Clarke, 2006, p. 141) so that I did not try to make meaning beyond what was said or written; to do so would have put my words in my participants' mouths. The first and second rounds of word clouds describe what a participant wrote or said, the third round summarized what participants said as a whole treatment, and the final round of word clouds interprets the verbs the participants used to crystalize the themes of students' perceptions towards their ecology and evolution laboratory experiences. Thematic analysis at the latent level seeks to identify and examine underlying ideas, assumptions, and conceptualizations (Braun & Clarke, 2006). Thematic analysis within a constructivist paradigm does not focus on an individual or motivation but places data into socio-cultural contexts and structural conditions (Braun & Clarke, 2006). As the categories were determined through thematic analysis and content checking through word clouds, themes crystalized that were based on participants' words.

The third set of word clouds, presented in Chapter IV, were word clouds from those who were interviewed, both individual interviews and the focus groups and focus on students' perceptions regarding their laboratory experiences, particularly the verbs students used when describing their laboratory experiences. The final set of word clouds, which were not used in interviews or focus groups, presented in Chapter IV, are a visual representation of the categories derived from the thematic analysis of the data set and are used to triangulate the data.   These sets of word clouds, representing the prevalence of student perceptions towards laboratory experiences, were used to define the themes. Since I want to provide a rich, thematic description of students' perceptions regarding their laboratory experiences, I used the entire data set to identify, code, and analyze themes. Figure 2 illustrates the data analysis method used.

Data Analysis Flowchart

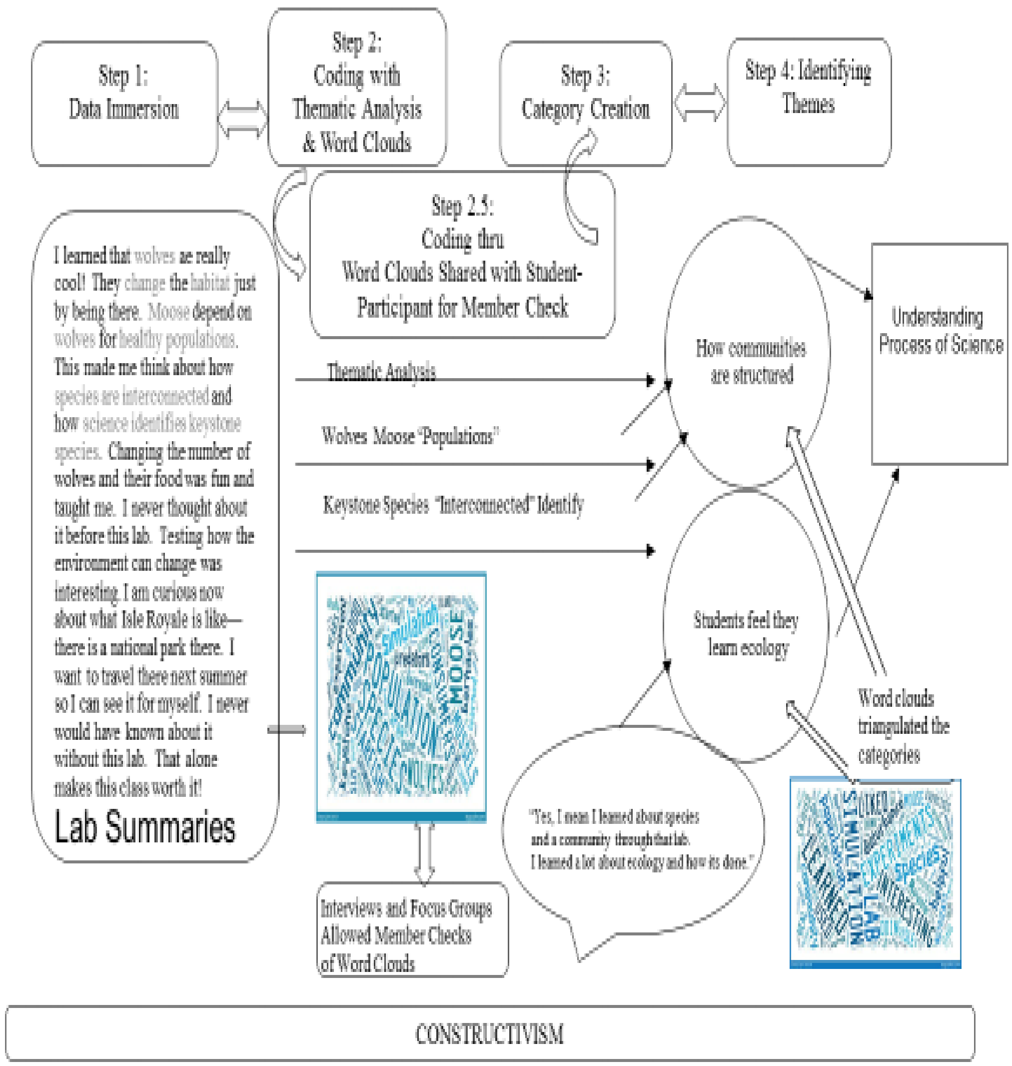


Figure 2. Data analysis flowchart. Illustrating the process of data analysis undertaken for understanding student perceptions towards their laboratory experiences, based off the work by Green, Willis, Hughes, Small, Welch, Gibbs & Daly, 2007.

There were multiple steps to the thematic analysis done to understand student perceptions towards their laboratory experiences. The first step was to "carefully read and re-read" the laboratory reports to gain an understanding of what students were experiencing, noted as "Data Immersion" in the figure above (Rice & Ezzy, 1999, p. 258). This step forms the basis for pattern recognition within the data from which emerging themes can become categories for analysis though no themes are formally identified (Rice & Ezzy, 1999). The second step was to begin coding the data through thematic analysis and create word clouds from laboratory summaries. The "Step 2.5" in the figure above outlines the coding done with word clouds and student-participants to create a visual representation of the laboratory reports data; it is marked as "Step 2.5" to emphasize that it was a bridge between the coding I had done and category creation that emphasized the student-participants' voices. Follow-up interviews with this population, under the conditions at the study site, were not feasible, so member checks needed to be done in real time. There were two parts to this. First, laboratory reports were entered into a word cloud generator and used as a visual aid during interviews and focus groups. I also read and re-read ("Data Immersion, Step 1," Figure 2) my notes and the laboratory reports to ensure that the codes arose from the data. The word clouds helped to highlight main ideas of the participants and kept analysis tied to the data. Recording conversations was not allowed by my study site so I took notes of interviews and focus groups and then entered those notes into a set of follow-up word clouds that were used during interviews and focus groups as the interviews and focus groups were on-going. This allowed for real-time member check of the student-participants' words. The third step, done within the same time frame as steps 2 and 2.5, was to generate codes through the organization of data into meaningful groups; as codes were identified, quotes that illustrated the code were included in the narrative. The codes were generated through sifting through the word clouds generated by the interviews and focus groups. Student accounts that departed from the dominant theme were retained so that readers would understand the multilayer complexity of student perceptions towards laboratory experiences. The fourth step was to combine categories to make themes; categories that were similar in nature were grouped together to support a theme for students' perceptions of laboratory experiences. This fourth step included defining and refining themes so that the story each theme tells could be expanded in the narrative. Word clouds were used again using only perception portions of students' laboratory reports to show how categories and themes arose from analysis of the data. Themes derived from grounded theory should link back to the research question but be distinct from it, using a combination of analysis and narrative to illustrate what was extracted from the data (Braun & Clarke, 2006).

Lab reports were uploaded based on the distance-delivery laboratory method students were enrolled in. I then took the word clouds to interviews and student focus groups to get triangulation on what the students were expressing in the word clouds from the participants (Figure 2). Word clouds allowed visualization by sizing words based on the frequencies of occurrence of words within a text (McNaught & Lam, 2010). When sharing the data with students with the idea of generating a conversation, word clouds allowed the data to speak to the students. I judged this to be a less intimidating way for students to see the frequencies of content or ideas rather than graphs. General biology does not have a math prerequisite and many students historically have taken remedial math while taking the course. Word clouds allowed students to own their data and participate in the research without regard to their ability to read a graph.

Understanding student perceptions of laboratory experiences required looking for categories from students' written responses and interviews. Guided by the methodology of grounded theory (Strauss & Corbin, 1990), I read and read the data, making notes about what the student-participants were saying. These notes were translated into categories and the categories collapsed into themes. Data analysis focused on identifying the big ideas students wanted to express about their laboratory experiences.

To identify the big ideas, I focused first on looking at what words were prominent in written laboratory reports. To isolate those words, I used a word cloud. When coding, I had to decide the "size" of a category, meaning how many words would be coded to a category, realizing that higher instances did not equate to a more crucial portion of the participant's responses. I decided that I would code for individual word frequency for the first two rounds of word clouds, the method of visually representing the data. "Stop words", such as "the", "and" and "a" were removed from initial analyses (McNaught & Lam, 2010). Next, I looked again at the lab reports for what meaning the student was trying to convey. For instance, was a student whose word cloud featured "moose" and "wolves" conveying meaning about animals, species, species interactions, or a different idea? To answer those types of questions, I looked at the context of the summaries and connected the context to the frequency to identify a category. This category could then be examined with the student during a video chat where the category was clarified by the student-participant to "species interactions" or "food webs".

Continuing the ecology virtual simulation laboratory reports example of the process, students frequently wrote about "moose." Similarly, when interviewing students individually or in focus groups, "moose" would be brought up frequently in discussing ecology virtual simulations, in the context as the object being manipulated, a variable. In word clouds, "moose" would dominate the pictorial representation of the data. This did not mean that "moose" were a category or theme of ecology virtual simulations or that similarly sized nouns, such as "wolves" were either. Prevalence, visually captured via word clouds, was counted at the word level of each lab report. The first round of word clouds was done for each participant's lab report for a visual reference to be used during any follow-up interview or focus group. These word clouds were considered a quick visualization of the data; they were part of the interview discussion but not the final data reporting. Data entered included lab summaries for one set of word clouds and notes from focus groups and interviews for a second set of word clouds. Word clouds were also generated during interviews and focus groups to use as member checks that the data I collected matched the main ideas participants were communicating to me. The second round of word clouds, presented in Chapter IV, were word clouds from all participants. These word clouds report the prevalence of ideas across the entire data set. I was satisfied saturation had been reached with categories as no new frequently used words or phrases emerged from the word clouds or thematic coding.

As categories became clearer due to data immersion, I began linking words in the word cloud generator so that I could see connections. For example, if a student wrote, "Now I understand evolution!" it would not continue to be beneficial to leave "understood evolution" separated in the word clouds as was done initially when the laboratory reports were entered verbatim. The thematic coding showed such phrases needed to be linked when entered in word cloud generators. Words can be linked in analysis by adding a dash between words. The above example would now be entered into a word cloud generator as "understand-evolution". After rereading the data, a word cloud generator confirmed the categories that had emerged from my reading of the data. Thematic data analysis focused on connecting patterns in perceptions (Aronson, 1994). The evolution simulations writing summary assignment was completed after students had received instructor feedback on their ecology simulation summary assignment, potentially motivating students to put more effort into future assignments.

Semi-structured individual interviews were held with volunteers after two ecology and two evolution laboratory experiences had been completed as the focus of this research was on how students used the laboratory experience to learn ecology and evolution content. Participants who expressed interest in being interviewed via a video chat agreed to talk with me to discuss their ideas. Interviews were done using the video chat "Google+ Hangouts" video chat application. Cotton College used Google Mail ("Gmail") as its college-provided electronic mail platform.

The Google+ Hangouts video chat application has a screen share feature, allowing both parties to share what is on their computer screen. Use of this feature allowed me to share word clouds with student-participants during the video chats, allowing me to accurately reflect what the students wanted to convey. Also, I would say, "I understand you to say…." and then encouraged the student-participant to express whatever ideas they wished. Interviews were not recorded but I took notes of participant's words during the interview, then asked the interviewee if my notes accurately reflected what they said as a participant check of the collected data. Using notes to capture what the student-participant was saying allowed me to focus on hearing the student while capturing the important ideas being conveyed (Fasick, 2001; Wengraf, 2001). It was important to Cotton College that I be an instructor first and researcher second; it was important to me that I honor that desire and be present in the conversation with my students. Cotton College and I agreed that because the interviews would happen during the semester the student was enrolled in my class, interviews would not be recorded. Cotton College did not want, and I agreed, the research to negatively impact students' feelings, subsequent to completion of the course and possibly impacting their success in the class. Since I wanted the students to feel comfortable and be honest in their responses, I felt that the administrations' concerns for student privacy were justified and did not seek to record the conversations, instead relying on taking notes from my chats with my students. Hammer (1994) noted that a student-participant who agreed to be audiotaped in interviews held by the instructor was dropped from the study because of his apparent high level of discomfort being interviewed by the instructor. Hammer (1994) asserted that the student was embarrassed to be interviewed by the instructor because the extent of his misconceptions would become apparent to the instructor. This was a situation that Cotton College and I wanted to avoid. A method of field notes allowed me to do respect both Cotton College's desires and my preferences for how I interacted with my students. Taking field notes in this instance was much like a student taking lecture notes: important points, concepts, and connections were written down. These notes were checked with the participant during the conversation to help ensure accuracy, much like a student asking a clarification question during lecture or office hours. The case for field notation over verbatim transcripts is detailed in Halcomb & Davidson, 2006. Conversations were casual and included time for the participant to ask questions about coursework and receive assistance on assignments. Both men and women, traditional and non-traditional students, were represented in interviews. There were a total of twenty students who used virtual simulations who volunteered to be interviewed individually. Seventeen students who used at-home kits volunteered to be interviewed individually. Questions for interviews and focus groups are included in Appendix E.

Focus groups were held during regularly scheduled virtual office hours. Participants were volunteers who expressed interest via the class discussion board in talking in a group about their laboratory experiences and perceptions. Groups had men and women in each group. Two groups, consisting of four students each volunteered from the sections using virtual simulations. The section using at-home kits also had two group, one consisting of five students and the other consisting of four. There were a total of nine men and eight women. Of the seventeen participants, ten were non-traditional students and seven were traditional students. Chats were casual but followed a set of semi-structured questions. Students seemed very sincere and showed genuine interest in wanting to give their input to be used to improve the course. Themes that emerged during the chats will be presented in table form, followed by a narrative with specific comments made by participants, identified by pseudonyms. Gender differences and traditional/non-traditional student differences will be noted when evident in the discussions.

Notes from oral interviews were taken as paraphrases and summaries of participants' words and were not transcribed verbatim, which is an acceptable practice for gathering data for thematic analysis (Aronson, 1994). Written summaries, interviews, and focus groups were analyzed for patterns in vocabulary, learning topics, and perceptions towards the laboratory experience (Taylor & Bogdan, 1984). Themes were identified by bringing together ideas (Leininger, 1985).

Themes that emerged from interviews, focus groups, and laboratory reports are presented in table form in Chapter IV. A narrative follows, explained and supported with specific comments made by the participants, identified by pseudonyms. Differences between traditional/non-traditional students are noted with evidence from the data.

Data were also inputted into a word cloud-generating website, Tagxedo.com, to form word clouds to visually represent participants' voices. Word clouds were shared with participants during the video chats as a way for the participants to validate the data collected from them. Data were also reported in narrative form. These methods of data representation are discussed in Cidell (2010) and Gottron (2009). Word clouds are an acceptable research tool to evaluate and validate findings in conjunction with reporting findings in narrative form (McNaught and Lam, 2010). Word clouds are useful ways for researchers to visualize the data quickly (Dugan & Muilenburg, 2012). Word clouds were also useful ways for participants to confirm their verbalized perceptions towards biology. Data saturation was achieved when no new or different words achieve prominence in the word clouds (Gottron, 2009). A member-check was conducted to ensure that the participants believed that their words were being represented appropriately.

The evolution virtual simulations used in this research were SimBio evolution lab simulations: "Evolutionary Evidence" and "Finches and Evolution". "Evolutionary

Evidence" explores evolution assumptions by targeting misconceptions common to introductory biology students through the use of an experiment in which the student manipulates variables.

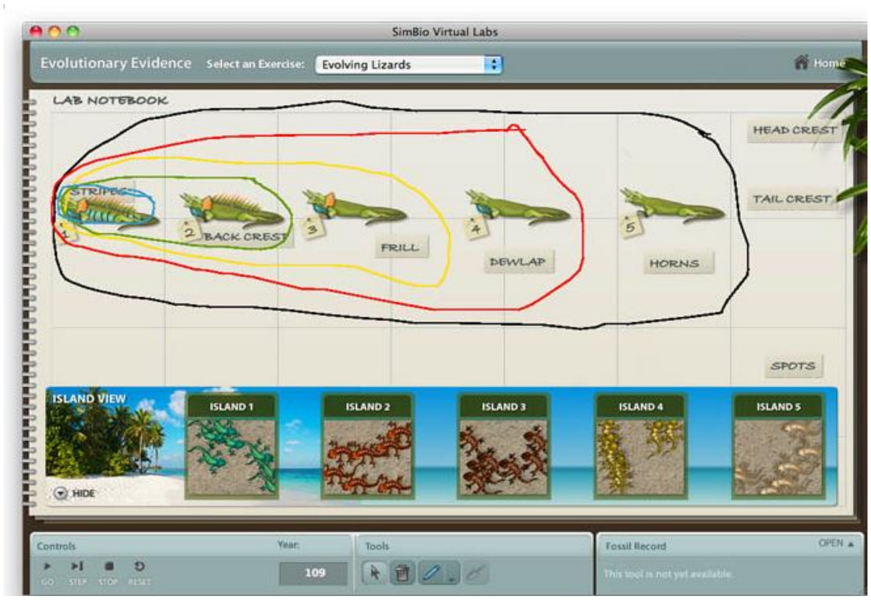


Figure 3. "Evolutionary Evidence" screenshot.

"Evolutionary Evidence" (Figure 3) offered students an opportunity to explore the evidence that biologists use to understand that life on earth evolved. Students were asked to validate that under selection pressure, organisms change over time. After validating the concept the students then designed an experiment about the concept. For example, after looking at how related species have nested sets of traits and how to quantify that relatedness, students created lizards and predict the order that lizard traits appeared. Exercises allowed students to experiment with different aspects of natural selection. Students could organize organisms (Figure 4). Students wrote hypotheses based on the idea of a common ancestor and tested it using related lizards living on five separate islands.

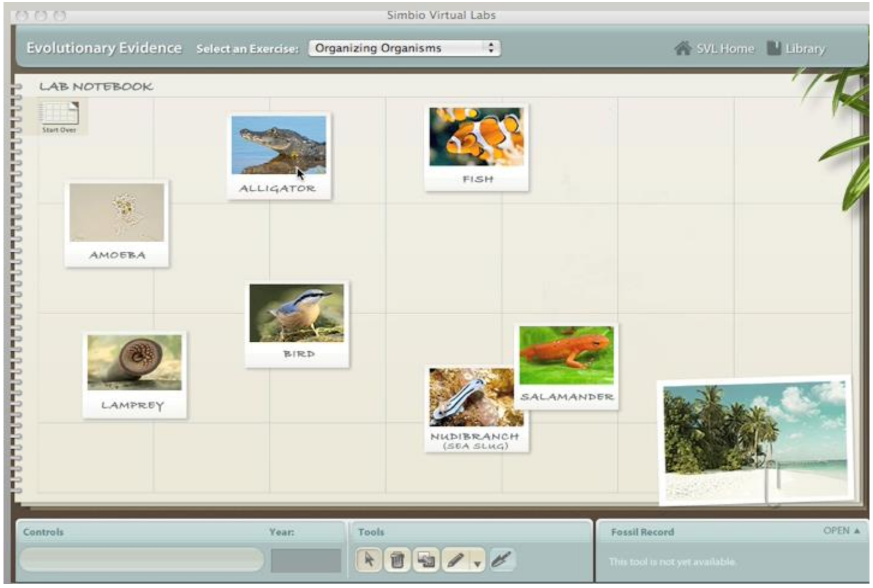


Figure 4. “Organizing Organisms”. Exercise in “Evolutionary Evidence.”

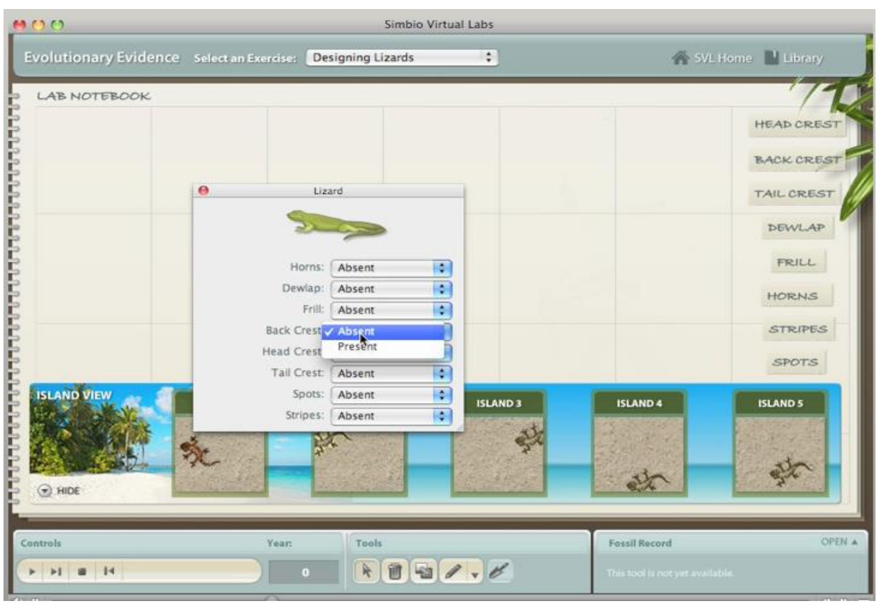


Figure 5. “Designing Lizards.” Exercise in “Evolutionary Evidence.”

Students used an exercise to test designed lizards against observed patterns (Figure 5). They then went on to an exercise with lizards that evolved due to mutation and selective pressures (Figure 6). Students had all lizards start on one island, determine how many traits will vary, then have single individuals swim to new islands. Students noted patterns of related traits as the lizards spread through the islands (Figure 7). A workbook guided students through the exercises and prompted them to make testable hypotheses and predictions with the variables available for manipulation (Figure 8).

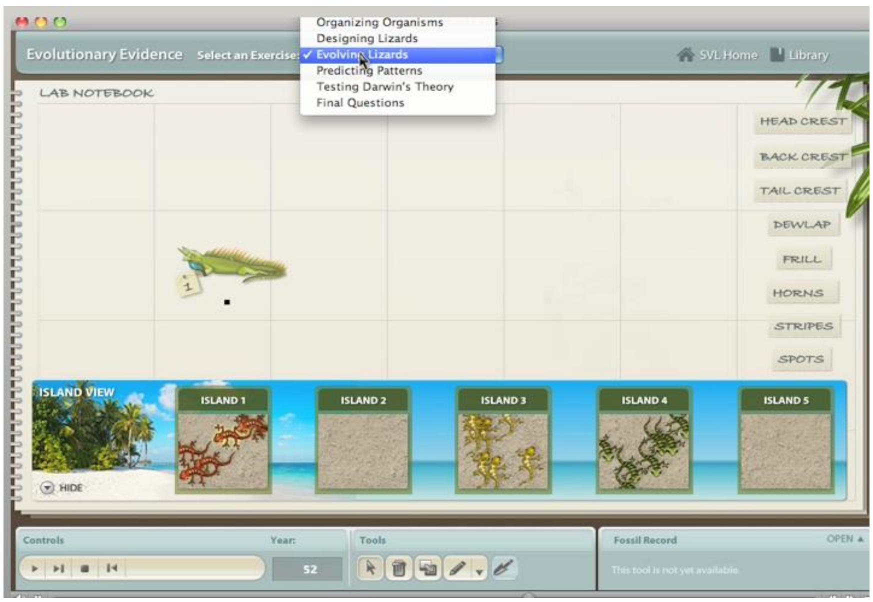


Figure 6. “Evolving Lizards”. Exercise in “Evolutionary Evidence.”

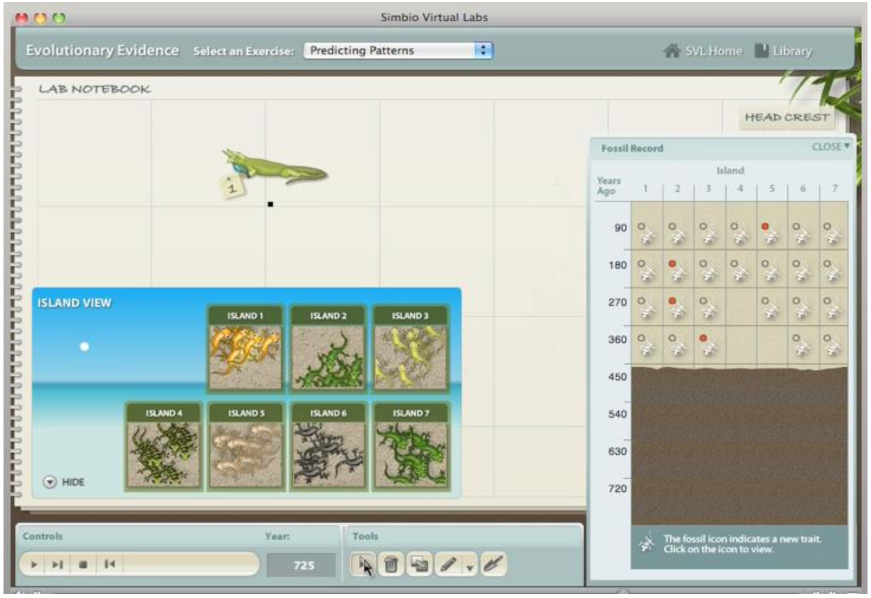
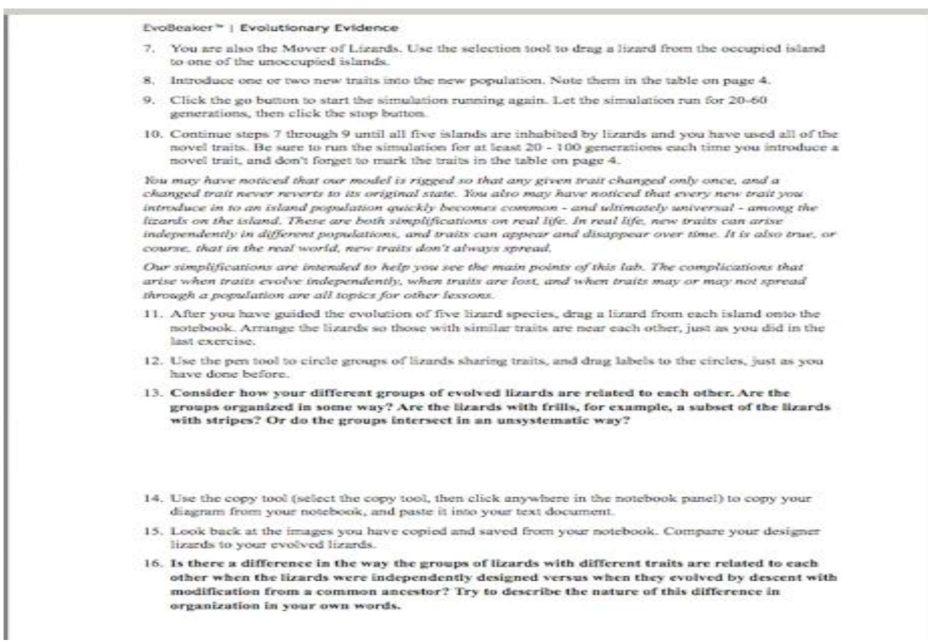


Figure 7. "Predicting Patterns.".



EvoBeaker™ | **Evolutionary Evidence**

7. You are also the Mover of Lizards. Use the selection tool to drag a lizard from the occupied island to one of the unoccupied islands.
8. Introduce one or two new traits into the new population. Note them in the table on page 4.
9. Click the go button to start the simulation running again. Let the simulation run for 20-60 generations, then click the stop button.
10. Continue steps 7 through 9 until all five islands are inhabited by lizards and you have used all of the novel traits. Be sure to run the simulation for at least 20 - 100 generations each time you introduce a novel trait, and don't forget to mark the traits in the table on page 4.

You may have noticed that our model is rigged so that any given trait changed only once, and a changed trait never reverts to its original state. You also may have noticed that every new trait you introduce in to an island population quickly becomes common - and ultimately universal - among the lizards on the island. These are both simplifications on real life. In real life, new traits can arise independently in different populations, and traits can appear and disappear over time. It is also true, or course, that in the real world, new traits don't always spread.

Our simplifications are intended to help you see the main points of this lab. The complications that arise when traits evolve independently, when traits are lost, and when traits may or may not spread through a population are all topics for other lessons.

11. After you have guided the evolution of five lizard species, drag a lizard from each island onto the notebook. Arrange the lizards so those with similar traits are near each other, just as you did in the last exercise.
12. Use the pen tool to circle groups of lizards sharing traits, and drag labels to the circles, just as you have done before.
13. **Consider how your different groups of evolved lizards are related to each other. Are the groups organized in some way? Are the lizards with frills, for example, a subset of the lizards with stripes? Or do the groups intersect in an unsystematic way?**
14. Use the copy tool (select the copy tool, then click anywhere in the notebook panel) to copy your diagram from your notebook, and paste it into your text document.
15. Look back at the images you have copied and saved from your notebook. Compare your designer lizards to your evolved lizards.
16. **Is there a difference in the way the groups of lizards with different traits are related to each other when the lizards were independently designed versus when they evolved by descent with modification from a common ancestor? Try to describe the nature of this difference in organization in your own words.**

Figure 8. Workbook page from "Evolutionary Evidence".

“Finches and Evolution” (Figure 9) explored genetic components of natural selection using Darwin’s finches as a case study based on work by Peter and Rosemary Grant on the Galapagos (Grant and Grant, 2002). Students manipulated several parameters and tested predictions of evolution during different exercises. They could set the beak depth and width to different values for each side of the wet/dry island and use that to predict survival of offspring. Parameters students could manipulate included beak

Figure 9. “Finches and Evolution” screenshot.

depth, beak width, correlation coefficient, mutation rate, initial frequency of beak depth, the carrying capacity, mating distance, mate selectivity, and chicks/parent-year

The ecology virtual simulations used were SimBio ecology simulations: “Isle Royale” and “Keystone Predator”. “Isle Royale” (Figure 10) examined population growth and predator-prey dynamics based on the Isle Royale experiments beginning in the 1940s (Brander, Peterson, & Risenhoover, 1990; Peterson, Thomas, Thurber, Vucetich, & Waite, 1998). Students could manipulate the density of grasses, fir, sugar maple, as well as moose and gray wolf. Students used these factors to understand predator-prey cycling and explore how populations change through time. In “Isle Royale,” which used data from long-running studies on predator-prey relationships on Isle Royale, students manipulated five different plant densities, weather conditions, and wolf populations but could not introduce bears or a virus which would have devastated the moose population. Similar limitations exist in extant laboratory exercises done on campus.

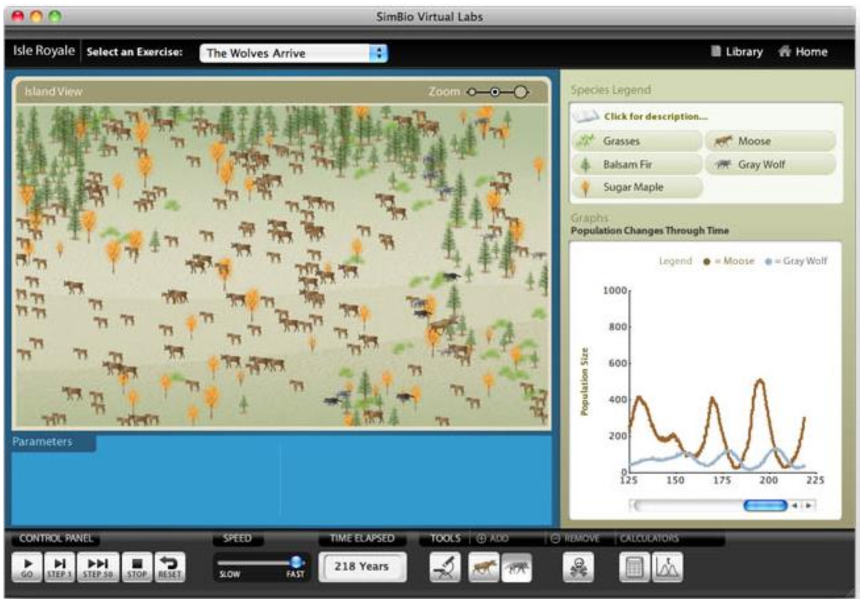


Figure 10. “Isle Royale” screenshot.

“Keystone Predator” (Figure 11) examined competition, food webs, ecological communities and keystone species and is based on the experiments Paine (1969; 1995) carried out in the Pacific Northwest. Students engaged with an ecosystem with 9 marine intertidal species. Using transplant experiments to deduce competitive relationships and samples from gut contents to construct food webs, students were able to synthesize experimental data to make predictions. Students also investigated what happened when each predator was removed by first making predictions based on their data then running removal experiments to test their predictions.

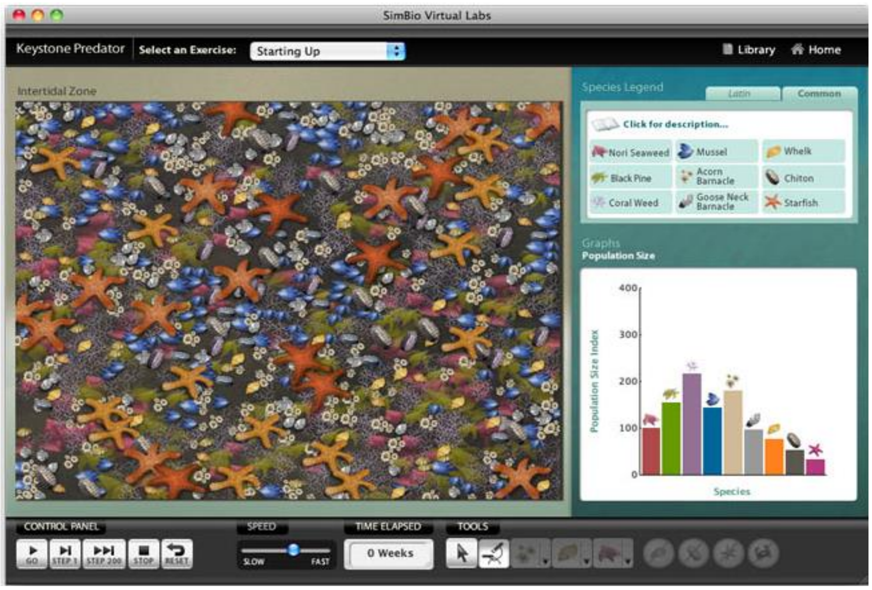


Figure 11. “Keystone Predator” screenshot.

At-home kits. The at-home biology experiments were based on laboratory exercises used in the on-campus course. The evolution at-home biology experiments were titled “Evidence of Evolution” and “Mechanisms of Evolution”. “Evidence of Evolution” explored evolution assumptions using case studies. Students were directed to examine two case studies: one from the National Center for Case Study Teaching in Science, “Man’s Best Friend?” and one from the University of California, Berkeley: “Island Biogeography and Evolution.” The cases were modified for use in an online class where students worked independently. Figure 12 shows one of the canid skull exercises students used in “Man’s Best Friend?”. Figure 13 shows one of the map students used to determine phylogenic relationships between lizard species in the Canary Islands in “Island Biogeography and Evolution.” Students completed each case study and wrote their answers to case study questions in their laboratory report. Instructions were posted on the weekly laboratory link where students accessed their laboratory materials; PDF files of both case studies were provided to students. Full instructions are provided in Appendix D.

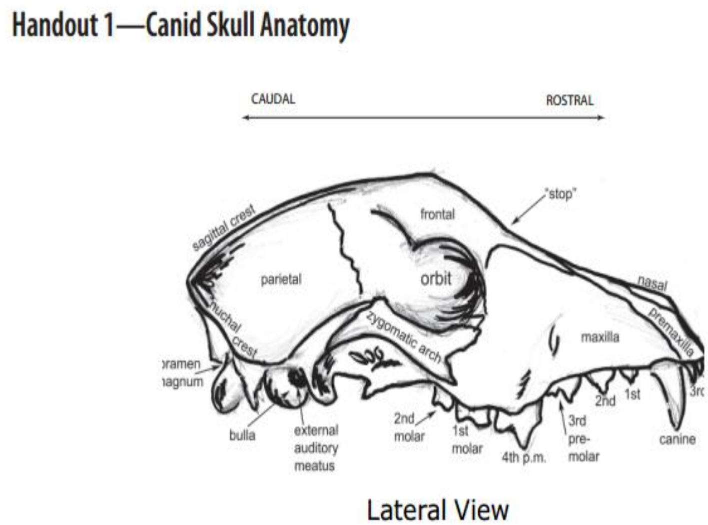


Figure 12. Handout from "Man's Best Friend?" The complete case study is available at The National Center for Case Study Teaching in Science.

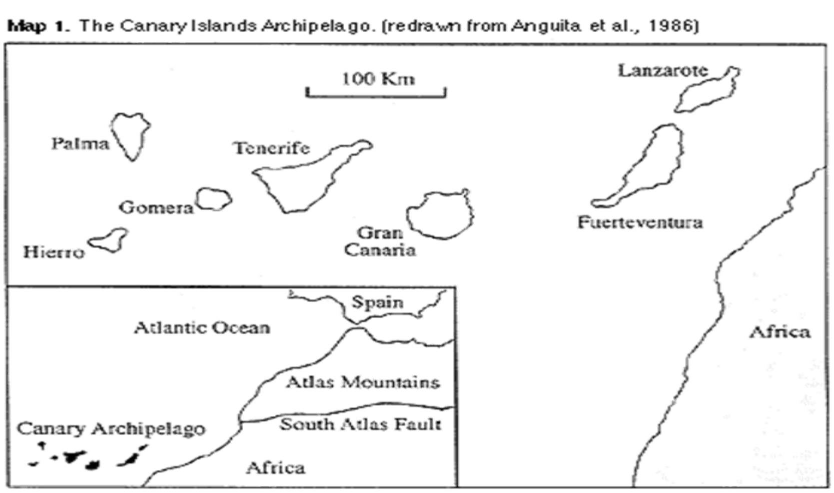


Figure 13. Handout from "Island Biogeography and Evolution."

"Mechanisms of Evolution" simulated evolution in action in a small population. I used a modified version of an activity from Bryn Mawr College: the unmodified activity can be found at http://serendip.brynmawr.edu. The modified activity used in this study is included in Appendix D. Students gathered original flavor and pretzel Goldfish ™ crackers or similar store brands, felt, and utensils to set up their hands-on simulations. Some students used pom-poms instead of crackers, felt, and utensils. Students used crackers to represent prey, felt to represent habitat, and utensils to represent predators (Figure 14). Instructions for the simulation were downloaded from the weekly laboratory instruction link in the Moodle course.

Figure 14. Natural selection hands-on set-up.

The ecology at-home biology experiments were "Nutrient Pollution" and "Sampling Ecosystems". "Nutrient Pollution" examined the effects of fertilizers on water quality.

Figure 15. Nutrient pollution hands-on set-up.

Students collected water from non-treated sources where they lived (Figure 15) and added varying amounts of water-soluble fertilizer to their samples (Figure 16). The laboratory instructions are provided in Appendix D.

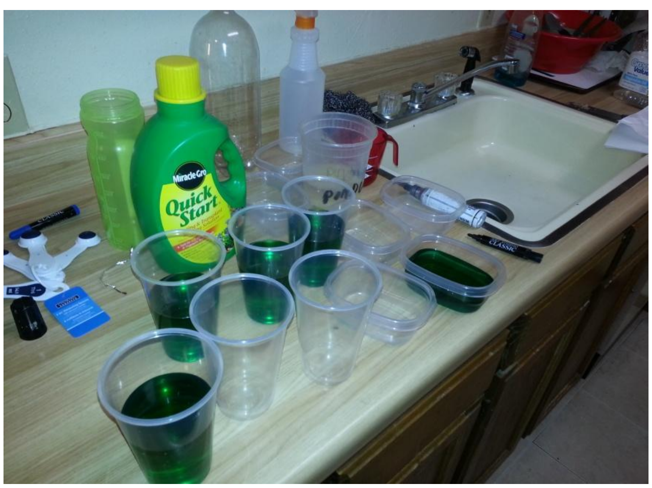


Figure 16. Nutrient pollution testing hands-on set-up.

"Sampling Ecosystems" encouraged students to ask questions about organisms that lived in their backyards. Students set up transect lines and made observations about the type of plant life they found, the percentage of cover provided by the plants, average daily temperatures, precipitation, and other abiotic factors. After the initial survey of the area, students placed polymer clay "caterpillars" into the environment (Figure 17). Students created hypotheses on interactions they expected to observe in their backyards with the polymer clay creatures.

Figure 17. Polymer clay caterpillars.

CHAPTER IV

RESULTS

Chapter Overview

This chapter reports the results of the research. The research involved an experimental design (Campbell & Stanley, 1963) to assess student learning gains with an instrumental case study of online general biology (Stake, 1995). The case had two subunits based on instructional approaches for the laboratory of online general biology: virtual simulations and at-home kits. The research focused on the ecology and evolution laboratory assignments as they were the most well-developed assignments for approaches. Results from quantitative analyses are reported for ecology, evolution, and overall laboratory approaches. Student learning gains were measured with a pretest/posttest and a midterm exam, all of which are department-wide assessments at the study site. Students' perceptions of their biology learning were assessed with the Colorado Learning About Science Survey-Biology (Semsar, et al., 2011). The students' perceptions of their distance-delivery laboratory method were evaluated through the analysis of laboratory reports, semi-structured interviews, and focus groups conducted as video chats.

The following questions guided this study:

Q1 What is the relationship between the type of laboratory instructional approaches and the ecology and evolution content mastered in an online general biology course?

H1 There was no significant difference between the pretest-posttest learning gains of online general biology students using two types of laboratory instructional approaches.

H2 There was no significant difference in learning gains between ecology/evolution questions in the pretest-posttest and non-ecology/evolution questions in the pretest-posttest using two types of laboratory instructional approaches.

H3 There were no significant differences between the final course grades of online general biology students using two types of laboratory instructional approaches.

H4 There were no significant differences between the laboratory grades of online general biology students using two types of laboratory instructional approaches.

Q2 What are the perceptions of community college students towards ecology and evolution laboratory experiences in online general biology?

Research Q1

Laboratory Instructional Approach and Learning Gains

Frequency data for three characteristics: pretest completion, gender, and student classification of traditional or non-traditional, of the students enrolled in online general biology during academic year 2012-2013 are presented in Table 5.

Table 5

Student Characteristics

Characteristic	Total N	Fall VS	Fall AHK	Spring VS	Spring AHK
Pretest	116	32	32	26	26
Gender					
Female	72	21	19	15	17
Male	44	11	13	11	9
Student Type					
Traditional	54	14	14	13	13
Non-Traditional	62	18	18	13	13

*VS stands for "Virtual Simulations Treatment" and AHK stands for "At-Home Kit Treatment".

There were two treatment groups: students using virtual simulations (VS) and students using at-home kits (AHK). The results in Table 6 are reported as the average number of questions answered correctly. The pretest means for the virtual simulations users in the fall showed no significant difference from the pretest means of virtual simulation users in the spring (t_{57} = 0.87, p = 0.39). The pretest means of the at-home kit users in the fall showed no significant difference from the pretest means of the at-home kit users in the spring (t_{57} = 0.71, p = 0.48). These results were expected because students were randomly assigned a distance-delivery laboratory treatment.

Also reported are the pretest means for gender and student classification. Females using virtual simulations pretest means compared to the pretest means of males using virtual simulations showed no significant differences in pretest averages. Traditional students using virtual simulations pretest means compared to non-traditional student pretest means showed no significant differences in pretest averages. Females using at-home kits pretest means compared to the pretest means of males using at-home kits (t_{21} = 1.05, p = 0.29) showed no significant differences in pretest averages. Traditional students using at-home kits pretest means compared to non-traditional student pretest means showed no significant differences in pretest averages (t_{26} = 0.79, p = 0.43).

Table 6

Pretest Data

Tests	Group	N	*M*	SD	*t*	d.f.	p
Pretest	VS-Fall	32	19.9	5.1	0.87	56	0.39
	VS-Spring	26	18.3	7.6			
	VS-Female	36	19.4	4.1	0.09	56	0.92
	VS-Male	22	18.9	2.4			
	VS-Traditional	27	19.7	3.5	0.75	56	0.45
	VS-Non-Traditional	31	18.6	6.9			
	AHK-Fall	32	19.3	8.1	0.71	56	0.48
	AHK-Spring	26	17.8	7.9			
	AHK-Female	36	19.5	4.6	1.05	56	0.29
	AHK-Male	22	17.1	4.8			
	AHK-Traditional	27	19.4	3.9	0.79	56	0.43
	AHK-Non-Traditional	31	17.9	7.5			

Students began with similar levels of content knowledge being measured by the pretest (Table 6). There was no statistical difference on the pretest between the groups. The pretest and posttest were the same assessment: the Biological Concept Inventory and the Conceptual Inventory of Natural Selection.

Differences in achievement became apparent beginning with the 50-item multiple-choice midterm. Results are reported in Table 7 with the average grade reported. The difference in performance on the midterm was significant for the different laboratory delivery type: the average on the midterm for the virtual simulation users was a 76.6% while the average on the midterm for the at-home kit users was 66.4%. The virtual simulation student users scored on average one letter grade higher than the at-home kit student users (Cohen's *d*= 1.13). This exceeds the threshold of the defined large effect size of 0.80 (Kirk, 1996), which suggests that the virtual simulations used had a large effect on students' midterm performance. Men and women using virtual simulations scored similarly on the midterm, with an average of 77.5% (N=22, standard deviation 6.2) for men and 76.1% (N=36, standard deviation 6.9) for women. Men and women using at-home kits scored similarly on the midterm, with an average of 66% (N=22, standard deviation 10.0) for men and 66.7% (N=36, standard deviation 11.5) for women.

On the posttest, virtual simulation student users averaged approximately 70%, or a letter grade C. At-home kit students averaged approximately a 64% on the posttest, or a letter grade D. On average, the virtual simulation student users scored one letter grade higher than at-home kit student users (Cohen's *d*=0.73). See Table 8.

Table 7

Midterm Data

Tests	Group	*M*	SD	*t*	d.f.	p	*d*
Midterm	VS	76.6	6.6	0.018	56	0.01	1.13
	AHK	66.4	10.9				
	VS-Female	76.1	6.9	4.18	35	0.000041	0.99
	AHK-Female	66.7	11.5				
	VS-Male	77.5	6.2	4.56	21	0.000022	1.38
	AHK-Male	66	10.0				
	VS-Traditional	77.7	7.56	3.48	26	0.000515	0.90
	AHK-Traditional	68.1	13.03				
	VS-Non-Traditional	75.5	5.7	3.86	30	0.00014	0.96
	AHK-Non-Traditional	66.4	12.1				

VS stands for "Virtual Simulations Treatment" and AHK stands for "At-Home Kit Treatment".

Table 8

Assessment Statistics

Tests	Groups	N	*M*	SD	*t*-test	p	*d*
Pretest	VS	58	18.6	8.1	0.63	0.34	
	AHK	58	19.2	6.3			
Midterm	VS	58	76.6	6.6	0.018	0.01	1.13
	AHK	58	66.4	10.9			
Posttest	VS	58	70.2	5.9	-2.52	0.01	0.73
	AHK	58	64.8	5.5			

*VS stands for “Virtual Simulations Treatment” and AHK stands for “At-Home Kit Treatment”.

When the normalized learning gains (Hake, 1998) of traditional and non-traditional students were compared to the laboratory instructional method, both traditional and non-traditional students who were randomly assigned the virtual simulation laboratory delivery method had higher learning gains. A course learning gain is calculated by the actual average gain divided by the maximum possible actual average gain where the maximum possible actual average gain is the pretest average subtracted from one hundred.

Learning gains were calculated for the two treatments in two ways. First, the instruments were left intact, with evaluation happening across the entire set of questions, comparing the pretest/posttest for virtual simulation users versus at-home kit users. Second, the instruments were disaggregated so that only evolution/ecology questions were used to calculate learning gains, again comparing the virtual simulation users and the at-home kit users. This set of data were then used to compare learning gains of both treatments with ecology/evolution learning gains and non-ecology/evolution learning gains. After learning gains were calculated, they were compared with a t-test. This allowed comparison of the whole class learning gains for virtual simulation users compared to at-home kit user learning gains. Also, learning gains were compared on just the ecology/evolution questions of the pretest/posttest as ecology/evolution lab exercises were the focus of the research. As expected, learning gains on the ecology/evolution questions for the virtual simulation users drove the outcome of virtual simulation users scoring higher on the posttest; comparing learning gains on the non-ecology/evolution questions between the two treatments showed no significant differences. Implications for this will be discussed in Chapter V.

Figure 18 illustrates this difference in learning gains. Table 9 provides the results of learning gains comparisons between the two treatments overall, and the learning gains comparisons between the two treatments traditional and non-traditional students. Table 9 also provides the results for the learning gain comparisons between the two treatments when the ecology/evolution questions are parsed out from the non-ecology/evolution questions on the pretest/posttest. These finding will be further discussed in Chapter V.

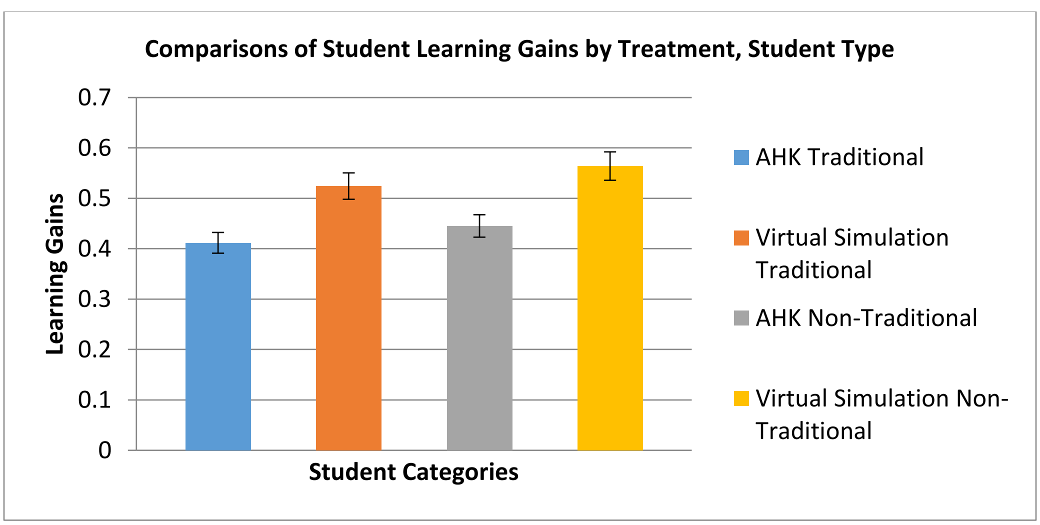


Figure 18. Student learning gains comparison.

Table 9

Learning Gains

Group	N	*M*	SD	*t*-test	*d*
AHK-Overall	58	0.43	0.14	0.004*	0.78
VS-Overall	58	0.54	0.13		
AHK-Traditional	26	0.41	0.14	0.003*	0.81
VS-Traditional	28	0.52	0.13		
AHK Non-Traditional	32	0.45	0.16	0.004*	0.73
VS Non-Traditional	30	0.56	0.14		
AHK-Eco/Evo	58	0.46	0.15	0.002*	0.83
VS- Eco/Evo	58	0.61	0.13		
AHK-allother	58	0.07	0.12	1.04	
VS-allother	58	0.08	0.11		

*Significant difference with $p<0.05$. VS stands for “Virtual Simulations Treatment” and AHK stands for “At-Home Kit Treatment”.

Students were to report the amount of time they spent on their laboratory exercises and if they repeated the exercises. Virtual simulation users (n = 54, some student data were not recoverable) averaged 124 minutes for each virtual simulation, with a range of 18 to 186 minutes. Virtual simulations were repeated an average of 1.3 times each with a range of 0-4 where 0 indicates a student did not complete a particular assignment but turned in a lab summary indicating that they reviewed but did not complete the lab assignment. Data for time and repeatability was captured through Moodle as the virtual simulations were linked to the class homepage. The links were visible only to virtual simulation users. At-home kit users (n = 12, most students did not report) spent an average of 192 minutes for each at-home experience, with a range of 0-300 minutes, where 0 indicates a student did not complete a particular assignment but turned in a lab summary indicating that they reviewed the instructions for the lab assignment. No at-home kit user reported repeating an exercise with the exception of three students who repeated the pom-pom game activity of the Mechanics of Evolution laboratory though students wrote about wanting to repeat particular exercises but refraining due to lack of time or consumable resources. At-home kit data usages were not captured independently as their instructions were designed to be downloaded and printed off. Students using at-home kits consistently downloaded directions.

CLASS-BIO Results

As part of class participation points, students were assigned the Colorado Learning Attitudes about Science-Biology (CLASS-BIO) survey. The survey was open to students during the first and last week of instruction. The survey was administered through Qualtrics. Approximately 70% of the students enrolled in online general biology completed both survey assignments, resulting in 81 completed surveys. The CLASS-BIO survey had seven categories derived from extensive studies detailed in Semsar et al., 2011. The seven categories included: Real World Connection, Problem Solving Difficulty, Enjoyment, Problem Solving Effort, Conceptual Connections, Problem Solving Strategies, and Reasoning. There were no significant shifts after instruction along the novice-to-expert continuum for student groups, including laboratory delivery method, student type, or gender. These findings will be discussed further in Chapter V.

Research Q2

Student Perceptions

The perceptions of Cotton College students towards online biology evolution and ecology laboratory experiences are presented below. The perceptions of students using virtual simulations are reported first, followed by the perceptions of students using at-home kits. In each section, the laboratory reports will be quoted first, followed by the word clouds, then tables of student responses to questions. The tables of responses will be expanded on with quotes from student video chats in narrative form. This lays out the categories coded from the data. The final set of word clouds then addresses how students' perceptions inform the categories and themes. The tables contain categories of student responses. From those categories, themes were described based on thematic analysis which showed categories of responses describing different aspects of phenomena. The linking of categories with theory, in this study constructivism, to identify themes allows this research to be generalized to other rural community college settings and helps give credibility to the research (Green, et al., 2007). Constructivism suggests that themes describing how students engaged with the laboratory experiences will inform students' perceptions of their laboratory experiences as constructivism posits that learners need to actively construct their understanding of phenomena through interactions (Crotty, 1998). Virtual simulation users' experiences are described first, followed by at-home kit user's experiences. In both treatments, ecology experiences are described first, followed by evolution experiences. After both experiences are described, they are compared and contrasted; from that analysis, themes that are supported by both sets of data emerged, as well as themes unique to each experience. The themes that were identified from the categories are presented at the end of the chapter after the entire data set, including a comparison of laboratory experiences, is reported.

Virtual Simulation Users' Experiences

Ecology simulations. Laboratory reports were approximately 800-1,200 words long. In ecology laboratory reports, students reported that they understood why populations reached carrying capacities, how predators alter populations, and how food webs operated. Excerpts are included here for illustrative purposes. From the Isle Royale simulation, students were mostly positive, noting that they liked the use of a real-world study, they enjoyed an opportunity to use math in the laboratory, and they were intrigued by the impacts of climate change. Kristie, a non-traditional female student wrote in her laboratory report:

> I really liked this lab. This lab showed me how the food supply effects a population significantly. The moose population would increase with more fir trees and grasses but when there was a shortage, the moose population decreased. When wolves came along they also helped the moose population by keeping the population to a minimum. They effect each other.

Kristen, a non-traditional female student wrote in her laboratory report:

> During this lab, I experimented with a population based on a simplified version of the Isle Royale community. I learned about species, communities, and how plants effect everything. I learned about population ecology and how what looks like little changes can make big differences. I really liked this lab because it was fun and challenging. I was glad it was based on a real study.

Mary, a traditional female student wrote in her laboratory report:

> I liked Isle Royale. I liked testing my predictions and seeing what would happen. I even liked using math and I don't like math that much. I watched the moose population sharply increase and decrease ahead of the wolf population. I could see that happen in the graph and predict changes based on understanding graphs.

Tammy, a traditional female student wrote in her laboratory report:

> In this experiment on Isle Royale, I investigated life without predators and with predators. I found this experiment very interesting and did not realize especially how climate change would affect the population of both the wolves and moose. I understand it would have some impact but not as much as it did. What I found interesting and did not expect was when the wolf population was up the moose population was down and when the moose population was up, the wolf population was down. I did not expect that all and predicted something else. Seeing the math in use made it more

> real for me and that helped me understand what a big impact the environment has on populations.

Brooke, a traditional female student wrote in her laboratory report:

> Starting this lab and as I was going through it, it got my attention. As it talked about the Isle Royale, just reading it first had me already ready to start the lab to see how everything was going to turn out. Seeing that there was math kind of made me even more excited about doing it just because I like math, so as I ended the lab I had learned a lot at that point. I've come to understand that the study of moose and wolves on Isle Royale began in 1958 and is thought to be the longest running study of its kind. During the lab I performed my own experiments to study populations using the graphs and it was fun.

Cameron, a traditional male student wrote in his laboratory report:

> This Isle Royale lab is about population ecology. We're investigating how the presence of predators affect the moose. It was great to test how weather affects the plant-moose-wolf system. I think that understanding how the community and population of different species interact is cool. Now I understand that some predators are more important than others to keep the thing in balance.

Chris, a non-traditional male student wrote in his laboratory report:

> I felt that Isle Royale covered the topic in-depth and provided a comprehensive and testable look at the model of predator-prey ecosystems. On an informal note, this lab produced unexpected results that I found quite intriguing and surprising; plus it was fun to study moose and wolves. I felt that the lab was straight forward and presented the information in a detailed, fun, and informative way that increased my understanding.

From the Keystone Predator simulation, students wrote about increased understanding of community structure. Tammy, a traditional female student wrote in her laboratory report:

> I found the Keystone Predator lab very interesting and I learned several things such as what is community structure and why it is important. I finally understand that there is a reason for everything and what you take away from an ecological community can affect everything in that community. Also in this experiment, I learned about food chains and food webs. Also, I learned what a keystone species is and they're so cool!

> When the starfish was removed, there was dramatic changes in the environment. The greatest impact on the structure of the community was the removal of starfish. The importance of this lab I feel was to show the importance of having a keystone species in every environment and how dramatically things can change if it is ever removed.

Alison, a non-traditional female student wrote in her laboratory report :

> The Keystone Predator lab was all about a series of famous experiments taken place in the 1960s in Washington. The experiments was designed to help us determine complexities in different species and how their interactions between each other play a major role in community structure. We also learned about keystone species—in this community, if you take out the starfish, the mussels take over the intertidal zone.

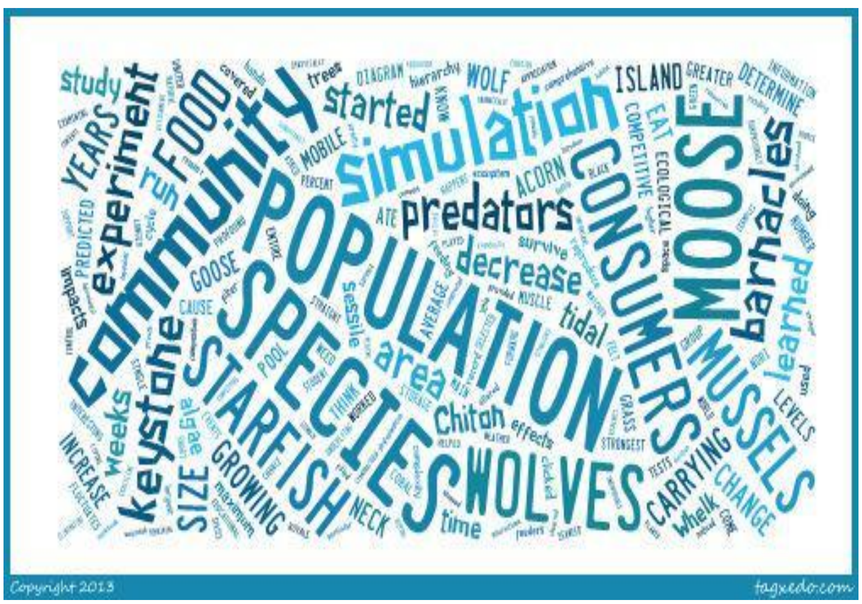


Figure 19. Initial ecology simulation word cloud.

Figure 19 is a word cloud depiction of frequencies of words used by students to describe their learning from ecology simulations. The word cloud was then shown during focus groups and interviews to solicit student feedback about ecology simulations. Common words also known as “stop words” (McNaught & Lam, 2010), such as “the”, were removed from analysis. This word cloud was developed in relationship with what students wrote in their laboratory reports and what they said during interviews and focus groups. We used these to clarify ideas and identify categories. The words most commonly seen focused our attention to particular ideas. The students spoke about how a moose population and a wolf population formed a community and how a population will grow until it reaches its carrying capacity.

The larger the word size, the more frequently the word appears in students' assignments. The words "population," "species," and "moose" appeared most frequently, appearing in 95% of completed student assignments. The words "consumers," "food," "simulation," "starfish," "community" and "mussels" appeared in approximately 80% of student summary assignments on ecology. These commonly occurring words led me to ask students to expand on why they selected these terms.

When I asked students about why these terms were selected, approximately 75% of students replied that the ecology simulations manipulated populations and species. The comments from John (interview) were typical: "I wrote about starfish and mussels because the simulation used them to explain how communities worked." Yolanda's answer (interview) also provided a typical response: "The starfish were eating the mussels for food. So I wrote about that." Kenny (interview): "The simulations asked me to change the community make-up of starfish and mussel populations. These species were important to understanding the ocean community." The Keystone Predator simulation also earned high praise from the students in focus groups. Mary (focus group): "I liked this one. It was a good story, with that scientist setting up experiments at the beach." Austin (focus group):

> Yeah, it was a good story. It was cool—I would've never thought about doing an experiment on a rocky beach so I learned about a community that I don't think about. It was cool to change the animals. I liked that it was easy.

Kenneth (focus group): “I agree it was easy to use. I could really see what I was doing. Never thought about animals on the beach but it’s great that scientists do.” Approximately 60% of the students perceived the Keystone Predator simulation to have engaging background information that was informative and interesting, the use of a novel environment (the intertidal zone), and a clearly laid out user interface.

The Isle Royale simulation, where students manipulated a number of variables affecting the moose-wolf dynamic, was the students’ favorite ecology simulation, as evidenced by their comments. John (interview): “This was the best simulation! I thought it was totally cool and I started looking into this system in real life.” Yolanda (interview): “I liked the moose simulation best. It was easy to understand and it used animals I’m used to.” Kenny (interview): “I really enjoyed the moose sim. It was cool to learn that scientists have been studying this like forever in real life. Wolves are awesome!” Chris (focus group):

> This simulation used North American mammals that we could relate to. It was based on real research done by scientists over a long period of time; they are still there! The interface on this simulation was easier for a user to interact with.

Austin (focus group): “Isle Royale is a real place. I want to go there because of this sim! It was my favorite.” This simulation was selected as a favorite by approximately two-thirds of the students participating in discussing virtual ecology simulations for the following reasons: the historical story line of research carried out on Isle Royale was perceived as engaging and inspiring, the use of mammals in the simulation, and the clearly laid out user interface.

The word cloud (Figure 20) that emerged from the member-checks that took place during the interviews and focus groups was condensed into a single word cloud for presentation here. Students agreed that the category word cloud was less informative to them than the word clouds we started with. We agreed that this was likely because no one single category jumped out as more important. As word clouds are built on frequencies, that no one category seemed significantly larger supported the idea that multiple categories were important to the student-participants.

Figure 20. Ecology simulation word cloud.

The table that follows describes the phrases students used to describe their perceptions towards the ecology virtual simulations. When students mentioned in interviews or focus groups some aspect of being challenged by their ecology simulations, it is noted on the table as “I was challenged by the ecology simulations to think more about our environment”. The phrases used were gleaned from the interviews and focus groups when I would say back to the participant, “So I understand you to say that you were challenged by the ecology simulations to think more about our environment." If they affirmed their answer, I grouped their response in that category. The word cloud in Figure 3 is built from the descriptions participants gave during interviews and focus groups of reflections from initial word clouds, coupled with thematic coding. Categories of ideas were discussed in interviews and focus groups with frequencies reported in Table 10.

Table 10

Ecology Simulation Frequencies

Category	Group	Frequency	Percentage Interviewed
I was challenged by the ecology simulations to think more about our environment	NT	12	100
	T	8	100
I thought the ecology simulations were fun	NT	11	92
	T	8	100
I think I learned a lot from the ecology simulations	NT	12	100
	T	8	100
I felt like I was doing ecology with simulations	NT	10	83
	T	5	62.5
I enjoyed learning about different organisms	NT	10	83
	T	6	75
The moose-wolf interaction captured my imagination the most of all the simulations	NT	9	75
we did this semester	T	5	62.5
The Keystone Predator simulation showed me how communities are structured by	NT	10	83.3
the species in them	T	8	100

NT stands for "Non-traditional student" and T stands for "Traditional student."

Evolution simulations. In evolution laboratory reports, students reported that they understood adaptations, found the simulations helpful to their understanding of evolution, and challenging. They wrote that they were able to see evidence for evolution in the simulations. From the Evolutionary Evidence simulation, they wrote about descent with modification and how Darwin's theory was valid. Several noted that the simulations allowed them to explore the topic of evolution for the first time, as it was a subject actively avoided in their high school biology course. Laboratory reports were approximately 700-1,500 words long. Excerpts are included here for illustrative purposes. Tammy, a traditional female student wrote in a laboratory report:

> In Evolutionary Evidence, we were asked to test Darwin's theory of descent with modification with several experiments. When I completed this lab, my data clearly shows the evidence that descent with modification is correct. The validity of Darwin's theory is pretty explanatory. All evidence has pointed it to be true with a couple modifications. Not every animal or plant is going to be perfect in the explanation of evolution but that is why we still have scientists to fix the holes that might arise. I learned several things during this lab and realized even though we might not consider ourselves and other organism in the same ancestry we definitely are more alike other organisms than realized. We need to keep an open mind on evolution but questions are always good to get answers for. Now I understand what scientists mean by evolution. We didn't talk about evolution in high school so it was good to learn. This lab was very interesting because it showed you the differences that occur when you recreate your own traits for lizards an put them in different times of the past. It was also fun. It is hard not to believe that descent with modification has not occurred.

Erica, a nontraditional female student wrote in a laboratory report:

> Overall, this lab really made evolution seem more realistic to me. The lab drew me to the conclusion that Darwin's theory has too many similarities between species of years passed on now not to be true. I used the scientific method to investigate where Earth's organisms came from. Throughout the labs, I did a variety of experiments and made predictions about what I thought the outcome would be. Overall, I thought the labs were very helpful, fun, and increased my understanding. They provided a valid case behind the origin of species.

Keith, a nontraditional male student wrote in a laboratory report:

> I liked the labs because they were fun experiments that helped me understand evolution; it has been many years since high school and I don't remember learning about it then. For example: organizing the lizard traits on the five islands shows the populations to be microevolution on the island with the simulated founder effect. This lab showed evolution isn't necessarily progressive. That natural selection is environmentally influenced and directional.

Kristie, a nontraditional female student wrote in a laboratory report:

> The labs connects to me to understanding the evolution of species. They were fun to do and the experiments showed traits passed down from

> organisms and other traits gained from adapting to the changing environment.

Kristen, a nontraditional female student wrote in a laboratory report:

> This lab helped me understand how populations evolve and acquire different traits and how those traits are from an earlier species history of life. Plus, the labs were easy and fun to do. The fact that they were set up as experiments to test was cool.

Mary, a traditional female student wrote in a laboratory report:

> I found Darwin's theory to be true because as time passes and the environment changes the characteristics of a species can also change. In the experiments, I tested the theory of evolution in experiments. Overall, I found these labs to be very informative and also fun. I was glad we did them so I could learn about evolution, something I haven't learned about before.

Alison, a nontraditional female student wrote in a laboratory report:

> I personally felt a lot happier about these experiments because I grasped a little more about what I learned and what the labs were trying to teach me. I feel that I understand more about how organisms survive now that I have done these labs. These labs were helpful for me to understand more about natural selection and how different species use mutations.

Crystal, a nontraditional female student wrote in a laboratory report:

> I allowed my six year old to help me with the experiments which were models of evolution. We really enjoyed doing these together and feel we understand evolution now. We had fun with science! Before this lab I had never really given any thought to why we evolve into what we are today, not only us as humans but every single other species.

Erica, a nontraditional female wrote in a laboratory report:

> These labs drew me to the conclusion that Darwin's theory as too many similarities between species of years passed down and now not to be true. In the latter part of the lizard lab, we discussed and worked with fossil records, which we also read about. People may always criticize Darwin and what he believed, but through this lab I have given the man more credit than I did before.

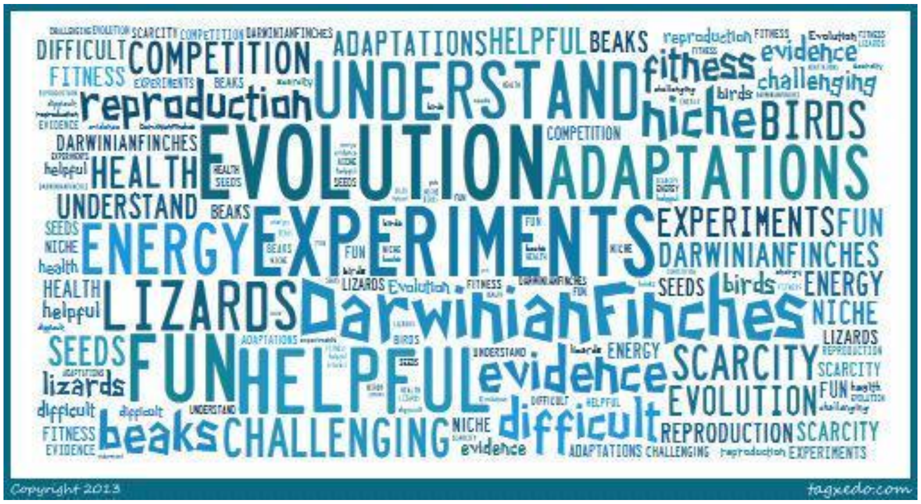


Figure 21. Initial evolution simulation word cloud.

Figure 21 is a word cloud depiction of word frequencies in student descriptions of evolution simulation learning. The word cloud was then used during video chats in conjunction with a list of questions to solicit student feedback about evolution simulations. The words “experiments,” “fun,” and “understand” appeared most frequently in student summaries of evolution simulation learning, appearing in 100% of completed student assignments. The words “energy,” “lizards,” “Darwinian finches,” “helpful,” “adaptations” and “scarcity” appeared in approximately 80% of student lab reports summarizing what they learned in evolution simulations.

When I asked students about why the terms in Figure 21 were selected, approximately 75% of students replied that the evolution simulations were experiments where they were asked to manipulate various variables related to the environments of lizards and finches. John (interview) replied:

> I had to change the environments of the lizards and birds. With the lizards, I was picking islands to populate. It was really more character change. But the birds, I had to manipulate how wet the wet side of the island was. All in all, it was fun to do, much better than just reading it in the textbook.

Yolanda (interview) responded: "I played God with the lizards because I designed them. But then I saw how they changed over time. It was fun to give the lizards different patterns." Ashley (focus group) said:

> I really had fun with these sims! I liked learning about how the adaptations helped the animals. I never really thought about how much energy it takes for animals to live.

Kenny (interview) reported:

> Evolution! At last I understand it. We didn't discuss it much in high school you know and I never understood what the fuss was. But these sims were a fun way to learn about it.

Austin (focus group) engaged:

> I liked learning about evolution in a way that was fun. I didn't really think scientists could do experiments with evolution but now I know they can and I know how. That was cool because now I understand better than before.

Barbara (interview):

> I am a person who likes to apply what I have learned. The sim did just that. All trait groups were organized in a systematic way building upon the last trait just like evolved lizards. Using descent with modification from a common ancestor theory, I was able to accurately predict the order in which traits would appear. When I was designing lizards, I couldn't distinguish which traits appeared first and which ones appeared last. It appears Darwin's theory is correct.

Four non-traditional students volunteered that their children, ranging in ages from 3-12 "played the simulations." One mother, Annika (interview), said she found her twelve-year old son up in the middle of the night running the Evidence of Evolution simulation:

> He was up at 2 am playing the sim! He'd run it a bunch but he wanted to finish one more run before he would go to bed. I let him because I didn't want him sneaking out of bed again. I think I'll let him do all the sims from now on! I kinda liked the sim but he was excited! That made me think more about it and I decided it was good.

She agreed with other students that the simulation was engaging. Crystal (interview) reported:

> I let my kids do the sims with me. They don't do much science in school, which is bad, but some of the science is against God. I'm questioning more now but it is good if the kids are seeing some science since they think it is fun.

Tracy (focus group):

> I don't agree with most science. Man is not smarter than God and God created the world and everything in it. But I will say the sims made me think about the world and maybe how God made everything. I know evolution isn't right—God has a plan for us. But I did let my kids (they're 3, 7, and 8) play with the computer program because I do want them to like school.

Barbara (interview):

> The virtual lab was very easy to use and was actually pretty fun. So much so that my five-year-old son helped me design and evolve the lizards. I think it is important to involve children at an early age into understanding the world in which they live especially if it involves something fun and hands on.

The word cloud that emerged (Figure 22) from the member-checks that took place during the interviews and focus groups was condensed into a single cloud. Students also found this word cloud less informative to them than the word cloud we started with but more informative than the ecology word cloud, perhaps because they were gaining confidence in the use of word clouds.

Figure 22. Evolution simulation word cloud.

The table that follows describes the phrases students used to describe their perceptions towards the evolution virtual simulations. When students mentioned in interviews or focus groups some aspect of being challenged by their evolution simulations to think about how organisms adapt or change over time, it is noted on the table as “I was challenged by the evolution simulations to think more about how organisms change over time”. The phrases used were taken from the interviews and focus groups when I would say back to the participant, “So I understand you to say that you were challenged by the evolution simulations to think more about how organisms change over time.” If they affirmed their answer, I grouped their response in that category. The word cloud in Figure 22 is built from the descriptions participants gave during interviews and focus groups of reflections from initial word clouds, coupled with thematic coding. Categories of ideas were discussed in interviews and focus groups with frequencies reported in Table 11.

Table 11

Evolution Simulation Frequencies

Category	Group	Frequency	Percentage Interviewed
I was challenged by the evolution simulations to think more about how organisms change over time	NT	11	92
	T	8	100
I thought the evolution simulations were fun	NT	7	58
	T	6	75
I think I learned a lot from the evolution simulations	NT	12	100
	T	8	100
I felt like I was doing experiments with evolution simulations	NT	8	67
	T	7	87.5
I enjoyed learning about evolution	NT	10	83
	T	6	75
The simulations helped me understand how environmental changes can drive population changes	NT	8	67
	T	7	87.5
The Keystone Predator simulation showed me how communities are structured by the species in them	NT	10	83.3
	T	8	100

Overall feelings about virtual simulations. As seen in Figure 23 and Table 12, students assigned the virtual simulation laboratory delivery method and who completed the labs were overwhelmingly positive about the method. As a normal part of the course, students were asked to summarize what they learned from the virtual simulations.

Figure 23. Overall feelings about virtual simulations.

Students completing the assignment reported that they liked the simulations because they were doing interesting labs. Excerpts from several student summaries are provided here as a means of putting the frequencies in context. John (laboratory report): “I thought the simulations were interesting. I never thought about all the different areas scientists look at.”

Austin (laboratory report):

> “The sims were cool! I can’t imagine doing online biology any other way. We got to see a whole bunch of experiments and that was neat. I liked that I could do the experiments at home, as many times as I wanted. I can’t imagine doing this class any other way.”

Liz wrote (laboratory report) in a summary:

> This biology class was a big step for me in my educational career. I’ve always had pretty easy classes, and this one was honestly a challenge. Labs were my favorite part overall. At first when I realized I would be taking labs online, I thought it was going to be very difficult and I wasn’t going to learn anything. However, my mind was most definitely changed. These simulations are not everyday labs that you can do in reality in a semester. There were many situations that were incredibly believable and fascinating that I could actually control! I could also repeat them until I understood. To

> anyone who is looking to study something biological, with today's technology, a virtual study is the best way to go in my opinion.

Liz goes on to detail the interactions of moose-wolf-vegetation on Isle Royale. Liz was a high-achieving female student who consistently scored well on exams, did well on the pretest/posttest, was engaged in discussions, and did 95% of all assigned work. She was a traditional student, who I learned through communications, was motivated to do well in school because education was something her parents taught her to value. Liz said (personal communication), "My parents expect me to do well and education is important to them so it is important to me." She planned to transfer to an in-state four-year university for the Fall 2013 semester.

Chris was a high-achieving, non-traditional, male student, who I learned through several phone call conversations, was employed as an information technology consultant. He was motivated to do well so that he could complete his Associate's degree before transferring to an in-state four-year institution. It was not clear what prior education Chris had in relation to science classes; his demographic data collected as part of the CLASS-Bio survey indicated he had only taken a high school biology class. In his summary, Chris wrote (laboratory report):

> The simulation labs are meant to give students an observable and testable look into the world of biology. I feel the labs are a good teaching tool that allows the students a chance to visualize exactly what is happening in a particular phase of instruction from the textbook. I feel that I learned a great deal of biology with the simulation labs. The labs are very organized and present the information well. In the lab Evidence of Evolution, the data is presented in easy-to-read visuals which gives a representation of how the lizards evolve and mutate in a given set of parameters controlled by the student-investigator.

Yolanda was a low-achieving student who struggled with conveying what she knew had learned from the weekly laboratory exercises. She reported that she had test anxiety and could not perform well on timed exams. Through email and phone conversations with her, I learned that Yolanda was taking the class because her son had recommended it to her. He had taken online general biology in 2010 and recommended the class to his mother when she went back to school. In her summary, Yolanda wrote (laboratory report):

> I don't have any dislikes about the simulations, however for the first time in 35 plus years I decided to go back to school and this class was the hardest one for me because of all the information you have to learn and remember at first. However what made the difference for me were the instructor and the labs. Ms. Ranney, you have helped me a lot to understand biology! But I have to tell you I couldn't imagine doing the labs any other way besides this online biology class. With that said, it was frightening at first, and I didn't know what to expect but when I open the first workbook and looked at the simulation, going through the exercises and the graphics that were on there, made the lab easy to do and exciting to do especially with the colorful graphics. It held my attention exercise after exercise, until completing each one. I would recommend this class to everyone. It's like the best alternative to being inside the actual classroom environment.

A list of the semi-structured questions that were used in the video chats appears in Appendix E. The students were positive about the simulations (Table 12). Example statements from students include: Yolanda (interview): "Like I said, I don't dislike the simulations but they were hard. I understood but it was hard. You and the sims are what helped me learn." Chris (focus group):

> Taking biology online… I wasn't sure what to expect but the simulations were helpful in 'seeing' biology in action. I saw how science works. I liked the sims and think you should keep them. I would like it if the sims had better graphics. They should look at the animation in top-selling games for examples. There are two downsides I see with the sims: the graphics are old school and boring—these aren't arcade games! And so should be updated to use better technology. Also, the interface could be clunky. They should work on that too.

Austin (focus group):

> I learned a lot from the sims. They were fun and I could do them over and over. Honestly, if someone failed this class, they didn't put in the time. Anybody could learn biology with those sims. I could do them as much as I wanted to and that helped. Keep 'em!

Ashley (focus group):

> I did a couple of the sims over and over, just to see if I got different results. I did and that was cool. The results were different but never so different that evolution didn't happen. I also liked that we started with evolution because then I was thinking about it all semester long. I don't know that I agree with it but I do understand now why scientists think it is the way the world works. I don't know if I would have gotten that in a classroom.

The students interviewed felt that they were actively engaged in the process of science, felt as though they were learning from the simulations, and were useful learning tools. There were two areas of improvement or change to the simulations suggested by a non-traditional student: an update on the technical aspects of the graphics/animation and the user interface used in the simulations. The traditional students tended to report that the graphics were not up to the current standards to which they were accustomed. They also said that this did not impact their ability to learn from the simulations or their completion rate. Austin said (focus group), "The graphics? Yeah, they could be better but this is school, you know?" Ashley (focus group):

> The graphics could be more animated, like on some of the games I play on my phone but I don't expect school stuff to be top-notch. I mean, what it looks like isn't going to stop me from doing the work or doing it again to understand it.

Jesus (focus group): "I don't see the labs as games, so I don't think the graphics matter but yeah, they could be better. It might help students if they were more alive."

Students viewed the simulations as challenging representations of science processes. John (interview) said, "I'm glad I am not a scientist. The sims took tons of time. It was quick for me but for a real guy doing it in the field, it would take his whole life!" Yolanda (interview) said, "Ecology is hard to understand. The sims made it better but I still don't understand why science takes so long." Kenny (interview) said, "I'm surprised at the about of knowledge I've gained but I still don't understand it all. I did feel like I was doing science though and that's good." Ashley (focus group) said, "I definitely question it all now. The sims were hard and made me think. I'm not sure if I understand science more or if I'm just questioning more now. If this is how scientists feel, don't they go crazy?" Austin (focus group) said, "Simulations enhanced my problem-solving skills but they were challenging." Students felt as though they had learned an extensive number of ecology-related concepts. Kenny (interview): "I know new vocabulary for ecology. I know new stuff. I don't get it all, but I know it. I know that there are these relationships that can be changed by changing one little thing in an ecosystem. These things matter!" Ashley (focus group): "I know lots of vocab. I know lots of new things, like what a 'keystone predator' is—one that keeps the ecosystem healthy but I never thought about it before and I'm not sure how this applies to man." Implications from this will be discussed in Chapter V.

The word cloud (Figure 24) that emerged from the member-checks that took place during the interviews and focus groups was condensed into a single word cloud for presentation here. Students agreed that the category word cloud was less informative to them than the word clouds we started with, though they felt this final word cloud did a good job at showing me they had valued the virtual simulations. The students were very positive about the virtual simulations and it would be interesting in future research for the interviewer to not be the instructor. Students agreed that the word cloud captured their perceptions towards their experiences with virtual simulations for online biology.

Figure 24. Final virtual simulation word cloud.

The table that follows describes the phrases students used to describe their overall perceptions towards the virtual simulations. When students mentioned in interviews or focus groups some aspect their simulations, I rephrased their response in the affirmative and asked them to confirm or deny that is what they had said. If they affirmed their answer, I grouped their response in that category. The word cloud in Figure 24 is built from the descriptions participants gave during interviews and focus groups of reflections from initial word clouds, coupled with thematic coding. Categories of ideas were discussed in interviews and focus groups with frequencies reported in Table 12.

Table 12

Overall Simulation Frequencies

Category	Group	Frequency	Percentage Interviewed
Simulations provided opportunities to experiment	NT	12	100
	T	8	100
Simulations kept me interested in the content	NT	12	100
	T	8	100
I think I learned a lot from simulations	NT	12	100
	T	8	100
I felt like I was doing experiments with simulations	NT	11	92
	T	8	100
I enjoyed learning about different species in the simulations	NT	10	83.3
	T	6	75
The moose-wolf interaction on Isle Royale captured my imagination the most of all the simulations we did this semester	NT	9	75
	T	5	62.5
I was challenged to learn about new areas of biology I had not considered before	NT	12	100
	T	3	37.5
The simulations were helpful to me thinking about biology	NT	10	83.3
	T	7	87.5
The graphics and user interface of the simulations could be improved.	NT	1	8
	T	6	75

NT stands for non-traditional students and T stands for traditional students.

At-Home Kit Users' Experiences

Ecology. Laboratory reports were 750-1,300 words long. In ecology laboratory reports, students reported that they understood their backyards, how humans change the environment, and how predators can alter communities. Excerpts are included here for illustrative purposes. From the Sampling Ecosystems exercise, students had mixed observations. They noted that they liked making the clay critters, enjoyed making observations in their backyards, and could see how insects play an important role in the environment. They also noted that they did not like the amount of time the exercise took and the perceived failures that sometimes occurred during the exercise.

Evelyn, a non-traditional female student wrote in her laboratory report:

> I really enjoyed the Critter lab. I had a lot of fun making the caterpillars and getting them ready to go outside. It was also very fun to see what was in my 12 x 12 square at times when I was measuring down my line of transect. I had a good time deciding where I was going to place them out doors as well. It was very interesting to see how they had changed when I went to check back on them for the first time. I live in a very humid area and it appeared they had all swelled up with water. We had a storm come through shortly before I had to go check on them for the last time so sadly I could not really assess any real damage done to the caterpillars but I did find one that had been smashed against a tree, or so it appeared. Overall though it was very interesting.

Kathy, a non-traditional female student wrote in her laboratory report:

> Our Ecology lab I thought was fun. It was fun to make the clay creatures and hopefully make them realistic enough that something would think they were alive. Unfortunately, some of my creatures got squished due to the fact that the day after I put them out, the yard was sprayed. So a couple of them met their fate by a big boot. I did have one that was moved, be it by an animal, I have no idea. There were a couple of my creatures missing. I'm uncertain what happened to them; I don't know whether something picked them up or if they are stuck to the bottom of a boot.

Raven, a non-traditional female student wrote in her laboratory report:

> The ecology experiment has not had dramatic results in observations. Maybe it was because the weather has not been cooperative during this time frame. Or maybe it was I just chose a poor location for good observation. Either way, it was much harder for me to realize much academic value. Poly clay creatures were a unique idea and I felt like maybe I could put other information into play that we had discussed. The colorations of the creatures did prove to be of benefit. The warning colorations were not "tampered with" by the animals as much as the more natural colorations. I suppose that one could say that the animal kingdom does play by the rules when it comes to predation and prey is concerned.

Molly, a traditional female student wrote in her laboratory report:

> This lab we did I found very interesting. Seeing how our clay creatures changed and got effected by being outside. I have never really thought about how much weather and animals effect just ordinary things outside but observing the clay creatures really showed me how much.

Dempsey, a non-traditional male student wrote in his lab report:

> This lab we made caterpillars and put them outside. Although nothing really happened to my bugs, it was still cool to see the small things that did take place. The weather took a toll on them more than anything because the weather has been crazy down here in Texas. Some birds came and inspected them and left a couple marks and one or two came up missing. I am not exactly sure where they went and what took them away. The weather did effect the bugs more than anything; they were had pollen coverage for a couple days before the heavy rain came through. Then the sun came out and they hardened up.

Ben, a non-traditional male student wrote in his lab report:

> This lab we have done was a lab on ecology. This is a lab that took awhile. I was not able to check every day but I was able to check every weekend when I went home. This lab was both amusing and well and intellectually stimulating. I enjoyed making predictions about what would happen to my critters and then return to find the opposite of what I had originally predicted.

Cameron, a traditional male student wrote in his lab report:

> I enjoyed this lab we did with the polymer creatures. I found this one very intriguing. It was fun to set up and interesting to see change overtime. I wish I could have set up a camera and seen what actually went on with some of these creatures.

For the Nutrient Pollution exercise, students wrote about increased understanding in watersheds, importance of chemicals, and how informative the lab was in making them understand ecology. Evelyn, a non-traditional female student wrote in her laboratory report:

> In the Nutrient Pollution lab, I did not know really what to expect out of it at first. I put all the mixtures together and that was very fun and interactive. I liked going back and checking on the mixtures after a few days to see them changing before my eyes. It was really very interesting to see how quickly algae grew in some of the containers while it seemed to kill out the algae in the others. It is amazing to me how often nutrient pollution occurs and how much damage it can cause to our water sources.

Ben, a non-traditional male student wrote in his laboratory report:

> After the completion of this experiment I felt I had better understanding of why it is important to control not only the use of chemicals in our environment, but also to control the runoff from agriculture settings in general. There is a rule now in place at Lake Texoma that controls and monitors the release of "gray water" into the lake. After the running of this lab I understand why it is important to control this. Previously, I thought it was just another government regulation that decreased the populations from using the lake in a recreational manner. Ultimately, it is to protect our water form ourselves and to help ensure that our waters remain safe for consumption for later generations.

Molly, a traditional female student wrote in her laboratory report:

> This lab took forever! If I was doing this lab again, I would have done it differently. I don't think I used the right kind of fertilizer and I also needed a better light source. I think mainly my water just turned colors, which is a result for sure. I really didn't have any real visible algae. I think this is mainly because my lab was setting in the window. It was getting some light and heat, but not as much as if I would have had a lamp. I'm not sure I learned anything from it but I could see what I should have learned was about pollution.

Figure 25. Initial ecology hands-on word cloud.

Figure 25 is a word cloud depiction of frequencies of words used by students to describe their learning from at-home ecology exercises. After completing the ecology unit, as part of the normal class assignments, students were asked to summarize the ecology exercises, including which ecology exercises they had completed, how the exercises tied into their textbook reading assignments, and what "big picture" piece of biology they felt the ecology exercises illustrated. The submitted assignments from student-participants were uploaded into a web-based word cloud creator. Common words, such as "the," were removed from analysis. These word clouds were then used during student discussions and interviews to solicit student feedback about ecology exercises where we created additional word clouds to clarify ideas and identify categories. The students spoke about how they found the exercises informative about their backyards because they got to hypothesis testing and were required to look around and see what happened.

The larger the word size, the more frequently the word appears in students' assignments. The words "informative," "backyard," "hypothesis," and "fun" appeared most frequently, appearing in 95% of completed student assignments. The words "replication," "understand," "humans," "birds," "predators" and "adaptations" appeared in approximately 80% of student summary assignments. When students were asked about why these terms were selected, approximately 90% of students replied that the ecology exercises manipulated organisms (e.g., grass, insects) in their own backyards.

When I asked students in video chats about why these terms were selected, approximately 85% of students replied that the ecology experiences allowed them to learn more about their own backyards and that nature is going on out there. In focus groups, students expressed that the exercises were fun and sometimes very time-consuming. For example, Molly (focus group) said: "It was really cool to see what happened to the clay creatures but it took way too much time. Sometimes I didn't do the lab—I just looked at what a result should be. I don't have time to set up labs."

Raven (focus group):

> The ecology labs were really intriguing since you got to see just how much nature can change just in a few weeks. I will definitely be more aware of nature now every time I go outside. Whether its going on a walk with my son, or just playing in the backyard. These experiments have changed the way I look at nature.

Shawn (focus group):

> These studies showed me how the weather had a major role in how other species in an area can perform compared to others. I would like to say that the weather has huge impacts on the community whether we can see the changes or not. I would also like to say that if the weather hadn't changed, we wouldn't have seen changes so science can be fickle.

The Sampling Ecosystems exercise, where students made polymer clay critters, placed them in their backyards and then made observations on what happened, was either loved or hated by the students, as evidenced by their comments. The comments made by Kathy (interview) were representative of the feelings of those who loved it: "I loved this lab! I thought it was so exciting to make things and then see what happened. I never would have thought to try that on my own!" The comments made by Ben (interview) were representative of the smaller group who was less than thrilled with it:

> The lab where we made clay critters to put out? It took way too long, both to set up and to do. Don't make future classes do it again! It was, as I said, intellectually rewarding but it was very frustrating. I did like seeing what was out behind the house but if you do it again, do it differently. Maybe send us the critters to use or something.

This exercise was well-liked by approximately 65% of the students participating in discussing at-home ecology experiences for the following reasons: they liked making the clay "caterpillars", they enjoyed observing what was in their backyard and seeing that interactions happened there, and the lab opened their eyes to ecological interactions they had not thought about before. When dislike for the lab was expressed, it was because of: the time it took to prepare for the lab and the time it took to make observations. Also, if students did not see the "caterpillars" being damaged, as evidenced by markings in the polymer clay, they expressed that they thought they had done the lab incorrectly. For instance, Jarred (lab report) wrote: "I did not see anything on my clay critters. They just sat there and nothing happened, which means I probably did something wrong." What Jarred failed to understand is that even though he could observe no changes does not mean "nothing happened." However, his sentiments were expressed in approximately 22% of the laboratory reports, suggesting it was not an uncommon perception among students.

The word cloud (Figure 26) that emerged from the member-checks that took place during the interviews, focus groups and thematic coding was condensed into a single cloud. Students in the at-home kit experience treatment felt that the category word cloud was informative, on par with the word clouds that we started with the interviews and focus groups. This will be discussed in Chapter V.

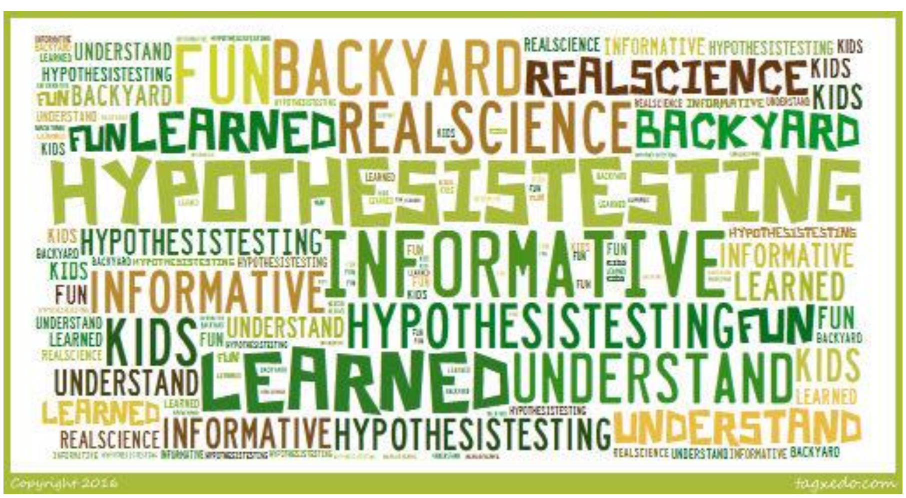


Figure 26. Ecology hands-on word cloud.

Table 13 contains the phrases students used to describe their perceptions towards ecology experiences in discussions. As students mentioned an aspect of finding an answer to a question they had or explicitly testing a hypothesis, it is noted on the table as “Labs provided opportunities to test a hypothesis”. The phrases used were taken from the interviews and focus groups when I would say to the participant: “I understand you to say that you found the labs gave you a chance to test a hypothesis.” If they affirmed this answer, I grouped their response in this category. Figure 25 is built on the descriptions participants gave of reflections from initial word clouds, coupled with coding from my notes of those discussions. Thematic coding was done after talking with students. Categories of ideas were discussed in interviews and focus groups, reported in Table 13. The implications from these findings will be discussed in Chapter V.

Table 13

Ecology Hands-On Frequencies

Category	Group	Frequency	Percentage Interviewed
Labs provided opportunities to test a hypothesis	NT	11	100
	T	10	100
Labs were informative	NT	11	100
	T	10	100
I think I learned a lot from the labs	NT	10	91
	T	10	100
I felt like I was doing real science	NT	7	64
	T	9	90
I enjoyed learning about what lives in my backyard	NT	11	100
	T	6	60
I feel I have a better understanding of ecology now	NT	9	82
	T	5	50
My kids were involved in the labs	NT	5	45
	T	0	-
The labs were fun	NT	10	91
	T	8	80

NT stands for non-traditional student and T stands for traditional students.

Evolution. In evolution laboratory reports, students reported that they found learning about dogs and humans fun, found the experiences informative and fun, and understanding the evidence challenging. They wrote that they were able to see evidence for evolution through the experiences and wondered why more of this evidence was not presented better in mainstream culture. Several wrote that the paper-based exercises made them feel like they "were doing homework" (Raven, lab report) rather than lab. Several wrote that this was the first time they had studied evolution, as it had not been taught to them in high school. Laboratory reports were approximately 900-1,400 words long. Excerpts are included here for illustrative purposes.

Kathy, a nontraditional female student wrote in her laboratory report:

> I must admit, this was a difficult lab for me. However, I was able to learn a lot during this lab. I learned that there are many factors that go into learning about certain species and evolution. Also, I learned that although it may be difficult to figure to graphing the different species, it is able to be done just by looking at the information that has been provided to you as well as using common sense. This lab was one that challenged me when I was needing challenging and at just the right level. I did not feel as if I did not know what to do or was at the point of giving up. However, it did require me to think. One of the things that challenged me was accepting the evidence for evolution presented. We never learned this in high school and honestly, I don't hear about it in the news or church or any where else in my life. Our nation needs more evidence presented.

Dempsey, a nontraditional male student, wrote in his laboratory report:

> So far, I am surprised with how much I learned from this lab. The Evidence for Evolution lab, I thought most of the lab was going to be busy work. I still thought it was interesting doing, but was not very hands on. So just going through the work sheet I definitely understood it better, but it was not the most interesting of labs. I don't remember much about the "Man's best friend" lab, and I just did it! I know I found it interesting learning the differences between wild and domestic animals. I thought it was interesting measuring the wild skulls and then the domestic.

Evelyn, a non-traditional female student, wrote in her laboratory report:

> The lab was very informative but not much fun. I learned a lot from the lab, like how eyes can come into being, but it was not very hands on. Doing the worksheets provided for the lab was very informing, just lacking a little "fun" though.

Molly, a traditional female student, wrote in her laboratory report:

> I found this lab very time consuming, but interesting. It was interesting to see the difference between the two skulls. It was tough mapping out the biogeography. Cutting apart all the paper strips was very time consuming. I didn't like it but liked learning about it. We should learn more about this stuff and earlier in life.

Raven, a non-traditional female student, wrote in her laboratory report:

> This was a very time-consuming lab. I admit, I did not complete the biogeography part with cutting apart the strips. I just kind of looked at what was supposed to happen and went from there. There has to be a better way to do this! This didn't feel like a lab, it felt like I was doing homework! I think it is interesting and looking at the canid skulls was very cool. I liked that part of the lab and thought I learned a lot from it. I learned how dogs adapted from wolves and that was cool. As a dog lover, I want to know more about where "man's best friend" comes from. There was a lot information and it was informative.

Ben, a non-traditional male student, wrote in his laboratory report:

> In this lab we learned about man's best friend and the different types of canids that were roaming the earth at one time. We also talked about how there were different types of canids that branched of into many different sub-species of other canids and then some even mixed. We were able to see all of this by looking at the skulls of these canids and discussing the differences of them. This was a very good lab for me because I was able to see the skulls and not just look at a chart that showed me the answers. I felt this was a very helpful lab when looking at deciphering the different skulls as well and trying to classify them into categories. We also looked at the distribution of lizards on islands. We talked about how they got there and how they changed. We were able to see this by looking at SNPs, which I personally had never heard of before. This stuff is fascinating.

Cameron, a traditional male student wrote in his laboratory report:

> These exercises were designed to cause the student to consider not only the theoretical side of evolution, but to also take into account the effects

> that nature has on all evolution. Theory tells us that if populations are fit and adapt to their environment they will survive. Nature tends to add a curve ball the mix! As populations are affected by nature and its powers they direction the population and the species take are also affected. A species can move out of geographical area because it is no longer suitable, but because of factors outside its control, such as weather conditions, it can die or change like the Canary Island lizards. Leading to enough differences evolved into a new species. These genetical changes and geographic isolation led to a period over many generations led to the advent of 3 separate species. Each one similar but different enough to prevent reproduction between the species. The results of all this makes me think. Did we all begin as "Lucy" and then evolve into separate species based on changes that resulted from natural selection? Or did we cause the extinction of other species in mortal combat that resulted in us? I think the answer lies somewhere between.

Figure 27 is a word cloud depiction of word frequencies in student descriptions of evolution at-home experience learning. The word cloud was then used during video chats in conjunction with a list of questions to solicit student feedback about evolution labs. The students using at-home kits for their evolution laboratory exercises described their evolution exercises as "informative," "fun," and "provided evidence" as seen in the word cloud depiction of their experiences (Figure 27). Words describing positive experiences with the lab assignments were recorded in 90% of student summaries. Other important descriptive words included: "understand," "challenging," and content vocabulary words recorded in approximately 65-70% of student assignments.

Figure 27. Initial evolution hands-on word cloud.

When I asked students in video chats about why the terms in Figure 27 were selected, approximately 65% of students replied that the evolution labs asked them to asked them to learn about information such as dogs. They said that they found the information “informative” and “challenging”. Interestingly, though the laboratory also went over the evolution of complex eyes, that topic was addressed by very few students in both the laboratory reports and in the interviews and focus groups. In focus groups, students explained that they felt that the exercises, Evidence of Evolution, involving the history of dog domestication among other topics, gave them a relevant example to see how evolution worked. They also talked about how they liked the pom-pom or goldfish cracker simulation in Mechanics of Evolution. Evelyn (interview):

> Comparing the domestic and wild canid skulls was more interesting than I though. Once I got to measure the differences, it was noticeable. Such as the differences in hearing due to the fact that the wild canid needed that keener sense for the prey it was hunting.

Kathy (interview):

> That lab (Evidence of Evolution) was tough. It made me think and gave me good information. I had some fun with it, but not as much as other labs. The other evolution lab with the crackers really made it so I understood how evolution works. I think the information is important and we need more of it in school.

Raven (focus group):

> I hated the evolution labs. They were important but they were not fun. They were hard! It was a bunch of reading. The one lab with all the paperwork was boring. I skipped some of it. I didn't have pom-poms or crackers so I didn't do the other one.

Shawn (focus group): "I thought it was ok. I liked the other evolution lab, where we played with crackers. I liked seeing how evolution worked that way." Ben (interview): "The evolution labs were challenging, both intellectually and personally. They opened my eyes to different ways of looking at the world."

"Mechanisms of Evolution" allowed students to experiment with how different adaptations could benefit prey or predators. Evelyn (interview): "I learned what fitness actually means; reproduction success, and the ability to survive to reproduction age and the capacity to reproduce". Student interviews highlighted how students found the labs to be challenging because of the necessary time management skills in carrying out the labs, the informative rather than experimental nature of the labs, and the understanding of evolution gained by the students. Evelyn (interview):

> If I had to do the labs over again, I would have done them differently by giving myself more time. The labs, like the canine one gave good information. I think sometimes I knew what the labs were going to say so it wasn't surprising but sometimes I learned more than I thought I would. I definitely understand evolution now more than before.

These findings will be discussed further in Chapter V.

The word cloud that emerged (Figure 28) from the member-checks that took place during the interviews and focus groups was condensed into a single cloud that included the results of thematic coding. Students found this word cloud to be informative and helped them to focus on the big ideas that they had discussed and reflect on their lab experiences more.

Figure 28. Evolution hands-on word cloud.

The table that follows describes the phrases students used to describe their perceptions towards the evolution laboratory experiences. When students mentioned in interviews or focus groups some aspect of the labs being challenging because the labs "took too long" or "took a long time to do" or "I didn't expect the labs to take so long" it is noted in the table as, "Labs were challenging because of time management". The phrases used were taken from the interviews and focus groups when I would say back to the participant, "So I understand you to say that you were challenged by some aspect of time management; either yours or mine in doing this lab." If they affirmed their answer, I grouped their response in that category. The word cloud in Figure 28 is built from the descriptions participants gave during interviews and focus groups of reflections from initial word clouds, coupled with coding from thematic analysis. Categories of ideas were discussed in interviews and focus groups with frequencies reported in Table 14.

Table 14

Evolution Hands-On Frequencies

Category	Group	Frequency	Percentage Interviewed
Labs were challenging because of time management	NT	9	82
	T	8	80
Labs were informative	NT	9	82
	T	7	70
I saw a lot of evidence for evolution in the labs	NT	8	73
	T	10	100
I understand more about adaptations	NT	8	73
	T	6	60
I understand more about scarcity of resources can drive natural selection	NT	6	55
	T	6	60
I really liked learning about how dogs were domesticated	NT	5	45
	T	6	60
I feel I have a better understanding of evolution now	NT	8	73
	T	7	70
My kids were involved in the labs	NT	5	45
	T	0	-
I had fun doing the labs	NT	9	82
	T	7	70

NT stands for non-traditional students and T stands for traditional students.

Overall feelings about at-home kits. As seen in Figure 29 and Table 11, students assigned the at-home kit laboratory delivery method and who completed the labs enjoyed the method. As a normal part of the course, students were asked to summarize what they learned from their laboratory experiences. Students completing the assignment reported that they liked the labs because they learned interesting information. The at-home kit users found the laboratory exercises to be “interesting labs” which they “enjoyed a lot” because the labs made them “think” (Figure 29). The exercises were described by students writing in their summaries as “water” pollution exercise being "fun" and "better labs" than what they expected to encounter in online biology (Figure 29). The lab exercises encouraged them to make predictions, investigate the "wild" in their backyard and have a better appreciation for what scientists do (Figure 29).

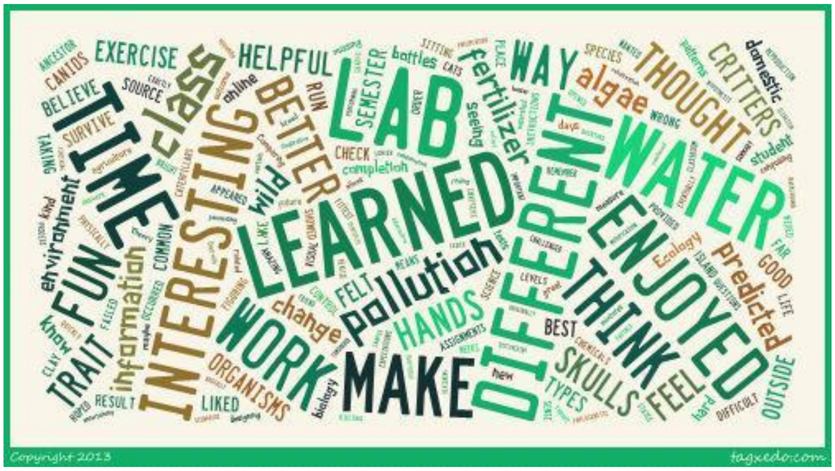


Figure 29. Overall hands-on word cloud.

Excerpts from the students' assignments are given here to illustrate.

Molly (lab report):

> In labs this year I have learned that not all streams contain algae and also to make sure to read instructions very carefully before conducting an experiment or else you could ruin the whole thing by adding more ingredients then needed. I have also learned that change can happen to a species with something as little as being cut off from the rest of the species.

Dempsey (lab report):

> The labs were interesting on several different levels because they provided informed me and gave evidence to a changing world. First, I live on a golf course that has different types of water sources immediately on the course. Second, knowing that the course uses several different means and types of chemicals throughout the year, the labs resonated very loudly what the effects of these practices were on my immediate environment and the long term consequences to evolution. I started thinking about how the choices we make impact the natural world and how animals adapt or don't.

Evelyn (lab report):

> Overall, I thought the labs were interesting a good learning experience. I learned from the labs and had fun doing them. It never dawned on me that I could measure evolution but we did! That evidence was neat—why don't we see more evidence like that in the media? I enjoyed the evolution labs because I learned at least a little something from each of them that I had not anticipated.

Jarred (lab report):

> During these labs I have learned many things. I have enjoyed these labs very much and they have all helped my learning as well throughout this semester. I feel that labs are important because for the people that are visual and tactile learners this gives them a better way to learn and a way they can boost their grade as well. Also, the labs help you put to use what you know in your head. For example, when working on the ecology lab I would have never thought that the animals in my back yard would pay attention to any of the clay critters I had laid out in my yard.

Breann (lab report):

> The labs for this Biology class have been not only illustrative, but actually fun. I haven't really learned anything new about the material or the hypotheses from the different labs, but I have learned a few more interesting lessons. In these labs I have learned that when dealing with biology it does not matter whether your experiment works like you wanted it to. What might seem like a failed experiment is never REALLY failed. It just had a different outcome than the one you wanted. and your actual experiment measurements or time may need to be altered to get a visible outcome.
>
> I have also learned that when dealing with projects it is much more fun and the project comes out better when you have a good partner. Everything from taking notes to making observations becomes a kind of tiny adventure when you get to see what your project has in store for you today. With a partner that is just as enthused as you are about the lab work time and assignments will fly.
>
> All in all, Though I may not have learned any new factual information, I have gained a new understanding of Biology and the scientific pertinence of curiosity. There is now a knowledge that where science and hypothesis are concerned there is no failure
>
> I have found the labs challenging for this class, but mostly because I am in a rural area and have not been able to get all the supplies needed. I realize

> that online classes are difficult, especially with labs required. I have enjoyed the labs and which I had more time to spend on them.

It is interesting to note that the appreciation expressed at what scientists do did not translate into more positive attitudes in learning about science as assessed through the CLASS-BIO survey. Implications from these findings will be discussed in Chapter V.

The students interviewed in the at-home kit student users group described their laboratory experiences with fewer positive adjectives about their laboratory experience as the virtual simulation student users and shared fewer stories of their children participating in the laboratory experience with them, though five stated that their children had participated. However, overall, they still felt favorably towards the at-home kit exercises. The biggest issue for these students was their ability to collect all the needed supplies from the supply list, set up the experiment, run the experiment for a given period of time, and take down the experiment. Ben, a non-traditional male student (interview), complained he felt like he spent more time managing the lab exercises than doing them and all students interviewed expressed the feeling that the labs took too much time. However, contrary to instructions on the written assignments, only ten students in the fall and two students in the spring recorded time on task. These students recorded time spent on task on approximately 90% of their labs where they indicated that the average time they spent on the laboratory exercise was 2.5 hours versus set-up/clean-up time of approximately 30 minutes total. Such a small, self-reported data set is too small to draw conclusions.

A non-traditional female student Kathy, who was an average achieving student, described her feelings about the laboratory exercises in a written summary of the laboratory exercises completed over the course of the semester:

> During these labs I have learned many things. I have enjoyed these labs very much and feel that the labs have helped my learning throughout the semester. I feel that labs are important because for people that are visual and tactile learners this gives them a better way to learn. Also, the labs help you put to use what you know in your head. For example, when working on an ecology lab I would never thought that the animals in my backyard would pay attention to any of the polymer clay critters I had laid out in my yard.

Kathy goes on to state in the interview that she felt that the opportunity to discuss with the instructor "why we were taking this class and being able to tell you a little bit of information about ourselves" was a "very good thing to have" because it "bridged the gap between professor and student." By the instructor asking students to think about what they wanted to learn in the class and what they wanted to be able to do with the knowledge once they left class, Kathy indicated:

> I felt that this was a very good way to really get us to think about what we would do with the knowledge that we have. If we simply sit around and do not use this knowledge then it is pointless. Knowledge is only of worth when it is shared with others to enhance their life.

A traditional male student, Cameron, was a student struggling to keep up with the pace of the class described his feelings about laboratory exercises in his laboratory report.

> The evolution lab with the lizards was difficult to figure out the graphing. This lab was one that challenged me when I was needing to be challenged. I did not feel as if I was going to get it but I talked to Ms. Ranney and then it was ok. The dog lab we learned about man's best friend and see how different types of dogs evolved by looking at the skulls. This was a good lab for me because I was able to see the skulls and not just look at a graph in a book.

Implications from student perceptions will be further discussed in Chapter V.

Figure 30. Final hands-on word cloud.

The word cloud (Figure 30) that emerged from the member-checks that took place during the interviews and focus groups and thematic analysis coding was condensed into a single word cloud for presentation here. Students agreed that the category word cloud provided about the same level of information to them as the initial word cloud did. The students were mostly positive about the contents of the laboratory experiences but expressed negative feelings about the amount of time the laboratory exercises took. Students agreed that the word cloud captured their perceptions towards their experiences with at-home kits for online biology.

The table that follows describes the phrases students used to describe their overall perceptions towards the at-home kits. When students mentioned in interviews or focus groups some aspect of experimenting, I rephrased their response in the affirmative and asked them to confirm that is what they had said. If they affirmed their answer, I grouped their response in that category. The word cloud in Figure 30 is built from the descriptions participants gave during interviews and focus groups of reflections from initial word clouds, coupled with thematic coding. Categories of ideas were discussed in interviews and focus groups with frequencies reported in Table 15.

Table 15

Overall Hands-On Frequencies

Category	Group	Frequency	Percentage Interviewed
Labs provided opportunities to experiment	NT	10	91
	T	7	70
Labs kept me interested in the content	NT	9	82
	T	8	80
I think I learned a lot from labs	NT	9	82
	T	8	80
I felt that the labs were mostly fun	NT	8	72
	T	5	50
These labs were different from ones I've done in other classes	NT	10	91
	T	6	60
These labs took a lot of time and work	NT	11	100
	T	10	100
I was challenged to think about new areas of biology I had not considered before	NT	8	72
	T	3	30
The water pollution lab was most relevant to my life	NT	10	83.3
	T	7	70

NT stands for non-traditional students and T stands for traditional students.

Comparing and Contrasting Experiences

Students' responses to their laboratory summaries, interviews, and focus groups questions were compared across the treatments to look for common and unique experiences associated with their ecology and evolution laboratory experiences. The comparisons utilized thematic analysis of the laboratory reports, and notes from the interviews and focus group responses, triangulated by reviewing the comparisons against the initial word clouds, as those were from all participants, not just those who participated in interviews or focus groups. One of the limitations that could arise from these results is that by utilizing interviews and focus groups is that not all students participated in these activities. Why they did not participate is subject to future investigation but for this research, using the widest possible data set for a compare/contrast analysis gave voice to the greatest number of participants.

After reading through the data, language was coded into categories when the language depicted a similar phenomenon. These categories were discussed with participants during interviews and focus groups. Categories that related to each other, giving a description of how students perceived their laboratory experiences were collapsed into themes. These themes will be presented at the end of this chapter. The categories formed the basis for several of the interview questions: reviewing word clouds then explaining why they wrote so much the words featured in their cloud, specifically what they learned from the lab activities, why the activities were or were not effective and what environment the student was in when the labs were being done. While frequency of a word does not provide a category alone, word frequency does help focus an interviewer's and interviewee's attention to big ideas under discussion. A limitation of the research is that the same questions were asked of each participant; future research in this area should be more flexible so that unique features in word clouds could be better explored.

Ecology laboratories. Searching across the data set revealed that both treatments perceived value from their ecology experiments. Both treatments were supremely positive about their laboratory experiences, with 100% of those partaking in either an interview or focus group stating that they felt they learned ecology from their laboratory or leaned "a lot" from the labs. Nearly 100% said that the laboratory experiences were fun. Both treatments wrote about either being challenged to think more about our environment (virtual simulations) or finding the labs informative on ecology (at-home kit users). Not as many respondents, but still a sizable majority, felt they were "doing" science with their laboratory; perceiving that the laboratories provided an opportunity to "do" science regardless of the real-world applicability of their laboratory is what is important. Students who perceive that they are engaged in valuable academic work that is valued by their instructors are more likely to persist in college (Tinto, 1997).

The at-home kit users were more likely to write about how their children were involved in the ecology laboratory activities. This was surprising given that none of the five participants expanded upon their kids working with them on laboratory activities in interviews and focus groups except to mention in passing that their children had participated and enjoyed it. The virtual simulation users did not mention children using the ecology simulations, though they did talk extensively about their children using the evolution simulations.

At-home kit users were also more likely to express connection at what lives in their backyard while virtual simulation users were more likely to express a desire to travel to areas used in the simulations, such as Isle Royale National Park. However, by expressing either idea, both groups were expressing an awareness of and appreciation for nature.

Virtual simulation users were more likely to mention specific content and vocabulary than at-home kit users. While at-home kit users wrote about how fun they found the labs to be, virtual simulations users' writing was dominated by specific vocabulary and content. In evaluating the frequencies of specific content, the moose-wolf interaction of the Isle Royale simulation was mentioned by 14 virtual simulation users in interviews and focus groups, while the Keystone Predator simulation was mentioned by 18 virtual simulation users. Twenty virtual simulation users were interviewed or involved in focus groups. The at-home kit users mentioned insects and predators in their writings regarding the polymer clay critters Sampling Ecosystems laboratory but they did not focus on either during the interviews or focus groups.

Evolution laboratories. Searching across the data set revealed that both treatments perceived value from their evolution experiments. Both treatments found that they learned about some aspect of evolution from their laboratory experiences, with nearly 100% of those partaking in either an interview or focus group stating that they saw evidence for evolution in the laboratory experiences. Both groups also viewed the evolution laboratory experiences as fun and helpful to their understanding of evolution. Both treatments wrote about the experiences being difficult or challenging, both in terms of content and in terms of understanding the evidence from the laboratories. Fewer students thought the evolution laboratories were fun compared to the ecology laboratories, with only 80% of students reporting they were “fun”. The at-home kit users were more likely to talk about the science content in these laboratories compared to their descriptions of ecology laboratories while the number of students talking about science content in the virtual simulation treatment remained about the same.

At-home kit users did not talk about their children partaking in these laboratory experiences while four women talked about their children “playing” the simulations in the virtual simulation treatment. The virtual simulation users also wrote about repeating these simulations more so than the ecology simulations whereas the at-home kit users were more likely to express a desire to repeat the ecology laboratories.

Overall perceptions. Both treatments found the laboratory experiences to be interesting experiences which made them think about biology. Both treatments felt they learned interesting information and caused them to think about their worlds differently than they had before. Both groups perceived that they were doing what they considered to be real laboratory exercises. Several students communicated to me that they had taken general biology before and were back to try again, this time in an online environment whereas previously they had attempted face-to-face biology courses. These students, with experience in traditional campus laboratory settings, expressed how much more they enjoyed these laboratory experiences, primarily because they could control the laboratory experience. Both treatments expressed that they liked having control over when and to some extent, where they did their laboratory experiments. At-home kit users were more likely to express frustration at location when they needed to set up a laboratory experience outside.

At-home kit users felt that the labs took more time and work than they were expecting in many instances. By comparison, no virtual simulation users expressed frustration at the amount of time they spent setting up the virtual simulations or running the virtual simulations; the virtual simulations seemed to fall within the expectations for the course for virtual simulation users, whereas the same was not true for at-home kit users. At-home kit users also expressed frustration at the challenges some of them faced in collecting the supplies they needed; none complained about the costs involved. Several noted that it would have been easier for them to collect supplies if they did not live in rural areas; as an online class serving a limitless geographical area, there was no reliable way for me to predict who would live where to minimize this frustration. No virtual simulation users expressed equivalent frustrations.

Themes

There were four themes that were constructed from evaluating the data by using grounded theory with thematic analysis; the word clouds and frequencies tables were used to triangulate my construction. Categories were collapsed into themes; a colleague reviewed the initial assignment of categories I had made to themes and offered a modification, which was accepted. Three of these themes were constructed from shared experiences across both treatments while one theme was constructed from an understanding of why one treatment worked better for more students. The themes that were constructed from shared experiences across these data were: laboratory experiences help students feel engaged with the course; laboratory experiences offer students opportunities to engage with or think the process of science; and laboratory experiences offer students opportunities to engage with or think about abstract or difficult subject matter. The theme that was constructed from an understanding of the differences between the treatments was: laboratory experiences for online students need to be as streamlined as possible to encourage the greatest completion.

Laboratory experiences helped students feel engaged with the course by stimulating their interest, encouraging their enjoyment, providing informative education formats, providing opportunities to appreciate the natural world, and by providing opportunities for families to engage in learning together. Categories in this theme included those that identified students saying or writing about having fun or enjoying their laboratory, staying interested or engaged, thinking about nature, and ones where children were identified as having participated. Ties to relevant literature and implications will be discussed in Chapter V.

Laboratory experiences offered students opportunities to think about the process of science by offering opportunities to design experiments, test hypotheses, and learn about new areas of biology. Categories in this theme included those that identified students saying or writing about feeling as though they were doing science, ecology, or evolution experiments, testing hypotheses, or an increased understanding of how biology worked or was done in the field. Ties to relevant literature and implications will be discussed in Chapter V.

Laboratory experiences offered students to engage with or think about abstract or difficult subject matter. Categories in this theme included those that students identified as having learned about ecology, evolution, or biology; and specific ideas such as learning about keystone species, environmental changes, assumptions of natural selection, adaptations, the importance of scarcity of resources, or how dogs were domesticated. Ties to relevant literature and implications will be discussed in Chapter V.

Laboratory experiences for online students need to be as streamlined as possible to encourage the greatest completion, both in terms of numbers of students completing the labs and the students who start the labs doing the complete exercises. While the hands-on ecology and evolution activities were the most discussed in laboratory reports, interviews and focus groups, they also engineered the greatest levels of frustration from students. Students doing hands-on activities appreciated the activities but making them more accessible in terms of reducing the amount of set-up or preparation time would increase student success. Ties to relevant literature and implications will be discussed in Chapter V.

CHAPTER V

DISCUSSION

Chapter Overview

In this chapter, I discuss my construction of what the study means for community college instructors and administrators, and make suggestions for future research. The discussion focuses on biology education at community colleges because as a case study, it is for the reader to draw broader conclusions and transferability to their particular situation (Stake, 1995). The results may be transferable to other community college settings, especially rural community colleges seeking to expand their online course offerings to include laboratory-based science classes, such as Cotton College did. Expanding beyond this audience is at the reader's discretion as this case examined community college learners; applying these findings to other segments of the higher education population, such as university students, may be done with the understanding that such students may have different characteristics. University students were not participants in this study and therefore, this is not their story of how they interact with distance-delivered laboratory experiences; it is a story of how community college learners at one rural college in a Bible Belt state did so. Within this boundary is how I will discuss the findings as addressing the findings outside of this exceeds the limits of case study methodology. In the previous chapter, the results clearly laid out that for ecology and evolution laboratory experiences, virtual simulation users had higher learning gains while sharing positive perceptions towards labs with at-home kit users. It was surprising then that the results did not translate into a shift in attitudes as measured through the CLASS-BIO survey results. Discussing these results will outline areas of possible future research geared toward examining how community college learners understand biology.

The research questions that were investigated were:

Q1 What is the relationship between the type of laboratory instructional approaches and the ecology and evolution content mastered in an online general biology course?

H1 There was no significant difference between the pretest-posttest learning gains of online general biology students using two types of laboratory instructional approaches.

H2 There was no significant difference in learning gains between ecology/evolution questions in the pretest-posttest and non-ecology/evolution questions in the pretest-posttest using two types of laboratory instructional approaches.

H3 There were no significant differences between the final course grades of online general biology students using two types of laboratory instructional approaches.

H4 There were no significant differences between the laboratory grades of online general biology students using two types of laboratory instructional approaches.

Q2 What are the perceptions of community college students towards ecology and evolution laboratory experiences in online general biology?

Community Colleges and Online Biology

As community colleges grapple with how to offer laboratory-based science classes online, there is a need to analyze the experiences of laboratory-based science classes successfully taught and learned online. Doing so adds to the discussion of how to effectively address the need of colleges to offer students flexible learning options while maintaining academic rigor. Overall, students in online general biology had greater success with virtual simulations than at-home kits; this could be because the kits were not as well-designed as the virtual simulations, student perceptions of a particular activity, or the superiority of virtual simulations at engaging learners with abstract information covered in evolution and ecology.

The kits were designed around exercises used in on-campus sections of general biology. Colleagues at Cotton College reviewed the kit activities before the online class was offered in 2008 to check for compatibility with our general biology curriculum and again after this research was complete to provide feedback that the kit components were based on on-campus experiences. My colleagues affirmed that the activities accurately reflected on-campus ecology and evolution laboratory activities. The simulations were also reviewed by Cotton College colleagues and it was observed that the simulations were more visually engaging than the lab kit activities. The lab kit activities tended to have black and white instructions without animations, graphics, or sound whereas the simulations had colorful animations. One colleague suggested that the visual appeal of the simulations may have influenced, subtly or not, how willing students were to engage with the materials. My colleague suggested that the at-home kit users might benefit from animated instructions with some type of laboratory avatar to liven up the at-home kits and thereby hook the students. Presentation of offline materials may be an important, though overlooked, component of engaging online students. Technological assistance, provided by the administration, would likely be necessary for many instructors to implement such a suggestion. My colleagues and I agreed the at-home kits were not as good as an on-campus laboratory experience that included microscopes for students to use to study cells; there was disagreement if sending a microscope to an online student would produce an equivalent experience to a campus-based laboratory experience. How well would an average or typical student learn to use the microscope without hands-on assistance? Some colleagues were disinclined to believe that a virtual simulation for cells or microscopes could compare to a campus-based experience while another felt that so long as a learning objective, such as demonstrate an understanding of the process of mitosis were met, how the student arrived there was not a concern. As faculty at a community college, the challenge remains to adapt biology content for online delivery in a way that allows students to be successful in meeting the learning objectives in all areas of an introductory biology curriculum while maintaining academic rigor, considering student costs, and other conditions set by curriculum committees or administration.

Student perceptions of the kit activities when expressed directly to me via email or phone calls often focused on how time-consuming students felt the activities to be; this was supported by the comments students had made in interviews and focus groups. Students spent less time on virtual simulations and did measurably better on examinations. Time is a valuable commodity for community college students and as such, should be taken into account by instructors designing courses. Pedagogical tools that help a student achieve course objectives in less time should be given higher priority over tools which take more time. Andragogical principles assume that learners are driven by intrinsic motivational factors and utility value of an assignment (Knowles, 1984); few things decrease joy of learning as much as assignments where students cannot see the value of the work. Previous research suggests that when students get bogged down in the housekeeping details of lab, they are less likely to remain engaged (Stuckey-Mickell & Stuckey-Danner, 2007). If virtual simulations are not an option for an instructor, student success may be enhanced by packaging all necessary materials and shipping them to the student once course fees were paid. Such an option would require administrator support for many small community colleges to successfully implement, in the form of release time for instructors to curate the materials or in the form of hiring a laboratory technician or student worker to do so. As not all topics in general biology were examined in this study, such as cellular work, there may be areas that would be well-served by using a kit where supplies such as a microscope and slides would need to be sent to students. The same may also apply when dissections were employed. The most important aspect from this research that I took with me to my next teaching project was that virtual simulations tended to work at conveying abstract ideas better than the hands-on activities I could design and deliver to distance students because online learners expected the learning to be online and on-demand; they were not looking for biology to join them on their kitchen table.

The superiority of the simulations at conveying abstract concepts to students was tied directly to student perception of what online laboratories should look like. Since many students were not looking for biology at their kitchen table or for it to play a starring role in their lives after the class, the simulation users may have had an unintended advantage over kit users: the simulations met their expectations of what online learning should like, it fulfilled their desire to have real-world applications by being based on actual research projects, and the simulations were easily repeatable. Repeatability may have been key in overcoming confusion related to the mechanism of evolution: several students explicitly mentioned repeatability as a key feature they liked about simulations whereas multiple kit users mentioned difficulty in setting up the experiences and while desirous of repeating the experiment, lacking the time to do so. If the lab meets the students' expectations, it seems more likely they will complete it.

As important as laboratory activities may be to a biologist or biology instructor, they did not appear to be perceived as the most important aspect of the class for students in online general biology whereas tools that explicitly prepared for an exam where highly regarded. Recall that 98% of the students involved in this study were self-described non-majors and so are therefore not preparing for a life of scientific rigor or laboratory experiences. When students using at-home kits report, "I didn't do the lab but I read through it and knew what the answers would be, so I'm writing about that" (Kayla, traditional female student; similar statements by 5 other students, reported in laboratory reports), or, "My time was to (sic) valuable to do this and I could get the information from the book" (Marlene, non-traditional female student; similar statements by 3 other students in laboratory reports) then perhaps the laboratory activities need to be rethought. Previous research (Abraham, et al., 2009) has shown evolution simulations to be an effective teaching tool to help students reduce their misconceptions regarding evolution. Thus, being able to use multiple times a tool known to be effective in reducing misconceptions regarding evolution may be key to helping students learn evolution, especially in populations resistant to learning about evolution. As the simulations are also efficient uses of students' time, they may be more willing to engage with such tools when they can perceive the activity as valuable. These statements by students reflect a violation of the fourth assumption of andragogy where adults are problem-centered rather than subject-centered in learning (Merriam & Caffarella, 1999, p. 272). An instructor may *know* or somehow be certain of the value of conveying content through laboratory activities, but that is of no importance if a student does not perceive the value. If a student does not perceive value to an activity, they are unlikely to complete that activity (Picciano, 2006). Students were motivated more by internal factors: What I did perceive as important to non-majors was the ability to successfully complete the course to fulfill general education requirements.

One of my observations of students in online general biology is that students find it easier to complete tasks that are self-contained, e.g., a software package with all pieces present and accounted for is easier to complete than a kit that required students to collect materials first. By "easier," I mean that students are more likely to complete the assignment on time, voice fewer complaints about the assignment's demands, and retain information about the assignment after it is complete. Carrying out research is hard work, as anyone who has spent time in a laboratory knows; the ecology experiences in the at-home kits required the compilation of numerous resources before beginning. In my experience, teaching community college students face-to-face about how to set up a laboratory exercise is difficult; doing it online presented extreme challenges. How can an instructor be sure that the student has collected the correct materials? How can an instructor offer a just-in-time teaching moment to re-direct a student who is proceeding incorrectly with laboratory instructions? At-home kits used in this research, with the limits imposed by Cotton College, were suboptimal in learning ecology and evolution. In terms of student success, the pay-off of overcoming these difficulties was sub-par: achieving superior results with a commercially available virtual simulation rather than a creative, inquiry-based, hands-on exercise makes greater instructional sense. As a community college instructor, I want my students, already balancing jobs, family, social commitments, and school, to work smarter, not harder.

Another of my observations of students in online general biology is that students often resist learning about evolution and ecology, more so than learning about cells, cellular respiration, or DNA. My observations have led me to believe that this resistance is due to a lack of pre-college instruction in either topic, outside sources influencing a student's belief about science, and how students utilize multiple different sources of information to arrive at a conclusion.

Discussion of Q1

Relationship Between Instructional Approach and Content

At the beginning of each semester of online biology, students were assessed through a pretest to gauge their knowledge of biological concepts coming into the class. Pretests can be an important pedagogical tool for instructors to assesses what their students know and what, if any, misconceptions are held by the students (Nelson, 2008). Research in discipline-based education learning gains routinely rely on using some form of a pretest (Knight & Wood, 2005; Hake, 1998; Hake, 2002; Sundberg, 2003; Anderson, 2002) to assess student learning gains. In this research, the Biological Concept Inventory and the Concept Inventory of Natural Selection were used together to evaluate student learning and misconceptions; combined, these were the pre/posttest given by the biology department at Cotton College. These instruments were selected because the faculty wanted to ensure that students were being taught the foundational concepts in biology and not have the department assessment tied to a particular textbook and its ancillary materials. The BCI was chosen because it covered themes in biology that faculty agreed should be learned by all general biology students at Cotton College, its development as a concept inventory with misconceptions as distractors, and its 30-item length. The CINS was included because of its emphasis on natural selection, its use of community college students' misconceptions as distractors in its validation, and its 20-item length.

These instruments were not mapped out at the time of selection to learning objectives of general biology. They were read over, discussed, and agreed on. A mapping of the instruments to laboratory objectives over the summer of 2016 by faculty showed that the laboratory objectives could be tied to specific questions on the two assessments but this is an activity that should have been done before the instruments were agreed on by the department. A laboratory-specific instrument for general biology has not been published, nor has systematic investigation of the efficacy of laboratories in undergraduate STEM education been sufficiently plumbed, even as reform of biology education is underway (DeHaan, 2005; Talanquer, 2014). In addition, a midterm exam composed of test bank questions from the test bank associated with the textbook and used by all instructors of the course regardless of delivery method, provides an additional point of reference to evaluate how students understood the material. The characteristics of the students who completed the class, delineated in Table 1, showed that of the 116 students who completed the pretest, approximately 60% were female and 40% were male, which is a split that closely mirrors the numbers of each gender enrolling in community college courses. Kasper (2003) reported that women comprise approximately 57% of community college enrollment nationwide while men comprise approximately 43%. There was no difference in the fall and spring semester students' pretest scores.

The midterm was administered midway through the term. The students in online biology took an average of approximately 27 minutes to complete the exam. The virtual simulation students took approximately 26.6 minutes to complete whereas the at-home kit students took approximately 28.3 minutes to complete. This difference was not statistically different. Students who scored higher on the midterm tended to take longer, utilizing approximately 45 minutes whereas students who scored lower on the midterm tended to utilize approximately 15 minutes. The time readings for seven students were not included because Cotton College's IT department confirmed that these students experienced some sort of technical difficulties. The midterm averages were not results that I was comfortable seeing when I want all of my students to be successful. Rather than focus energy on how to improve the content delivery, finding ways to encourage students to use more of the allotted time on the exam, to think about what the question is asking, might change what learning gains were realized in the course.

Another way to think about the difference in learning gains realized on the midterm is to look at how the students perceived their ecology and evolution laboratory experiences. Both groups perceived that they were engaged with the course by doing labs, that they were thinking about the processes of science from doing labs, and that they had opportunities to engage with abstract or difficult content during labs. The difference between the treatments was that those using at-home kits had a harder time completing the labs. By streamlining the laboratory experience, more students would complete the labs which means that more students could spend time reflecting on difficult content and gaining confidence thinking through processes of science; whether that streamlining means using better at-home kits or more virtual labs is an area of future research. At-home kit users liked the hands-on activities but did not like preparing for those activities. In the students' perception, the preparation at times did not justify the learning gains they would realize, especially when they were struggling to connect why learning about ecology or evolution was personally relevant to their career aspirations. The reality for Cotton College is that the virtual lab option won approval from the administration because it is the lower cost option for students; it is likely that instructors at other community colleges would face similar pressures from administration if they are at a rural institution with students of similar characteristics to this study site.

When learning gains on the ecology/evolution questions were compared to the learning gains on non-ecology/evolution questions, unsurprisingly, the virtual simulation users outperformed the at-home kit users. The results show strong evidence that the simulations helped students learn ecology and evolution concepts and helped them to apply what they learned. The at-home kits users did not have such a strong benefit from their ecology/evolution experiences. This suggests that instructors should critically evaluate the use of virtual simulations for use in their classes and perhaps re-evaluate any bias towards the intrinsic value of hands-on learning with abstract or culturally resistant concepts. The low learning gains seen from non-ecology/evolution questions are also unsurprising when one considers that the instruments used as the pretest/posttest were heavily weighted towards ecology and evolution concepts and that the non-ecology and non-evolution labs for both treatments were not as well-developed as the ecology and evolution labs were. Further, the labs after the midterm were less likely to include alignment to the assessment: there were four labs after the midterm that included no applicable questions to the CINS portion of the assessment and all labs after the midterm had fewer questions aligned specifically with the assessment compared to the labs prior to the midterm. That students showed low learning gains on the non-ecology/evolution portions suggests that the laboratory experiences were not effective in providing learning opportunities that could be applied to those instruments. If different concept inventories or a more extensive assessment were given, it is likely that different results would have been observed. The scales included on the BCI and CINS were clearly not perfect at capturing the totality of what students learn in a general biology course but they were not meant to be; they were the instruments selected by the study site's faculty to help ensure that faculty covered ideas that commonly met with resistance from the student population.

I expect students who express less frustration at doing labs or whose expectation for what labs will look like are met, to do better with the material. Andragogy posits that student-centered activities produce engaged learners; the virtual simulations were better at engaging students in such areas as explaining why a lab was important for a learner to know, allowing students to make decisions on what variables to change, and using content situated in the real world. These areas support an increase in student learning, which likely contributed to increased learning gains. Also, consider research that shows increased student learning gains when students are engaged in inquiry-based laboratory experiences (Gormally, Brickman, Hallar & Armstrong, 2009). These students valued authentic science exposure and gained self-confidence in their reasoning skills and related scientific abilities (Gormally et al., 2009). While both treatments in this research were inquiry-based laboratory experiences, the virtual simulations were more likely to be completed and repeated, giving virtual simulation users greater exposure to inquiry-based laboratory experiences than at-home kit users, thus supporting a higher learning gain outcome. Another reason why virtual simulation users may have had higher learning outcomes overall and in ecology/evolution laboratory experiences lies in scaffolding. The virtual simulation users had scaffolding built into every simulation, with each variable manipulation, which could reduce the cognitive load and allow students to learn more, as was seen in research examining scaffolding and achievement in problem-based and inquiry learning (Hmelo-Silver, Duncan, & Chinn, 2007). At-home kit users had far less scaffolding available to them as they worked through hands-on activities because they were completing the activities outside of a laboratory classroom and beyond the immediate assistance of an instructor. Better at-home kit activities would be one solution, and including more video support for commonly encountered problems might be another, for instructors who use hands-on activities in an online laboratory course, as both options would increase the scaffolding of complex materials for online students and would follow the suggestions of previous research findings (Hmelo-Silver & Barrows, 2006; Hmelo-Silver, Duncan, & Chinn, 2007).

In chapter IV, a difference in performance on the midterm was presented. The difference of a letter grade between the two pedagogical groups suggested that there was some component to the virtual simulations that better supported student learning compared to at-home kit usage. Interviews and focus groups did not yield a definitive answer on what that component was but did suggest that students using virtual simulations had their expectations for the course met: it was an online class and they expected the experience to be online. They found the virtual simulations to be easy-to-use, which might be why more students completed, or claimed to have completed, the laboratory activities. Virtual simulations were engaging and appeared to have more entertainment value than at-home kits, as seen when several mothers reported that their children were "playing" the simulations. Looking at the entertainment value, and how that may engage learners, may be potentially useful for community college instructors to do when selecting laboratory content for an online biology course.

The tools used to assess student learning gains in the pre/posttest were multiple-choice instruments designed to assess students' conceptual and content knowledge of biology. The BCIS and CINS instruments were designed to look at misconceptions students commonly hold to better understand accurate student conceptual knowledge. The midterm was designed by Cotton College biology faculty to assess students' content knowledge quickly and so that all sections of a course were targeting similar "big ideas" in biology. The midterm and posttest results suggested that the difference between instructional methods was not a statistical artifact but represented a real difference in pedagogical approaches to support student learning. Ultimately, the goal of this research is to inform other biology instructors about ways biology can be successfully delivered online.

Historically at the study site, instructors shied away from the teaching of evolution. Located in what one faculty member described as the "belt buckle of the Bible Belt," teaching evolution at Cotton College was not a well-accepted idea. For instance, my mentor at the college advised me when I first started to avoid using the "e" word in my lectures but to rather help students understand evolution as speciation through gradual change as this approach was perceived to be more acceptable to the community. This advice was repeated by a long-time adjunct faculty member and a full-time faculty member in another science discipline. By adopting a department-wide assessment plan, it forced all instructors to in effect “teach to the test” but the payoff was that all students were being exposed equally to foundational concepts in biology, including evolution. However, the assessments were not laboratory specific. A shortcoming of using these instruments is that the focus may be on content more readily available to students in the lecture and not focused with precision on laboratory experiences. An assessment that focused on introductory biology laboratory content would be of great benefit to instructors evaluating the effectiveness of laboratory experiences. An assessment explicitly linking laboratory and lecture content would be another invaluable tool for instructors that remains to be developed. Such tools could help increase transferability of community college courses for science majors, identify areas where instructors could provide additional learning opportunities, or provide data on what learning is occurring in a laboratory by students. This limitation of not directly assessing laboratory learning highlights an area for further research to develop laboratory instruction assessment tools and as an area where instructors might further evaluate their learning objectives for laboratories.

Looking at the learning differences between traditional and non-traditional students was an additional component to evaluate the effectiveness of a pedagogical method to deliver biology online. Traditional students might be expected to have the highest learning gains with virtual simulations because these students belong to the more tech-savvy Y generation. The traditional students in this study were part of Generation Y, also known as the Millennial generation, people born between 1982 and 2000 (Ivanova & Ivanova, 2009). This age group tends to have a great deal of experience using computers, software, the Internet, and social media because such technologies have developed alongside this generation. The effect size of the learning gain difference between virtual simulation and at-home kit traditional students supported this conclusion.

Biology educators who serve significant numbers of non-traditional students and are looking to deliver biology courses online may find it interesting that the virtual simulations were more beneficial to non-traditional students because of time management abilities, repeatability, and inclusion of family members. Students using virtual simulations in an online general biology course, whether they were traditional or non-traditional students, had higher learning gains than students using at-home kits. Non-traditional students using virtual simulations scored significantly higher on their midterm and posttest evaluations with the instructional approach having a large effect size as evaluated via Cohen's *d* of 0.96. This large effect size suggested that the instructional approach for laboratory methods mattered a great deal to non-traditional students. Virtual simulation users discussed how the virtual simulations presented engaging material, as seen in comments such as Kenny's comments that the Keystone Predator simulation was easy to use, and understandable, or Austin's comment that it was a "good story". Other simulations, such as the Isle Royale simulation, also elicited comments that the material was engaging such as John's interview comment, "This was the best simulation! I thought it was totally cool and I started looking into this system in real life." This perception by students that the material was engaging may have been one reason such a large effect size was seen. At-home kit users, while expressing engagement with the material also expressed frustration, as highlighted by comments made by Molly in her interview: "It was really cool to see what happened to the clay creatures but it took way too much time. Sometimes I didn't do the lab—I just looked at what a result should be." Not only does such a comment highlight ethical concerns to me as an instructor, but such a comment also forces me to look at the validity of what I was asking my students to do. Is such a comment indicative of someone who does not yet understand the time commitments required of a biology class or of someone who is motivated only by those activities that have a clear, direct relationship to successfully mastering the learning objectives?

While Molly may not understand the time commitments and would not deserve credit for laboratory reports, such comments raise interesting concerns for instructors. What exactly is a student to master in laboratory? What exactly is the value they are getting in exchange for their time, resources, and efforts? Is there a better way to meet laboratory objectives? This research supports the idea that students will do laboratory activities that meet with their perceptions of what an activity for an online biology laboratory should look like. Virtual simulation users spent an average of approximately 2 hours compared to an average of just over 3 hours by at-home kit users. The at-home kit users time includes the time it took to gather materials and set up the lab whereas the virtual simulation users time represent time spent engaging with content. While only 12 at-home kit users reported how much time they were spending on laboratory activities, if their extra hour of time spent was typical, that is a significant additional expenditure of resources by the at-home students compared to the virtual simulation users. That extra hour the at-home kit users spent on housekeeping would have been better spent on engaging with the content. Even if materials are sent to online biology students, time will still be spent in preparing the laboratory experience, which may be enough to reduce the engagement of students such as Molly. Further research on what community college instructors expect students to learn through laboratory activities is necessary even as a consensus on such issues so far as eluded higher education biology instructors. The Introductory Biology Project (IBP) was a five-year National Science Foundation grant project with the goal of bringing together stakeholders to change the way introductory biology is taught based on *Vision & Change* (2011) and to ensure that the biology taught is biology as it is practiced in the field and laboratory. However, consensus by IBP participants on what should be taught in an introductory biology class has not yet emerged, nor as the project produced a tangible network of resources.

As students constructed their understanding of biology over the semesters, I kept reflecting back on these words: “No one in the class has seen, touched, measured, or chemically analyzed a sponge, yet all feel they’ve learned. Given the fact that they can’t walk directly from the lecture hall to the ocean, they have” (Janovy, 1995, p. 101). The learning outcomes guided my assessment of student learning. The majority of the students had learned some basic biological concepts and principles, fulfilling the first outcome. They had also demonstrated, as necessary for the second and third outcomes, an ability to solve problems requiring abstract and analytical reasoning, and they collected, analyzed, and reported data demonstrating comprehension of biological principles. They applied the habits of critical thinking when they wrote their lab summaries and included descriptions of how they found science relevant to their daily lives, required for the fourth outcome. As far as responsible decision making, measuring the second part of the fourth outcome may be beyond the purview of any instructor, though they could and did discuss what a responsible decision would look like and the processes they would use to arrive at a conclusion. Taken as a whole, these course learning outcomes were designed to begin developing "scientific habits of mind" (Smith & Tanner, 2010) that experts employ when working with content, though achieving fluency or expertise in such habits were not the goals. An introductory or general biology course is not the end of a student's education, but a step on a journey to develop such habits.

Comparing the pretest to the posttest, the students had learning gains between 41% and 55%, with the virtual simulation users having higher average learning gains. These results were not unexpected given that these students were non-majors who had multiple commitments outside of class. The literature reflects that a wide variety of students often have the same success or better using virtual simulations compared to hands-on or traditional laboratory methods. In a study of high school students, students using virtual simulations had better understandings of high school genetics as seen with more accurate statements and explanations than students using traditional lab work (Gelbart, Brill, & Yarden, 2009). Riess and Mischo (2010) demonstrated that 6^{th} grade students using virtual simulations to understand an ecosystem had significantly higher learning gains than students using traditional laboratory methods. Ketelhut and Nelson (2010) in a study with 500 seventh-graders using either a virtual laboratory or a physical laboratory to study biology, found that virtual laboratories help students be engaged as well or better than physical laboratories. Further, they found that girls using the virtual laboratory learned more than girls in the physical laboratory or boys in either virtual or physical laboratories, while boys learned more in the physical laboratory. This research extends the idea that students had the same or better success with virtual simulations than hands-on activities to the realm of online delivery of a biology class.

Demonstrating knowledge and understanding of basic biological concepts and principles is one way to know if they learned biology, and as an instructor, that is a significant part of how I assessed them. Another way to evaluate if students learned biology relies on assessing student thinking so that how well students have developed “scientific habits of mind” (Smith & Tanner, 2010) comes to the forefront of assessment. While concept inventories support the systematic collection of evidence by teachers that may encourage faculty to reflect on how they teach, concept inventories do not help instructors evaluate how well students “think like biologists,” which is a goal of undergraduate biology (Smith & Tanner, 2010). The vocabulary and closed-ended, multiple-choice format of the questions limits how much learning by students can be assessed (Smith & Tanner, 2010). Not only is there difficulty in gaining consensus on the “big ideas” in biology (Garvin-Doxas et al., 2007; Michael, Modell, McFarland, & Cliff, 2009), there is also little consensus on when undergraduate students should become scientifically literate and able to answer their own questions (Wright, 2005). How to understand and evaluate student thinking as they develop “scientific habits of mind” (Smith & Tanner, 2010) remains a challenge for biology education. Concept inventories will remain a tool instructors use to evaluate students’ demonstration of knowledge, concepts, and principles. However, research into ways to assess biological thinking by students is necessary so that instructors can gain a clearer picture of how their courses fit into a biology program. Assessing how students have developed habits of mind over the course of a semester may be important to understanding how well constructivism works in college classrooms, since constructivism requires that learning requires tapping into prior knowledge and changing beliefs about ideas (Colburn, 2000).

CLASS-BIO Discussion

Student response rate to the CLASS-BIO survey was 70%, consistent with previously reported CLASS-BIO survey completion rates (Semsar, et al., 2011). Surprisingly, there were no significant shifts after instruction along the novice-to-expert continuum reported by students. This is contrary to what Semsar et al. (2011) reported with some regression towards novice expected by those students who were contemplating science-related career fields. Perkins et al., 2005 argues that changing student beliefs about the nature of science is critical for meaningful science learning to occur. My students did not show such a change in their beliefs yet clearly showed learning gains in content knowledge as measured through the pre/posttest. Those previous studies examined attitudes of university-level students in major biology courses. Students moved from novice-like to expert-like in their understanding of content when they not pursuing a future in scientific research but regressed towards a more novice-like understanding of content after instruction if they were biology majors (Semsar, et al., 2011). Those results suggested that the primarily non-majors population in this study should have shifted towards more expert-like in their understanding of content. They did not make a shift in belief about the nature of biology knowledge. Understanding why not would be useful to other community college instructors teaching in similar settings. Future research at community colleges in the American Bible Belt could investigate how religious outlooks, education, and beliefs may be impacting student science learning.

There are several possible explanations why I was unable to capture quantitatively how students' perceptions may have shifted. The first may be that the students were not motivated to reflect before answering the survey questions. Giving a survey at the end of the semester when students are taking final exams, with some preparing to graduate, is not an ideal time to capture these data. The second possibility is that the CLASS-Bio survey was not able to capture minuet changes in perceptions. The CLASS-Bio survey is administered as a five-point Likert scale but scored using a three-point system. This means that students may have shifted from agree to strongly agree or disagree to strongly disagree but because the scoring is collapsed, such changes are not quantifiable. There is good reason to collapse the scoring in that there is no way to consistently define a degree of difference between the strongly agree/disagree and agree/disagree. It may be that for some populations, asking the questions with only agree or disagree as possible answers, shifts could be captured. Further, using a survey instrument with a population that may have cultural biases against science may mean that the instrument needs to be modified or that a new instrument needs to be developed. How a student conceptualizes ideas that may be opposed to their personal belief system could be a fruitful area of future research. Another area that would be beneficial to explore is how well the scoring system of the CLASS works for this population. While Adams et al. (2006) argued there was no reliable way to measure the difference between a strong disagree and disagree, or an agree or strongly agree, community college students might respond to the survey differently than the university students it was validated with.

The interviews with the three students in May, 2013 were helpful in providing a possible reason why no shift was seen if a majority of the students in the class were highly religious. The many other students who reported informally spending similar hours to Sophia's family in church services may be why no significant shift was seen. If a conservative number of three hours a week of church services is typical for a student served by this community college and the student has lived and attended church in the community for at least ten years prior to taking online general biology, that suggests the student will have heard over 1500 hours of sermons or religious teachings. While religion and science are not enemies, when students' worldviews are grounded in a literal interpretation of Genesis, shifting attitudes towards science within 48 hours of instruction over the course of a semester is challenging. Further, this course did not focus on the nature of science, which had it and had it asked students to inventory their thinking about religion and evolution, may have produced different results in the survey. For instance, in a study of first year students assigned a First Year Seminar devoted to understanding the nature of science, the number of students who expressed anxiety in learning about evolution had decreased significantly by the end of the course due to the reflections on their personal beliefs and evolution learning, coupled with scientific teaching on the nature of science (Martin-Hansen, 2008). When conflict is perceived between religion and science amongst secondary students, extreme positions can be fortified by students (Taber, Billingsley, Riga & Newdick, 2011); this may have been the case in this study. Gauch argues that science must be public, universal and evidence-based, which religious experiences are not (Gauch, 2006). This suggests that if shifting attitudes towards science is important to an instructor, assigning more reflective assignments may allow students to see how their religious and scientific views diverge and where and when such views may be relevant to their lives. Another course of action for instructors concerned about how students perceive conflict between their religious views and science is to enlist the assistance of clergy. A study by Dickerson, Dawkins, & Penick (2008) suggests that clergy are aware of potential conflict between faith and science. Further, clergy may view church services and other formal, organized faith-based times (e.g., Bible studies), as opportunities for informal science education opportunities because clergy often recognize a need for better understandings of science and how science relates to faith for their congregations (Dickerson, Dawkins, & Penick, 2008). However, this research did not formally probe for such connections and a future project looking for any connections might help biology instructors structure instruction better to meet the needs of their students. In meeting the needs of their students in this way, community college faculty have another opportunity to strengthen ties to their students and build bridges between their colleges and communities, which serves to strengthen the missions of community colleges to provide educational opportunities to the people they serve. The timing of the post-survey, at the end of the semesters, when time tends to be in short supply for students, may have also contributed to students not completing the survey.

Discussion of Q2

The research findings suggest that both treatments had similar positive perceptions towards their respective laboratory experiences. Students, regardless of treatment, perceived that laboratory experiences helped them feel engaged with the course; laboratory experiences offered students opportunities to engage with or think about the processes of science; and laboratory experiences offered opportunities to engage with or think about abstract or difficult content. Previous research on student perceptions have found similar results (Stuckey-Mickell & Stuckey-Danner, 2007;

Stuckey-Mickell, Stucky-Danner, & Taylor, 2007). Where this research was most helpful for expanding our knowledge of online students' perceptions was in the difference of perceptions: virtual simulation users perceived laboratory to take a reasonable amount of time that fit their expectations for the course whereas at-home kit users tended to find that laboratory took too much time and did not fit their expectations for the course. This difference of perception may contribute to the different learning gains experienced by the two treatments and is important for maintaining engaged students over the course of a semester. This difference in perceptions is also critically important to community college instructors designing online biology courses.

The inclusion of the student-participants in the category creation was an important step in the process of theme development. Word clouds offered students a visual representation of their data, which allowed them to freely discuss their perceptions without being intimidated by any mathematics involved in analyzing their data. Had graphs been used to represent their data or even frequency tables, it likely would have lent a more formal feeling to our conversations and reduced participation. However, by using a word cloud, students were engaged, which was expected based on other researchers' observations of word clouds' power to engage even reluctant learners (Viegas, Wattenberg & Feinberg, 2009). The fast and visually rich graphic that was created gave participants a basic understanding of the data that allowed participants of all mathematical abilities to participate equally. Word clouds have been used as research tools for similar preliminary analyses (McNaught & Lam, 2010). While some students had successfully completed college-level mathematics courses, not all had and the use of word clouds allowed students to interact with the data and not become intimidated by frequencies. Visual representations of data through word clouds are acceptable ways to showcase data to non-technical audiences (Viegas, et al., 2009). The trade-off of more precision through other forms of data reporting, such as a frequency table of coded categories, versus inclusivity seemed appropriate given I was the instructor and the researcher. Knowing that my population often lacked a strong math background meant that the word cloud was a valuable tool for helping my students help me with the research.

Students using virtual simulation software performed better on the midterm and final than students using hands-on at-home exercises for laboratory. Interviews with a sample of students suggested that virtual simulation students were able to do two key things that hands-on students were less likely to do: 1) complete the laboratory exercises fully; and 2) repeat the laboratory exercises when the student wanted clarification. Virtual simulation users could repeat a laboratory exercises as many times as they wished; while theoretically at-home kit users could restock their supplies and repeat the experiment, only three reported doing so and only for the pom-pom game in the natural selection exercise in the Mechanics of Evolution laboratory. It is interesting to note that the exercise that was repeated was set-up as a game; this may suggest an important design element for hands-on activities, though with only three students reporting, it is too small to draw conclusions from. In the evolution laboratory exercises it would have been possible to repeat the exercises as they were either paper-based examinations as in Evidence of Evolution, or used non-consumables as in the at-home kit exercise "Mechanisms of Evolution." The ecology laboratory exercises would have required setting up additional experiments with consumable materials.

Using virtual simulation software was perceived by students as easier to set-up, maintain, and complete than setting up, maintaining, and completing hands-on activities. Interviews with students suggested that for an online class, students expected the work to be virtual and so entered class with a mindset that facilitated success with virtual simulation software. Students completing hands-on assignments tended to either enjoy the activities or felt they were "routine drudgery" as one student clarified. Stacy (laboratory report): "I found this lab very time consuming because it was full of routine drudgery. I found the labs challenging for this class, but mostly because of the time they took. I realize that online classes are difficult, especially with labs required." Students enjoying the activities nevertheless expressed a desire for the set-up to take less time, though several stated that anything more than pushing a button was an excessive expectation for a laboratory class. Dempsey (focus group): "Favorite lab is the one where we tested the effects of fertilizer. I found it interesting on several different levels. I just wish it took less time to do." Lauren (laboratory report): "I am sorry to say that I did not do many of the labs. Between doctor appointments, family illnesses, and work I did not have as much time as I had hoped. I tried to make time to complete them but they were not that easy to understand and long." Paul (focus group): "If I were teaching this, I would made the labs short and sweet. Push a button and get 'er done! I'm taking this online so I don't have to do things hands-on." Ken (laboratory report): "When you are in lab online it is more difficult to learn over a computer than it would be if the student was sitting in the classroom learning the material." As one student assigned hands-on activities wrote in an email, "I need online classes because I don't have alot (*sic*) of time. I just wanna be done!" Such comments suggested that students valued the convenience of virtual simulations more than any perceived value, often by the instructor, of hands-on learning.

Students using virtual simulation software were able to easily repeat the exercises as many times as they desired whereas students assigned hands-on activities did not report repeating many exercises. The exception to non-repetition was “Mechanisms of Evolution” where pom-poms or crackers were captured with forks on a furry background. This activity was reported as being repeated by three students, including one student who was a mother and decided to include her two young children in the second round. Students using hands-on activities expressed a desire to have repeatability in their exercises but when probed further on this, expressed concern about their ability to find time to repeat exercises. Students were less concerned about the cost of acquiring any necessary consumable materials to repeat the activity; their primary, and often only expressed, concern was time. Lauren (laboratory report): “I would have done the labs if I’d had time.” Rebecca (focus group): “I would have bought more clay to make more critters if I’d had more time. I thought that experiment was interesting and wished we’d had more time. I think my favorite labs were the ones that were hands-on where we had to actually observe and do something for. They lasted longer but I found in those I learned the most and will probably retain the information better because I learned it by actually doing it.” Students’ inability to repeat activities because of the time they perceive an activity to take suggests that for the benefit of student learning, virtual simulation software should be given further consideration by instructors teaching online biology classes.

Non-traditional students with children who were assigned the virtual simulations were also likely to engage their children in their laboratory exercises as a form of computer gaming. In the interviews, students, especially mothers, reported that their children wanted to "play" the simulations after their mother was done with her work. Two mothers also reported relying on their children's expertise of computers to understand instructions or "fix" technical problems they believed they were having. While one husband-wife student team in the at-home kit treatment did include their children routinely in setting up laboratory exercises, fewer non-traditional students reported involving their children in laboratory exercises. This was surprising given many of the hands-on ecology exercises students completed involved activities typically thought of as being traditionally within the realm of childhood activities: being outside, observing nature, and collecting pond water.

Conclusion

Students randomly assigned virtual simulation software to explore ecology and evolution topics as their laboratory component in an introductory general biology class scored significantly higher on a midterm and post-test assessment than students randomly assigned use of hands-on at-home laboratory exercises. Student learning materials were otherwise identical. The effect size the virtual simulations versus the at-home kits suggested that the laboratory treatment had a medium to large effect on most students' outcomes. Student summaries, video chats, and focus groups suggested that students using virtual simulation software perceived that the laboratory component took a manageable amount of time. Also, based on what students had to say, the repeatability of the virtual simulations may have encouraged students to repeat an exercise until they felt they understood a concept. Hands-on at-home exercises were perceived by students using them to take too much time to make them repeatable. While the exercises complied with the institution's curriculum committee's recommendations for structure and content, the students using them felt they were being asked to do too much for the process to be repeatable.

The results of this study suggest to community college instructors that virtual simulation software may provide online students with viable alternatives in biology education. Instructors may wish to consider the cost of such software compared to the kits as online students may expect the course to be entirely virtual. Administrators may wish to consider the expanded number of students their institutions can reach by not requiring students attend a local campus for an on-campus laboratory portion of a general education biology course and the cost of laboratory kits for their students compared to the cost of virtual simulation software.

The students involved in the study ended the class with greater understanding of evolution and ecology: looking over student comments such as, "Now I know what evolution is about" and "I never thought of that before" encourages me that discourse on evolution and ecology can open students minds to new ideas—the most foundational objective in all of higher education. The labs were as student-centered as the constraints of content allowed them to be in my opinion. The labs were scaffold so that learners had support as they completed experiments, they built on their previous knowledge, and could better explain their understanding of the living world. While an increase in learning gains is associated with movement from novice-like to expert-like understanding (McDaniel, Lister, Hanna, Roy, 2007), having the students' attitudes shift as well would have added support that students were able to successfully construct their own knowledge in online biology. Future researchers could compare the shift in attitudes with shifts along the novice-to-expert continuum to design better online instructional approaches.

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APPENDIX A

INSTITUTIONAL REVIEW BOARD

MATERIALS

[redacted] Institutional Review Board

December 17, 2012

Dear Ms. Ranney,

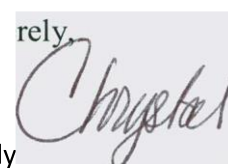
This letter is in response to your request submitted December 10, 2012 to the Institutional Review Board (IRB) to perform research at [redacted] State College. This letter is in reference to the following research project:

> Project Title: Understanding how computer-based evolutionary and ecology simulations and hands-on laboratory experiences are perceived by online adult community college learners.

Principle Investigator: Beverly Ranney

It is the finding of the IRB that your research falls under [redacted] "exempt" studies category. Therefore, no further information or documentation is required at this time. [redacted] IRB grants you permission to perform your research study.

[redacted] appreciates your scholarly endeavor to improve online education with evidenced based research. Please contact me at [redacted] if you need further assistance.

Sincerely 

[redacted]

Chrystal [redacted], MS, RN

Dean of Technical Education

Institutional Review Board, Chair

[redacted]

UNIVERSITY *of* NORTHERN COLORADO

Institutional Review Board

DATE:	May 1, 2013
TO:	Beverly Ranney
FROM:	University of Northern Colorado (UNCO) IRB
PROJECT TITLE:	[451390-1] Understanding how computer-based simulations and handson laboratory experiences are perceived by online adult community college learners
SUBMISSION TYPE:	New Project
ACTION:	APPROVAL/VERIFICATION OF EXEMPT STATUS
DECISION DATE:	May 1, 2013

Thank you for your submission of New Project materials for this project. The University of Northern Colorado (UNCO) IRB approves this project and verifies its status as EXEMPT according to federal IRB regulations.

Beverly -

Thank you for a clear and thorough IRB application. I have no requests for revisions or additional materials.

Best wishes with your research and thank you for your patience in the review process.

Sincerely,

Dr. Megan Stellino, UNC IRB Co-Chair

We will retain a copy of this correspondence within our records for a duration of 4 years. If you have any questions, please contact Sherry May at 970-351-1910 or Sherry.May@unco.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within University of Northern Colorado (UNCO) IRB's records.

CONSENT FORM FOR HUMAN PARTICIPATION IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO
[redacted]

Project Title: Understanding how computer-based evolutionary and ecology simulations and hands-on laboratory experiences are perceived by online adult community college learners.

Principle Investigator: Beverly Ranney **Phone Number**: (970) 351-1290
Email: Beverly.ranney@unco.edu
Faculty Supervisor: Dr. Richard Jurin **Phone Number**: (970) 351-2220

Purpose and Description: The primary purpose of this study is to determine the effectiveness of laboratory delivery methods for online biology students. Over a 20-minute interview, you will be asked to describe your perceptions of and experiences with the laboratory exercises. You may be asked questions such as, "What did you like about your laboratory exercises? What did you dislike?" or, "Can you please explain why you did (or did not) like this exercise?".

The interview will take place over the phone and I will be writing down your responses to the questions. At the end of the interview, I will summarize what you had to say and ask you if that summary is an accurate reflection of what you told me. I will take every precaution in order to protect the confidentiality of your participation. I will assign a numeric code to you and only I will know that your name is connected to a particular code. When I report data, your name will not be used. Data collected and analyzed for this study will be kept in a locked cabinet in the Biology Department of the University of Northern Colorado, which is only accessible by Dr. Richard Jurin of the biology department.

Potential risks in this interview are minimal. You may feel some discomfort talking about the laboratory exercises but your participation is voluntary and in no way will your answers impact your grade. Future students and biology education researchers are the populations who most benefit from the results of this study.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact Ms. Crystal [redacted], Dean of Technical Education, [redacted]. You may also contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

____

Participant's Signature Date

____

Researcher's Signature Date

CONSENT FORM FOR HUMAN PARTICIPATION IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO
[redacted]

Project Title: Understanding how computer-based evolutionary and ecology simulations and hands-on laboratory experiences are perceived by online adult community college learners.

Principle Investigator: Beverly Ranney **Phone Number**: (970) 351-1290
Email: Beverly.ranney@unco.edu
Faculty Supervisor: Dr. Richard Jurin **Phone Number**: (970) 351-2220

Purpose and Description: The main purpose of this study is to determine the effectiveness of different laboratory delivery methods for online general biology students. As part of a normal coursework, you complete a pretest, midterms, and a final exam. You also complete weekly lab reports and may post in the discussion board section of the class. I wish to examine these pieces of data to determine what laboratory delivery method gives students the best way to succeed in online biology.

There are no foreseeable risks to you in participating. I will do my best to keep your data confidential. I will remove your name from all data. All data will be kept on a password-protected flash drive stored in a locked filing cabinet in a locked office on the University of Northern Colorado campus. After three years, the data will be destroyed. Your decision to participate will not impact your grade; your grade is determined only by the number of points you earn as outlined in the syllabus. There are no foreseeable benefits to you from participating in the study. Your participation will help improve future online biology courses.

Participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact Ms. Crystal [redacted] You may also contact the Office of Sponsored Programs, Kepner Hall, University of Northern Colorado Greeley, CO 80639; 970-351-2161.

____
Student's Signature Date

____ _____________________
Researcher's Signature Date

APPENDIX B

SYLLABUS

BIOL [redacted]: General Biology

COURSE DESCRIPTION

Welcome to *the study of life*! This course examines biological principles from cells to communities, especially structure and function. You will explore evolution, ecology, cells, genetics, metabolism, and homeostasis. This course will help build a foundation of knowledge about how all living organisms from a simple yeast cell to a gigantic blue whale live and survive. This course fulfills one of the general education requirements for [redacted].

Outcomes:

The student:

1. Demonstrate knowledge and understanding of basic biological concepts and principles, including comprehension of life and living systems, various biological laws and theories, and their importance.
2. Solve problems and reach tenable solutions that require abstract and analytical reasoning.
3. Collect data, analyze it, and submit reports demonstrating comprehension of the principles involved.
4. Apply the habits of critical thinking as demonstrated by descriptions of how science is relevant to their daily lives and use this understanding to make responsible decisions about the impact of human activities on the environment.

GENERAL INFORMATION

Instructor: Beverly Ranney

Class Time: Online, logging on at least once a week is required

Email:Beverly.ranney@[redacted].edu

Office Hours: Mondays 11-12, Wednesdays 11-1

TEXT

The text for this course is the same as the one used on campus, available from the bookstore. The textbook is “Biology, 11nd edition” by Mader. The ISBN is 9780077583132.

If you would like to buy a used copy of the book (and I encourage you to use this option!), there should are used versions available via Amazon, Chegg.com, and other used book retailers. Also, consider renting your textbook from the bookstore or an online source.

OTHER REQUIRED MATERIALS

1. See our Moodle homepage for your assigned laboratory materials.

ATTENDANCE

Attendance is mandatory for this class. Attendance is measured through two matrices: logging into class and submitting assignments on-time.

ACADEMIC INTEGRITY

As members of a scholarly community dedicated to healthy intellectual development, students and faculty are expected to share the responsibility for maintaining high standards of honesty and integrity in their academic work. All material for this course must be your work and no one else's. Cheating or plagiarism in any form will not be tolerated. This includes, but is not limited to, copying someone else's work, and using banned material while taking exams. The penalty for cheating or plagiarism is a zero for the course.

Honor Code: all members of the [redacted] State College community are entrusted with the responsibility to uphold and promote five fundamental values: Honesty, Trust, Respect, Fairness, and Responsibility. These core elements foster an atmosphere, inside and outside of the classroom, which serves as a foundation and guides the [redacted] community's academic, professional, and personal growth. Endorsement of these core elements by students, faculty, staff, administration, and trustees strengthens the integrity and value of our academic climate.

DISABILITIES

Students who believe they may need accommodations in this class are encouraged to contact the -Student Support Services [redacted] as soon as possible to better ensure that such accommodations are implemented in a timely fashion.

EVALUATION

Exams (2)	30%
Final Exam	25%
Quizzes	15%
Discussion	5%
Laboratory	25%

GRADE BREAKDOWN

90-100%	A
80-89%	B
70-79%	C
60-69%	D
< 60%	F

READING SCHEDULE

Our reading schedule is posted on Moodle. Look to spend several hours each week reading your textbook!

EXAMS

There will be **three exams** during the semester, including the final exam. The format for all exams will be online, multiple choice. Exams are multiple-choice questions. Some questions require you to read passages. You may return to unanswered questions at the end.

You may only open the exam once—once you open the exam, your timer starts! You have 75 minutes to complete the exam. If you have computer issues, you must call the [redacted] Help Desk: ([redacted]. If you are concerned about your ability to maintain an Internet connection on test day, please let me know three work/school days in advance and I will make arrangements for you to take the test at the [redacted] Testing Center on campus. Exams must be submitted before 11:00PM in order for you to receive credit. If you take it too late or if you forget to do the exam, it will not be reopened for you, so take it early as to not miss the deadline. You must access the exam through Moodle.

The date for the final exam is posted on our Moodle page! The final will be open from 7:00 AM-11:00 PM. No early finals will be given and exam dates are not negotiable. Make-up exams are only given for documented circumstances beyond the student's control. All exams are administered online through Moodle.

QUIZZES

For every two chapters, there will be a quiz covering the material presented in those chapters. Quizzes are open notes, text, or other resource to aid you in completing the quiz. I want you to think of the quizzes as a review opportunity to aid you in finding the holes in what you do not know. Each quiz is due on Sunday by 11:30 PM. It must be submitted before 11:30 PM in order for you to receive credit. If you take it too late or if you forget to do the quiz, it will not be reopened for you, so take it early as not to miss the deadline. Make-up quizzes are only given in documented, extenuating circumstances. Because the quizzes are open note, please be prepared for the quiz! I will not ask you questions that can be easily Googled, such as definitions. I expect you to apply information, analyze information, and select appropriate answers.

DISCUSSIONS

We will have several discussions throughout the semester on our class discussion board. Interesting discoveries are happening in biology and we want to discuss where these discoveries are taking us. Be prepared to put on your reflecting caps and join a discussion every other week on interesting topics in biology. You will be graded on your analysis of the question, the evidence you provide, and your contribution to the continuation of the conversation (so avoid comments such as, "I totally agree with you! That is such a good point!"). Look on the discussion boards to see what new ideas pop up! Also, a special discussion board, "Instructor's Posting Area," serves as a board for announcements for the class, study tips, and rare extra credit opportunities, so stay logged in!

MOODLE

You can access your Moodle courses by going to [redacted]. Once logged in, you will be able to access Moodle for this course. All students are expected to use the resources on the Moodle site.

LABORATORY

This course has a required laboratory portion associated with it. There is not a separate grade reported for lab, instead the laboratory grade is entered as a portion of the lecture grade. A lab schedule will be posted on the Moodle open page.

RESEARCH of CLASS

This course is part of a research project investigating the effectiveness of laboratory methods. As part of your normal course work, you complete weekly laboratory activities with a report, take a quiz, and prepare for exams. My research seeks to understand if your laboratory exercises are effective in helping you learn evolution and ecology. **This means your participation makes a difference!** I am using student test scores covering evolution and ecology and comparing to see how effective the laboratory activities are in helping students understand biology. In addition, I am seeking students willing to be interviewed, either individually or as part of a group, about their laboratory experiences. **Participation is voluntary and a consent form is attached to our first discussion board post.** Voice your opinion! Participation does not impact your grade but it does help future online biology students have the best experience possible while giving you a chance to tell me how you feel about those long hours you are putting into class! ☺ Please contact me with any questions!

APPENDIX C

INSTRUMENTS

Pre/Post Test Instrument

1. Many types of house plants droop when they have not been watered and quickly "straighten up" after watering. The reason that they change shape after watering is because ...
A. Water reacts with, and stiffens, their cell walls.
B. Water is used to generate energy that moves the plant.
C. Water changes the concentration of salts within the plant.
D. Water enters and expands their cells.

2. In which way are plants and animals different in how they obtain energy?
A. Animals use ATP; plants do not.
B. Plants capture energy from sunlight; animals capture chemical energy.
C. Plants store energy in sugar molecules; animals do not.
D. Animals can synthesize sugars from simpler molecules; plants cannot.

3. In which way are plants and animals different in how they use energy?
A. Plants use energy to build molecules; animals cannot.
B. Animals use energy to break down molecules; plants cannot.
C. Animals use energy to move; plants cannot.
D. Plants use energy directly, animals must transform it.

4. How can a catastrophic global event influence evolutionary change?
A. Undesirable versions of genes are removed.
B. New genes are generated.
C. Only some species may survive the event.
D. There are short term effects that disappear over time.

5. There exists a population in which there are three distinct versions of the gene A (a1, a2, and a3). Originally, each version was present in equal numbers of individuals. Which version of the gene an individual carries has no measurable effect on its reproductive success. As you follow the population over a number of generations, you find that the frequency of a1 and a3 drop to 0%. What is the most likely explanation?
A. There was an increased rate of mutation in organisms that carry either a1 or a3.
B. Mutations have occurred that changed a1 and a3 into a2.
C. Individuals carrying a1 or a3 were removed by natural selection.
D. Random variations led to a failure to produce individuals carrying a1 or a3.

6. Natural selection produces evolutionary change by…
A. changing the frequency of various versions of genes.
B. reducing the number of new mutations.
C. producing genes needed for new environments.
D. reducing the effects of detrimental versions of genes.

7. If two parents display distinct forms of a trait and all their offspring (of which there are hundreds) display the same new form of the trait, you would be justified in concluding that ...
A. both parents were heterozygous for the gene that controls the trait.
B. both parents were homozygous for the gene that controls the trait.
C. one parent was heterozygous, the other was homozygous for the gene that controls the trait.
D. a recombination event has occurred in one or both parents.

8. You are doing experiments to test whether a specific type of acupuncture works. This type of acupuncture holds that specific needle insertion points influence specific parts of the body. As part of your experimental design, you randomize your treatments so that some people get acupuncture needles inserted into the "correct" sites and others into "incorrect" sites. What is the point of inserting needles into incorrect places?
A. It serves as a negative control.
B. It serves as a positive control.
C. It controls for whether the person can feel the needle.
D. It controls for whether needles are necessary.

9. As part of your experiments on the scientific validity of this particular type of acupuncture, it would be important to ...
A. test only people who believe in acupuncture.
B. test only people without opinions, pro or con, about acupuncture.
C. have the study performed by researchers who believe in this form of acupuncture.
D. determine whether placing needles in different places produces different results.

10. What makes DNA a good place to store information?
A. The hydrogen bonds that hold it together are very stable and difficult to break
B. The bases always bind to their correct partner.
C. The sequence of bases does not greatly influence the structure of the molecule.
D. The overall shape of the molecule reflects the information stored in it.

11. What is it about nucleic acids that makes copying genetic information straightforward?
A. Hydrogen bonds are easily broken.
B. The binding of bases to one another is specific.
C. The sequence of bases encodes information.
D. The shape of the molecule is determined by the information it contains.

12. It is often the case that a structure (such as a functional eye) is lost during the course of evolution. This is because ...
A. It is no longer actively used.
B. Mutations accumulate that disrupt its function.
C. It interferes with other traits and functions.
D. The cost to maintain it is not justified by the benefits it brings.

13. When we want to know whether a specific molecule will pass through a biological membrane, we need to consider ...
A. the specific types of lipids present in the membrane.
B. the degree to which the molecule is water soluble.
C. whether the molecule is actively repelled by the lipid layer.
D. whether the molecule is harmful to the cell.

14. How might a mutation be creative?
A. It could not be; all naturally occurring mutations are destructive.
B. If the mutation inactivated a gene that was harmful.
C. If the mutation altered the gene product's activity.
D. If the mutation had no effect on the activity of the gene product.

15. An allele exists that is harmful when either homozygous or heterozygous. Over the course of a few generations the frequency of this allele increases. Which is a possible explanation? The allele ...
A. is located close to a favorable allele of another gene.
B. has benefits that cannot be measured in terms of reproductive fitness.
C. is resistant to change by mutation.
D. encodes an essential protein.

16. In a diploid organism, what do we mean when we say that a trait is dominant?
A. It is stronger than a recessive form of the trait.
B. It is due to more, or a more active gene product than is the recessive trait.
C. The trait associated with the allele is present whenever the allele is present.
D. The allele associated with the trait inactivates the products of recessive alleles.

17. How does a molecule bind to its correct partner and avoid “incorrect” interactions?
A. The two molecules send signals to each other.
B. The molecules have sensors that check for "incorrect" bindings.
C. Correct binding results in lower energy than incorrect binding.
D. Correctly bound molecules fit perfectly, like puzzle pieces.

18. Once two molecules bind to one another, how could they come back apart again?
A. A chemical reaction must change the structure of one of the molecules.
B. Collisions with other molecules could knock them apart.
C. The complex will need to be degraded.
D. They would have to bind to yet another molecule.

19. Why is double-stranded DNA not a good catalyst?
A. It is stable and does not bind to other molecules.
B. It isn't very flexible and can't fold into different shapes.
C. It easily binds to other molecules.
D. It is located in the nucleus.

20. Lipids can form structures like micelles and bilayers because of ...
A. their inability to bond with water molecules.
B. their inability to interact with other molecules.
C. their ability to bind specifically to other lipid molecules.
D. the ability of parts of lipid molecules to interact strongly with water.

21. A mutation leads to a dominant trait; what can you conclude about the mutation's effect?
A. It results in an overactive gene product.
B. It results in a normal gene product that accumulates to higher levels than normal.
C. It results in a gene product with a new function.
D. It depends upon the nature of the gene product and the mutation.

22. How similar is your genetic information to that of your parents?
A. For each gene, one of your alleles is from one parent and the other is from the other parent.
B. You have a set of genes similar to those your parents inherited from their parents.
C. You contain the same genetic information as each of your parents, just half as much.
D. Depending on how much crossing over happens, you could have a lot of one parent's genetic
information and little of the other parent's genetic information.

24. A mutation leads to a recessive trait; what can you conclude about the mutation's effect?
A. It results in a non-functional gene product.
B. It results in a normal gene product that accumulates to lower levels than normal.
C. It results in a gene product with a new function.
D. It depends upon the nature of the gene product and the mutation.

25. Imagine an ADP molecule inside a bacterial cell. Which best describes how it would manage to "find" an ATP synthase so that it could become an ATP molecule?
A. It would follow the hydrogen ion flow.
B. The ATP synthase would grab it.
C. Its electronegativity would attract it to the ATP synthase.
D. It would be actively pumped to the right area.
E. Random movements would bring it to the ATP synthase.

26. You follow the frequency of a particular version of a gene in a population of asexual organisms. Over time, you find that this version of the gene disappears from the population. Its disappearance is presumably due to …
A. genetic drift.
B. its effects on reproductive success.
C. its mutation.
D. the randomness of survival.

27. Consider a diploid organism that is homozygous for a particular gene. How might the deletion of this gene from one of the two chromosomes produce a phenotype?
A. If the gene encodes a multifunctional protein.
B. If one copy of the gene did not produce enough gene product..
C. If the deleted allele were dominant.
D. If the gene encoded a transcription factor.

28. Gene A and gene B are located on the same chromosome. Consider the following cross: AB/ab X ab/ab. Under what conditions would you expect to find 25% of the individuals with an Ab genotype.
A. It cannot happen because the A and B genes are linked.
B. It will always occur, because of independent assortment.
C. It will occur only when the genes are far away from one another.
D. It will occur only when the genes are close enough for recombination to occur between
them.

29. Sexual reproduction leads to genetic drift because ...
A. there is randomness associated with finding a mate.
B. not all alleles are passed from parent to offspring.
C. it is associated with an increase in mutation rate.
D. it produces new combinations of alleles.

30. How is genetic drift like molecular diffusion?
A. Both are the result of directed movements.
B. Both involve passing through a barrier.
C. Both involve random events without regard to ultimate outcome.
D. They are not alike. Genetic drift is random; diffusion typically has a direction.

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to the islands one to five million years ago (Lack, 1940). Recent DNA analyses support the conclusion that all of the Galapagos finches evolved from the warbler finch (Grant, Grant & Petren, 2001; Petren, Grant & Grant, 1999). Different species live on different islands. For example, the medium ground finch and the cactus finch lie on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes, as shown in this figure.
Choose the one answer that best reflects how an evolutionary biologist would answer.

30. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predator and unlimited food so that all individuals survived?
A. the finch population would stay small because birds only have enough babies to replace themselves
B. the finch population would double and then stay relatively stable.
C. the finch population would increase dramatically.
D. the finch population would grow slowly and then level off.

31. Finches on the Galapagos Islands require food to each and water to drink.
A. When food and water are scarce, some birds may be unable to obtain what they need to survive.
B. When food and water are limited, the finches will find other food sources, so there is always enough.
C. When food and water are scarce, the finches all eat and drink less so that all birds survive.
D. There is always plenty of food and water on the Galapagos Islands to meet the finches' needs.

32. Once a population of finches has lived on a particular island for many years,
A. the population continues to grow rapidly.
B. the population remains relatively stable.
C. the population dramatically increases and decreases each year.
D. the population will decrease steadily.

33. In the finch population, what are the primary changes that occur gradually over time?
A. The traits of each finch within a population gradually change.
B. The proportions of finches having different traits within a population change.
C. Successful behaviors learned by finches are passed on to offspring.
D. Mutations occur to meet the needs of the finches as the environment changes.

34. Depending on their beak size and shape, some finches get nectar from flowers, some eat grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?
A. Most of the finches on an island cooperate to find food and share what they find.
B. Many of the finches on an island fight with one another and the physically strongest ones win.
C. There is more than enough food to meet all the finches' needs so they don't need to compete for food.
D. Finches compete primarily for food with closely related finches that eat the same kinds of food, and some may die from lack of food.

35. How did the different beak types <u>first</u> arise in the Galapagos Islands?
A. the changes in the finches' beak size and shape occurred because of their need to be able to eat different kinds of food to survive.
B. Changes in the finches' beaks occurred by chance, and when there was a good match between beak structure and available food, those birds had more offspring.
C. The changes in the finches' beaks occurred because the environment induced the desired genetic changes.
D. The finches/ beaks changed a little bit in size and shape with each successive generation, some getting larger and some getting smaller.

36. What type of variation in finches is passed to the offspring?
A. Any behaviors that were learned during a finch's lifetime.
B. Only characteristics that were beneficial during a finch's lifetime.
C. All characteristics that were genetically determined.
D. Any characteristics that were positively influenced by the environment during a finch's lifetime.

37. What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?
A. The finches were quire variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
B. All finches are essentially alike and there are not really fourteen different species.
C. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.
D. Different lines of finches developed different beak types because they needed them in order to obtain the available food.

Venezuelan Guppies

Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue and iridescent (reflective) spots. Males cannot be too brightly colored or they will be seen and consumed by predators, but if they are too plain, females will choose other males. Natural selection and sexual selection push in opposite directions. When a guppy population lives in a stream in the absence of predators, the proportion of males that are bright and flashy increases in the population. If a few aggressive predators are added to the same stream, the proportion of bright-colored males decreases within about 5 months (3-4 generations). The effects of predators on guppy coloration have been studied in artificial ponds with mild, aggressive, and no predators, and by similar manipulations of natural stream environments (Endler, 1980).

Choose the one answer that best reflects how an evolutionary biologist would answer.

38. A typical natural population of guppies consists of hundreds of guppies. Which statement best describes the guppies of a single species in an isolated population?
A. The guppies share all of the same characteristics and are identical to each other.
B. The guppies share all of the essential characteristics of the species; the minor variations they display don't affect survival.
C. The guppies are all identical on the inside but have many differences in appearance.
D. The guppies share many essential characteristics, but also vary in many features.

39. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the "most fit"?
A. large body size and ability to swim quickly away from predators
B. excellent ability to compete for food
C. high number of offspring that survived to reproductive age

D. high number of matings with many different females

40. Assuming ideal conditions with abundant food and space and no predators, what would happen if a pair of guppies were placed in a large pond?
A. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to replenish the population.
B. The guppy population would grow slowly at first, then would grow rapidly, and thousands of guppies would fill the pond.
C. The guppy population would never become very large because only organisms such as insects and bacteria reproduce in that manner.
D. The guppy population would continue to group slowly over time.

41. Once a population of guppies has been established for a number of years in a real (not ideal) pond with other organisms including predators, what will likely happen to the population?
A. The guppy population will stay about the same size.
B. The guppy population will continue to rapidly grow in size.
C. The guppy population will gradually decrease until no more guppies are left.
D. It is impossible to tell because populations do not follow patterns.

42. In guppy populations, what are the primary changes that occur gradually over time?
A. The traits of each individual guppy within a population gradually change.
B. The proportions of guppies having different traits within a population change.
C. Successful behaviors learned by certain guppies are passed on to offspring.
D. Mutations occur to meet the needs of the guppies as the environment changes.

Canary Island Lizards
The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent. Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to see.

Choose the one answer that best reflects how an evolutionary biologist would answer.

43. Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?
A. Finding food is not a problem since food is always in abundant supply.
B. Since lizards can eat a variety of foods, there is likely to be enough food for all of the lizards at all times.
C. Lizards can get by on very little food, so the food supply does not matter.
D. It is likely that sometimes there is enough food, but at other times there is not enough food for all of the lizards.

44. What do you think happens among the lizards of a certain species when the food supply is limited?
A. The lizards cooperate to find food and share what they find.
B. The lizards fight for the available food and the strongest lizards kill the weaker ones.
C. Genetic changes that would allow lizards to eat new food sources are likely to be induced.
D. The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

45. Populations of lizards are made up of hundreds of individual lizards. Which statement describes how similar they are likely to be to each other?
A. All lizards in the population are likely to be nearly identical.
B. All lizards in the population are identical to each other on the outside but there are differences in their internal organs such as how they digest food.
C. All lizards in the populations share many similarities, but there are differences in features like body size and claw length.
D. All lizards in the population are completely unique and share no features with other lizards.

46. Which statement could describe how traits in lizards pass from one generation of lizards to the next generation?
A. Lizards that learn to catch a particular type of insect will pass the new ability to offspring.
B. Lizards that are able to hear, but have no survival advantage because of hearing, will eventually stop passing on the "hearing" trait.
C. Lizards with stronger claws that allows for catching certain insects have offspring whose claws gradually get even stronger during their lifetime.
D. Lizards with a particular coloration and pattern are likely to pass the same trait on to offspring.

Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional female lizards. Which lizard might a biologist consider to be “most fit”?

	Lizard A	Lizard B	Lizard C	Lizard D
Body Length	20 cm	12 cm	10 cm	15 cm
Offspring surviving to adulthood	19	28	22	26
Age at death	4 years	5 years	4 years	6 years
Comments	Lizard A is very healthy, strong, and clever	Lizard B has mated with many lizards	Lizard C is dark colored and very quick	Lizard D has the largest territory of all the lizards

A. Lizard A
B. Lizard B
C. Lizard C
D. Lizard D

47. According to the theory of natural selection, where did the variations in body size in the three species of lizards most likely come from?
A. The lizards needed to change in order to survive, so beneficial new traits developed.
B. The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
C. Random genetic changes and sexual recombination both created new variations.
D. The island environment caused genetic changes in the lizards.

48. What could cause one species to change into three species over time?
A. Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
B. Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.
C. There may have been minor variations, but all lizards are essentially alike and all are members of a single species.
D. In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

Midterm Instrument

1. Our domesticated honey bee—originally from Europe—is slow to sting, requires abundant flower nectar, gets up late in the morning, and stores much honey but only produces enough new brood to swarm once a year. Because the European honey bee was performing poorly as a honey producer in South America, the African subspecies was imported in a breeding experiment. The African honey bee formed small nests, foraged earlier and on smaller nectar sources, produced less honey stores and more brood, swarmed four or five times a year, and was fast to sting. However, when the African queens escaped, the two populations interbred and the African genotype spread several hundred miles north each year. Surprisingly, a hundred miles behind the expanding range of the African honey bees, the European and hybrid strains died out and the bees were essentially 100 percent African. How would this be explained in evolutionary genetics terms?
    a. Gene flow is not occurring and therefore these are two separate species
    b. This is a natural consequence of the Hardy-Weinberg equilibrium
    c. Obviously the African bee genes are dominant over the European honey been alleles.
    d. Gene flow is occurring between these subspecies but the African bee is ‘ecologically better suited’.
    e. This can be understood as a classic case of genetic drift.

2. A student proposes that left-handedness is a recessive trait that is therefore hidden in much of the human population. A survey of a class of 36 students finds that 27 (0.75) are right-handed and 9 (0.25) are left-handed. Using the Hardy-Weinberg formula, what would the expected genotypes and allele frequencies be in this theoretical population?
    a. 0.75 homozygous dominant and 0.25 homozygous recessive, and a 3-to-1, right-to-left handed allele ratio in the population.
    b. 0.25 homozygous dominant, 0.50 heterozygous, and 0.25 homozygous recessive, and a 0.75 dominant allele frequency and a 0.25 recessive allele frequency.
    c. 0.25 homozygous dominant, 0.50 heterozygous, and 0.25 homozygous recessive, and a 0.5 allele frequency for each allele.
    d. 0.50 homozygous dominant, 0.25 heterozygous, and 0.25 homozygous recessive, and a 0.5 allele frequency for each allele.
    e. They cannot be estimated using these limited data.

3. Which of the following is/are a biological "population?"
    a. all of the corn plants in a cornfield
    b. all of the variable-colored ladybird beetles of the species *Harmonia axyridis* in a forest

c. all male and female English sparrows that reside in your community
d. all of the human population of a rural western town
e. All of the choices are correct.

4. If the Hardy-Weinberg equilibrium is met, what is the net effect?
    a. evolution leading to a population better adapted to an unchanging environment
    b. evolution leading to a population better adapted to an unchanging environment
    c. very slow and continuous evolution with no increased adaptation
    d. no evolution because the alleles in the population remain the same

5. Over the course of millions of years various environments have changed. As grasslands slowly took the place of forests the inhabitants were forced to adapt or they went extinct. During this time period the horse evolved from a small cat sized creature to the size of the modern horses we see today. This is an example of which type of natural selection?
    a. Directional
    b. Disruptive
    c. Stabilizing
    d. The horse did not undergo any type of Natural Selection during the course of its evolution
    e. The horse has not been on the Earth for millions of years.

6. The biological species concept relies mainly on ___________ to define a species.
    a. Reproductive isolation
    b. Morphological differences
    c. The presence of analogous traits
    d. Comparative biochemical analysis

7. Reproductive isolation
    a. Means there is no gene flow between two groups of organisms (species).
    b. Is necessary for species to remain separate.
    c. Is maintained by certain prezygotic and postzygotic barriers
    d. All of the choices are correct.
    e. None of the choices are correct.

8. In speciation which of the following is mismatched?
    a. allopatric speciation-geographic isolation
    b. sympatric speciation-geographic isolation
    c. adaptive radiation-chance for new species to adapt to new habitats
    d. post-zygotic isolation-hybrid offspring sterility

9. The history of life on Earth can be studied by looking at ____________ instead of __________.
    a. Macroevolution, microevolution
    b. Microevolution, macroevolution
    c. Sexual selection, macroevolution
    d. Gene flow, microevolution

10. Which of the following time periods contains the others?
    a. Cretaceous
    b. Triassic
    c. Jurassic
    d. Mesozoic

11. The first known multicellular organisms evolved approximately how many years ago?
    a. 3.5 BYA
    b. 2.1 BYA
    c. 1.4 BYA
    d. 100 MYA

12. The northern copperhead is *Agkistrodon contortrix contortrix,* the southern copperhead is *Agkistrodon contortrix mokasen*, and the cottonmouth is *Agkistrodon piscivorous*. Therefore,
    a. All are subspecies of *Agkistrodon*.
    b. They are three distinct species.
    c. The copperheads are subspecies and the cottonmouth is a separate species.
    d. They are all the same species.

13. The amino acid sequences in cytochrome c were determined for chickens, ducks, and humans. Scientists found a difference of 3 amino acids between chickens and ducks, but between chickens and humans there were 13 differences. One may conclude that
    a. chickens are as closely related to humans as they are to ducks.
    b. chickens are more closely related to ducks than they are to humans.
    c. chickens are more closely related to humans than they are to ducks.
    d. None of the above.

14. Which of the following best represents analogous structures?
    a. The arm of a human and the wing of a bat.
    b. The arm of a human and the leg of a human.
    c. The wing of a butterfly and the wing of a bee.
    d. The wing of a bat and the wing of a butterfly.

15. Which piece of evidence best supports the endosymbiotic theory of organelle evolution?
    a. Mitochondria and chloroplast are the same size as bacteria.
    b. Mitochondria and chloroplast divide by binary fission.
    c. Mitochondria and chloroplast both contain DNA and some can make their own proteins.
    d. The outer membrane of chloroplast and mitochondria resemble that of a eukaryotic cell while the inner membrane resembles that of a bacterial cell.

16. With the appearance of photosynthetic cyanobacteria and aerobic bacteria during the Precambrian era,
    a. An oxidizing atmosphere developed on Earth.
    b. The formation of the ozone shield occurred.
    c. The amount of UV light reaching the Earth was reduced and chemical evolution slowed.
    d. All of the choices are correct.

17. Which of the following would change the allele frequencies of a population?
    a. DNA is stable from generation to generation and does not change, so allele frequencies do not change.
    b. Tall people in a population preferentially marry other tall people and do not marry people who are short or average height.
    c. A population on an island remains isolated and no one leaves or moves onto the island.
    d. All of the above would change allele frequencies of a population.

18. The most common source of genetic variation in sexually reproducing organisms is
    a. Mutation.
    b. Recombination of alleles through meiosis and fertilization.
    c. Duplication of chromosomes.
    d. Duplication of genes.

19. Which of these conditions is NOT among the requirements of the Hardy-Weinberg equilibrium of allele frequencies in a population?
    a. Small population with genetic drift.
    b. No net migration of alleles into or out of the population.
    c. No net mutations.
    d. No selection of one genotype over another.
    e. Random mating population.

20. Mutations that result in resistance to specific antibiotics in bacterial organisms occur:
    a. Only when the bacteria are exposed to the drug to which they become resistant
    b. More often when the bacteria are exposed to the drug
    c. At any time, even when the bacteria are not exposed to the drug.
    d. Only when the bacteria are exposed to radiation or other mutagens.

21. Variations within a population are maintained by
    a. Mutation
    b. Genetic recombination due to fertilization.
    c. Gene flow.
    d. All the choices are correct.

22. If two adjacent populations of the same species show gene flow, then the two populations will
    a. Become more similar in their gene pools.
    b. Become isolated from each other.
    c. Develop into different species.
    d. Adapt to different conditions and become separate.

23. All the members of a single species that occupy a particular area at the same time are known as a:
    a. Subspecies
    b. Gene pool
    c. Population
    d. Group
    e. Sub-population

24. What is the term used to describe the changes in allele frequency of a population over generations?
    a. Genetic drift.
    b. Founder effect.
    c. Microevolution.
    d. Directional selection.

25. A random alteration in the sequence of DNA nucleotides that provides a new variant allele is:
    a. Gene mutation
    b. Polymorphism
    c. Gene frequency
    d. Disruption

26. While studying gull egg laying abilities a researcher noted that the birds laid an average of 7 - 9 eggs per clutch at the beginning of the study. After studying the population for 15 generations the researcher noted that the birds now laid an average of 3- 4 eggs per clutch. What type of natural selection is occurring in the population of gulls?
    a. Stabilizing
    b. Directional
    c. Disruptive
    d. There is no selection occurring in this population.

27. Why type of selection is occurring in a population if the distribution graph shifts from the left end of the spectrum to the far right end?
    a. Directional
    b. Stabilizing
    c. Disruptive
    d. Populations do not undergo selection, they are fixed.

28. An organism does not necessarily have to ensure that its own genes are passed to the next generation. The adaptation to the environment due to the reproductive success of an organism's relatives is
    a. Altruism
    b. Kin selection
    c. Natural selection
    d. Direct selection

29. Learned behavior that causes a family of baby ducks to follow their mother is called
    a. Imprinting
    b. Operant conditioning
    c. Insight learning
    d. Extinction
    e. Motivation

30. Hippopotamuses perform territorial displays that include mouth opening. This is _____ communication.
    a. Auditory
    b. Visual
    c. Chemical
    d. Tactile

31. An ecosystem contains
    a. only the biotic components of the local environment.
    b. only the abiotic components of the local environment.

c. only the energy flow components of an local environment.
d. both the biotic and the abiotic components of the local environment.

32. Energy flow in an ecosystem begins with
    a. Omnivores
    b. Herbivores
    c. Autotrophs
    d. Carnivores

33. Approximately what percentage of the energy in one trophic level is incorporated into the next trophic level?
    a. 1%
    b. 10%
    c. 30%
    d. 60%
    e. 100%

34. In a grazing food chain,
    a. Primary consumers eat detritus.
    b. Primary consumers eat photosynthetic organisms
    c. Secondary consumers eat detritus
    d. Secondary consumers eat photosynthetic organisms.

35. Which of the following statement(s) about the hydrologic cycle is (are) true?
    a. Because this is a true cycle, it is impossible to run out of fresh water for human use.
    b. All water molecules that evaporate from the ocean precipitate on land and move by gravity through groundwater to the ocean again.
    c. Some water evaporates from land and from plants.
    d. Once water sinks into the ground, it is safe from human exploitation or pollution until it has rejoined the ocean.

36. Incoming solar radiation affects
    a. The rise and fall of air masses.
    b. Evaporation or precipitation of moisture.
    c. The seasons.
    d. All of these choices are directly or indirectly affected by solar radiation.

37. If the Earth was standing still (not rotating) and was a solid, uniform ball, wind directions would
    a. Cease
    b. Run north and south
    c. Run east and west

d. Remain the same since the Earth's rotation does not affect wind directions.

38. Which region of the Earth receives the least amount of solar radiation during the Winter solstice?
    a. Northern Hemisphere
    b. Southern Hemisphere
    c. Equatorial regions
    d. Between 30^0 North and 30^0 South
    e. All of the Earth's regions receive the same amount of solar radiation during the Winter solstice.

39. Which of the following does NOT characterize the tundra?
    a. Permafrost
    b. Trees
    c. Shrub
    d. Caribou

40. In what order do these layers occur in deep lakes in the temperate zone? From the surface to the bottom of the lake, one would find the
    a. epilimnion - thermocline - hypolimnion.
    b. thermocline - epilimnion - hypolimnion.
    c. hypolimnion - epilimnion - thermocline.
    d. epilimnion - hypolimnion - thermocline.

41. Which of the following statements about keystone species is NOT true?
    a. The extinction of keystone species can lead to other extinctions and a loss of biodiversity.
    b. Keystone species are defined as a population subdivided into several small isolated populations due to habitat fragmentation.
    c. Examples of keystone species are grizzly bears, bats, beavers and alligators.
    d. The numbers of individuals in the keystone species in their respective community may or may not be excessively high.

42. Which of the following statements about biological diversity is NOT true?
    a. Scientists estimate that 10-50 million species exist.
    b. Biodiversity is described in terms of genetic, community, and landscape diversity.
    c. Biodiversity refers to the variety of life on Earth.
    d. Biodiversity is evenly distributed throughout the biosphere.
    e. Many species that are in danger of extinction have not been identified and studied.

43. Rosy periwinkle, the nine-banded armadillo, and some species of fungus and bacteria have __________ value to man.
    a. Agricultural
    b. Medicinal
    c. Consumptive use
    d. Indirect
    e. No

44. As "civilization" spread around the world, several species benefitted greatly from new human-made habitats, including the house fly, the Norwegian rat, and many crop plants. Generally, with expansion of human populations and agriculture,
    a. there has been an increase in biological diversity.
    b. biological diversity has remained the same, with human-associated organisms replacing the few natural species displaced.
    c. biological diversity has decreased but mainly with the elimination of pests by humans.
    d. biological diversity is decreasing at an accelerating rate with the elimination of many unstudied species.

45. Which of the following are characteristics of a keystone species?
    a. They influence the diversity of the community.
    b. They evoke an emotional response in people.
    c. They have a very large population.
    d. They are always mammals.
    e. None of these are characteristics of keystone species.

46. What is the main reason for the changes that are occurring in the Earth's climate?
    a. Large scale deforestation.
    b. Disruption of the waste recycling by decomposers.
    c. Over harvesting of wild species for consumptive value
    d. Drainage of wetlands producing a disruption of water purification.
    e. An increase in soil erosion leading to siltation of rivers and estuaries.

47. Approximately what % of the known biodiversity on Earth is composed of plants?
    a. 18-20%
    b. 50-55%
    c. 12-15%
    d. 63-65%
    e. 6-8%

48. Identify the correct sequence that freshwater will flow through.
    a. clouds - streams - river - wetlands - delta – ocean
    b. clouds - river - stream - delta - wetlands – ocean

c. ocean - clouds - stream - estuary – river
d. cloud - river - stream - delta - marsh – ocean
e. ocean - delta - estuary - river - stream – marsh

49. Kansas and Pennsylvania are approximately at the same latitude. Yet why are the potential natural communities in Kansas mostly grassland and in Pennsylvania mostly temperate forest?
    a. Different temperatures
    b. Different levels of moisture
    c. Different soil texture and pH levels
    d. Different vegetation due to different seed banks

50. Compared with the numbers of grasshoppers or deer, there are not a lot of mountain lions. The reason that large and fierce top-level carnivores are rare in an ecosystem is that
    a. Such animals do not tolerate other members like them.
    b. Through natural selection, most fierce animals have been killed off by others.
    c. Food chains are only 10 to 20% efficient at each step, and top carnivores are therefore limited by the availability of food in their range.
    d. Only a few such animals are permitted by succession in a biome, and there are only a few biomes.

APPENDIX D

LAB EXAMPLES

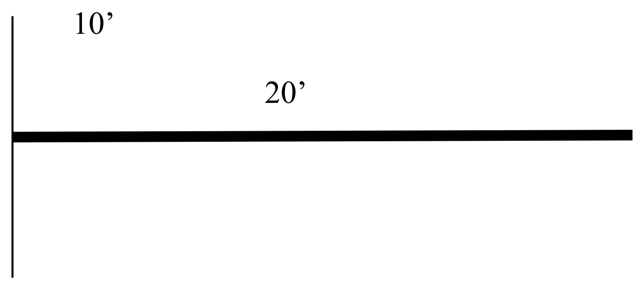
Ecology Observations Lab with Polymer Clay Critters

Lab Instructions

With this lab, we are looking into a couple of ideas. The first: what is the world outside your door like? What observations about a relatively small area can you make—for instance, what insects, plants, or birds do you notice routinely? Can we quantify this area? The second: what biology is happening in the world outside your door? What observations about predators and prey can you make—in this case, can you observe a bird going after a caterpillar? Why would a scientist want to make observations along a transect rather than a general survey? These are the ideas we'll be thinking about during this laboratory.

The lab is involved, so you'll want to plan accordingly. First, select an area that does not get a lot of foot traffic. Second, make some observations of the area. Third, gather your supplies. You'll need: a notebook or Word file for tracking your observations, a measuring tape, a 12" x 12" square (I make one out of PVC but you can lay two rulers at right angles), cardboard, superglue, dress pins, and a selection of polymer clay creatures from last week's lab. If you are living in an apartment complex, you will need to get creative—or email me for an alternative assignment if all else fails ☺ If you have balcony/porch/small private outside access we can simply shorten your transect.

1. Decide on your area of transect. You will need a space approximately 20' long and 10' wide where you can leave your polymer creatures for about 12 days.
2. Measure out your transect and take a picture of your area.
3. Beginning at one end of your transect, lay out a 10' line perpendicular to the 20' transect. See the diagram below.



4. After you lay out the beginning transect, take a 12" x 12" square and randomly place it along the 10' line. Record what is in the square: percent of each vegetation type, count any insects or other animal. Record weather data (estimate cloud cover, temperature, precipitation). Record your general observations about the area (are you near a water source? Are you near a road? These observations are important to ecologists).
5. Repeat step 4 two more times along the first 10' line (so 3x for the 10' line total).
6. Move the 10' line down the 20' line by 5'.

7. Repeat steps 4-6 until you have reached the end of the transect.
8. After you've recorded this "baseline" data, place your creatures along the transect. Super glue them to a piece of cardboard and secure the cardboard to the ground (use dress pins) so a bird or other predator can't carry the polymer creature off.
9. Make a prediction about what you expect to find. Write it down on your lab notebook page. What data will you need to collect to test your prediction? For instance, if you are near a pond, you might predict that a raccoon will investigate the clay creatures. The data you would need to support that prediction would be evidence of a raccoon, such as tracks, bite marks, or scat.
10. Return every 3 days and record any damage to the polymer clay creatures. Take pictures!
11. After 12 days, repeat the transect line data collection. This means you'll need to repeat steps 3-7.

    This experiment will be due in mid-April. Do not delay starting! Once you have the general idea down, the collection of data will go quickly. Email me if you have questions: Beverly.ranney@newmoodle.wosc.edu

Water Pollution Lab

Nonpoint source pollution (NPS pollution)is the largest source of water pollution. NPS pollution is typically related to land use activities such as agriculture, urban areas, mining, forestry, and construction activities and occurs when pollutants are carried into waterways. Prevention of NPS pollution begins with understanding how our activities impact the quality of air, land, and water.

1. What is a watershed?

   In this activity, I want you to gain a hands-on understanding of what a watershed is, what influences a watershed, predict water flow patterns in the watershed model you create, and observe drainage patterns.

   When precipitation occurs, water can flow over land as runoff and collect in channels (streams, canals, ditches, etc). A watershed is the land area that drains water. Eventually, water collects into streams that feed into rivers which feed into lakes or oceans. If you had a birds-eye view of the land, watersheds resemble branching tree patterns. If you have flown over Oklahoma, it can be difficult to see the watersheds because you are on the Great Plains but look for channels that feed into bigger rivers, which in turn eventually feed into lakes or reservoirs, or the Mississippi River. The Arkansas and Canadian Rivers eventually feed into the Mississippi River, which empties into the Gulf of Mexico.

   Gather a piece of paper , five water-based markers (such as Crayola markers), a pan or sink and a spray bottle filled with water.

   Crumple up your paper. Leave a few ridges but otherwise smooth out the paper. Use your markers to color along the creases of the paper. Set up a system to have one color code for fertilizers, one for pesticides, one for waste from livestock, and one for litter. If you have an additional pollutant you'd like to include, do so. Put the now-colored paper in the pan or sink and shape it so it follows a topography with a slight rise. You need some hills and valleys—even in Oklahoma, the ground is not totally flat! Think of Quartz Mountain or the Wichita Mountains in the distance. Predict where your NPS pollutants will go (write those predictions down). Take a picture of your set-up to include in your write-up. Let it rain on your watershed! Spray your paper and observe where the pollutants head. What happened and why? What does this suggest to you about the importance of solubility of a pollutant for water quality? Would it be easier to remove non-soluble pollutants from the water and do we do that?

This is a very basic hands-on approach that asks you to think about pollutants in the area. It would be great to send you out into the environment with a water testing kit but that is cost prohibitive. The next experiment is to get you thinking about fertilizer use and our natural water sources. Remember, humans are not the only ones relying on water!

2. Fertilizer run-off

   In this activity, I want you to observe the effects of fertilizer on algae growth. **This activity requires advance preparation on your part.** Here's what you need: 6 clear containers (such as empty water or soda bottles), surface water (so find water in a local pond or river, it cannot come from the tap, enough to fill all the containers ¾ of the way full), fertilizer (you can use granular or liquid but you need approximately 6 tablespoons worth), a sunny window or grow light, a permanent marker (to label your containers), and a way to measure how much fertilizer you add.

   Now that you have gathered your supplies, label your containers. Set up an experiment with the pond water and different concentrations of fertilizers. Predict which will have the most algae growth. All containers must be in a warm, well-lit or sunny location. Be sure you have one container with no added fertilizer (this is your control). Add different amounts of fertilizer to your containers and record what happens over the course of a week. Take these pictures of your setup, initial, after 3 days, and at 7 days to include in your summary report. Email me if you have questions.

   The lab report is due March 4.

Understanding Populations

Population Growth – Exponential and Logistic Models vs. Complex Reality

By Dr. Ingrid Waldron, Dept. Biology, University of Pennsylvania, © 2011. This Student Handout, the Teacher Notes, and an alternative version without equations are available at http://serendip.brynmawr.edu/exchange/bioactivities/pop

I. Exponential Population Growth

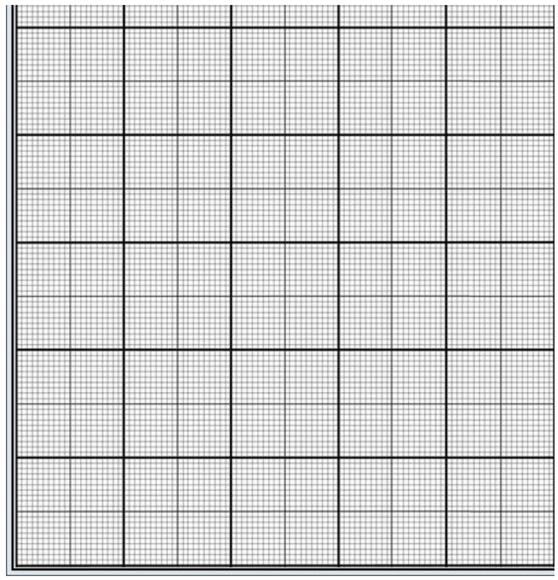
1a. Suppose a single bacterium is placed in a flask that contains lots of food for bacteria. In this flask, each bacterium grows and divides in two every 30 minutes. Therefore, the number of bacteria in the population doubles every 30 minutes. How many bacteria do you think there will be by 5 hours after the single bacterium is placed in the flask (just guessing)? _______

1b. Complete the table to calculate how many bacteria there will be at each time.

1	bacterium at the beginning = 0 minutes
	bacteria by 30 minutes
	bacteria by 1 hour
	bacteria by 1 hour and 30 minutes
	bacteria by 2 hours
	bacteria by 2 hours and 30 minutes
	bacteria by 3 hours
	bacteria by 3 hours and 30 minutes
	bacteria by 4 hours
	bacteria by 4 hours and 30 minutes
	bacteria by 5 hours

2. Plot the number of bacteria at each time; connect the points to show the population growth.

Number of Bacteria


Time (hours)

3a. How long would it take for the population of bacteria to increase from 1 bacterium to 500 bacteria?

3b. How long would it take for the population to increase from 500 bacteria to 1000 bacteria?

Notice that, when a population doubles in each time interval, the number of bacteria in the population increases faster and faster as the population gets larger. This kind of population growth is called <u>exponential population growth</u>.

4. For these bacteria, population growth can be represented by the mathematical equation:

$\Delta N = N$, where

- N is the number of bacteria at the beginning of a 30-minute time interval
- ΔN (pronounced delta N) is the change in the number of bacteria from the beginning to the end of the 30-minute time interval

Explain the biological reason why ΔN in a 30-minute interval is equal to N at the beginning of the 30-minute interval.

5. A female cottontail rabbit begins reproducing by one year of age and typically has 3-4 litters of 4-5 baby rabbits each year. A cottontail rabbit can live up to eight years in captivity. If a population begins with a pair of breeding adults, and the rabbits have maximum reproduction and survival, how many rabbits do you think there would be after six years (just guessing, without calculating)?

6. Calculate rabbit population growth over the first six years, based on these assumptions:

- The population starts with 1 female rabbit and 1 male rabbit, both born in the previous year.
- Each year has a breeding season, and each baby rabbit born in the previous year matures to become a breeding adult by the beginning of the next breeding season. Therefore,

  N (the number of rabbits in the population at the beginning of a year)

  = the number of breeding adults for the year.

- Each rabbit lives for eight years (maximum survival due to abundant food and no predation or disease), so there will be no deaths during the first six years.
- Once a female begins breeding, she produces 20 baby rabbits each year for the rest of her life. Half of the babies are female, so half of the population is female.
- Therefore, ΔN (the change in the number of rabbits from the beginning of the year to the end of the year) = the number of baby rabbits born that year = ½N * 20 = 10N.

  In other words, the increase in the number of rabbits each year equals the number of breeding females times the number of baby rabbits each female has in a year.
- N + ΔN at the end of a year will equal N at the beginning of the next year.

6a. Complete the following table.

Year	# Breeding Adults for this year = N	# Baby Rabbits produced during the breeding season = ΔN	Total # Rabbits at the end of the year = N + ΔN
1	2		
2			
3			
4			
5			
6			

6b. How close was your guess to the calculated number of rabbits by six years?

6c. Explain the biological reason why ΔN (the number of baby rabbits produced during the breeding season) is smallest in the first year and bigger in each successive year.

As the size of the rabbit population increases, there is a proportionate increase in the growth of the rabbit population; thus, the rabbit population shows exponential growth. The enormous potential for exponential growth of rabbit populations is illustrated by the experience in Australia where 24 wild rabbits released in 1859 resulted in a population of more than half a billion rabbits by the 1920s!

Notice that, even though rabbits reproduce sexually and bacteria reproduce by cell division, both populations show exponential population growth. The general equation for exponential population growth is:

$\Delta N = R\,N$, where

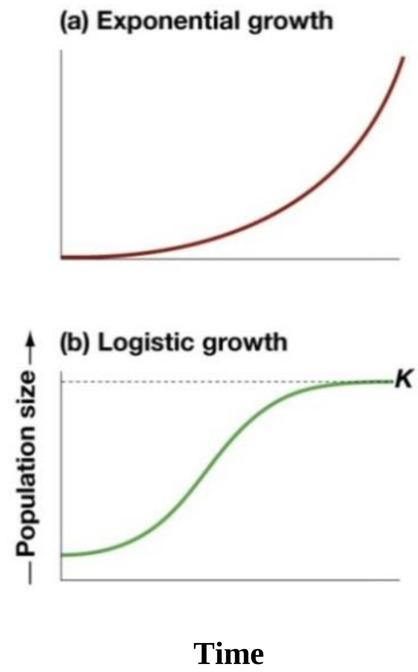
- ΔN is the change in number in the population from the beginning to the end of a time interval
- N is the number in the population at the beginning of the time interval
- R is the per capita rate of change in the size of the population

7a. The equation shown above can be thought of as one type of model of exponential population growth, and the graph (on page 1) can be thought of as another type of model of exponential population growth. Comparing these two types of models, what is one advantage of a graph as a model of exponential population growth?

7b. What is one advantage of the equation as a model of exponential population growth? (Hint: Think about how you calculated the expected number of rabbits after six years.)

8. Extrapolating the exponential population growth of rabbits raises the question: Why isn't the world completely covered in rabbits? Which of the assumptions in question 6 do you think are probably not true for most rabbit populations? Which of these assumptions are probably increasingly unrealistic as population size increases?

II. Logistic Population Growth



Exponential population growth cannot continue forever, since all organisms require resources to grow and reproduce, and the environment where a population is growing has a limited supply of resources (e.g. a limited supply of food or water). As a population gets larger, there is increasing competition for resources. This results in decreased reproduction and/or increased mortality, so the rate of population growth slows down. Eventually, the population will reach a maximum size which is called the carrying capacity of the environment; the carrying capacity depends on the amount of resources available in the environment. The second figure illustrates this type of logistic population growth with a carrying capacity = K.

This table shows the equations for the exponential and logistic models of population growth.

Exponential population growth	Logistic population growth
$\Delta N = R\,N$ where • ΔN is the change in the number of individuals from the beginning to the end of a time interval • N is the number of individuals at the beginning of the time interval • R is the per capita rate of change in the size of the population	$\Delta N = R\,N \dfrac{(K - N)}{K}$ where • ΔN, N and R are the same as for exponential growth • K = the carrying capacity of the environment

9. Complete the following table.

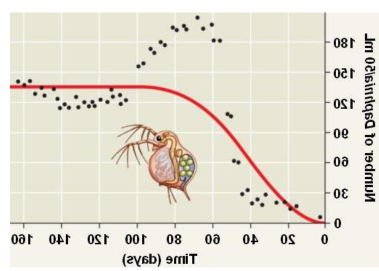
Explain why logistic population growth:	Provide an explanation based on the equations for exponential and logistic population growth.	Provide a biological explanation.
– Looks like exponential population growth when N is small.		
– Slows to 0 as N gets close to K.		
– Is more rapid when N = 0.5 K and slower when N = 0.1K or N = 0.9K		

III. Mathematical Models vs. Complex Reality

In order to make a manageable mathematical model, scientists need to make some simplifying assumptions. Often these simplifying assumptions are not accurate for real populations. If the simplifying assumptions are not accurate for the population being studied, then the model will produce predictions that differ from actual trends in population size. These points are illustrated in this table and the examples that follow.

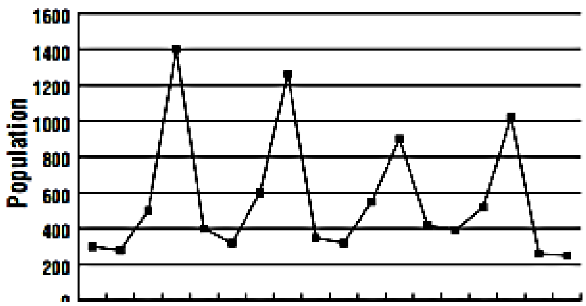
	Exponential Population Growth Model	Logistic Population Growth Model
Simplifying assumptions	• The per capita rate of change in population size is constant; this depends on abundant resources for the growing population.	• Carrying capacity is constant. • As population size approaches carrying capacity, mortality increases and/or birth rates decrease so population growth slows promptly and the population does not exceed the carrying capacity.
Situations in which these simplifying assumptions tend to be accurate	• When a species moves into a new environment • After a population has been drastically reduced (e.g. by severe weather or human hunting)	• Often begins when a species moves into a new environment or after a population has been drastically reduced; followed by slowing population growth in a stable environment
What happens when the simplifying assumptions are not accurate	• May see logistic population growth	• Changes in carrying capacity can cause corresponding changes in population size. • If the population grows beyond the carrying capacity, then population size must eventually decrease. If the population is too big, it can damage the environment and reduce carrying capacity.

10a. This figure shows the changes in population size for a laboratory population of Daphnia (water fleas) that had a constant supply of food. Why did the trends in population size differ from an exponential growth curve?



10b. What do you think is the reason that the trends in population size differed from the logistic population growth curve? (Hint: Think about which of the simplifying assumptions for the logistic population growth model was probably not valid for this population.)

11a. This question includes two examples of exceptions to the assumption that carrying capacity is constant. First, explain how seasonal changes in carrying capacity can account for the annual cycles in population size observed for this population of cottontail rabbits in Ohio.



Jan A J O Jan A J O Jan A J O Jan A J O

(A = April; J = July; O = October)

11b. When wolves recolonized a national park in Canada, this resulted in increased carrying capacity for songbirds. Researchers compared two areas in the park: an area around a town which wolves avoided vs. an adjacent area with many wolves. The researchers found that the area with many wolves had:

- greater mortality for elk and lower elk population density
- lower consumption of willow leaves and branches, so the willows grew more
- greater abundance and diversity of songbirds.

Use these research results to suggest a hypothesis to explain how wolves influenced the carrying capacity for songbirds.

12a. Some of the factors that influence changes in population size have **density-dependent** effects – that is, the effects of these factors increase as population density increases (population density is the number of individuals per area of land or volume of water). Name some the factors we have considered that have density-dependent effects.

12b. Does the exponential model include density-dependent effects? ___ yes ___ no

Does the logistic model include density-dependent effects? ___ yes ___ no

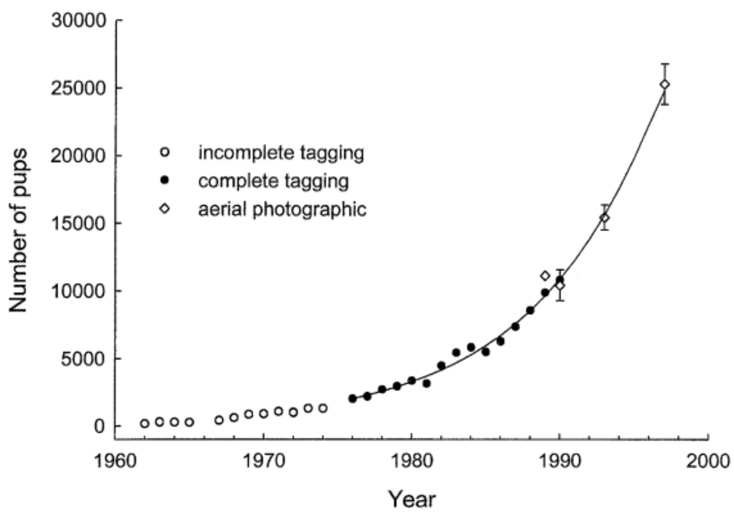
Explain your reasoning.

12c. Some factors have **density-independent** effects on changes in population size. For example, freezing weather, tornadoes, floods and fires can drastically reduce population size, independent of initial population density. These types of density-independent effects are not included in the exponential or the logistic population growth models, so these models do not accurately predict changes in population size for a population that is strongly influenced by density-independent effects. Give an example to illustrate this.

13. For each of the following graphs:

- State whether the changes in population size shown in the graph follow:
  - the exponential population growth model
  - the logistic population growth model
  - a different pattern of population growth.
- Give a biological explanation for the observed changes in population size; include any effects that may have resulted from changes in carrying capacity.

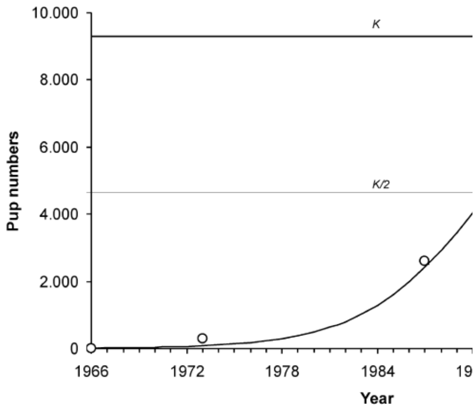
13a. This figure shows the growth of a population of gray seals on a Canadian island; this population was recovering from a drastic reduction in population size due to human hunting. (Number of pups is an index of total population size; the different symbols represent the scientists' different methods of estimating the number of pups; from Bowen et al., ICES Journal of Marine Science 60:1265-74, 2003.)



Which model:

Biological explanation:

13b. This figure shows the growth of a population of Antarctic fur seals on islands near Antarctica; this population was also recovering from a drastic reduction in population size due to human hunting. (Number of pups as an index of total population size; K = carrying capacity; from Hucke-Gaete et al., Polar Biology 27: 304-311, 2004.)

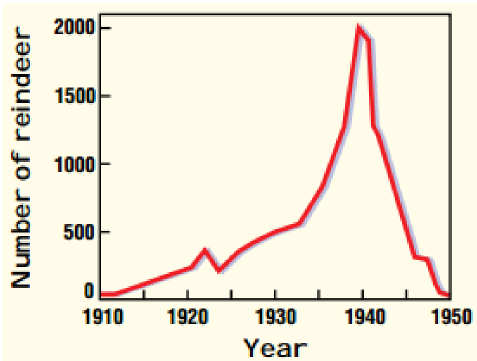


Biological explanation:

Which model:

13c. What is one hypothesis that could account for the difference in the population growth curves for these two populations of seals?

13d. This figure shows changes in the size of a population that began with 25 reindeer on an island off the coast of Alaska. Initially, food was plentiful, but after several decades the large population of reindeer had drastically reduced the amount of lichen (which the reindeer depend on for winter food).
http://go.hrw.com/resources/go_sc/bpe/HE0PE332.PDF



Which model:

Biological explanation:

14. Complete the following table to summarize an advantage and a disadvantage for the exponential population growth model and for the logistic population growth model.

	Exponential Population Growth Model	Logistic Population Growth Model

One useful insight from this population growth model		
One reason why observed changes in population size often differ from the trends predicted by this model		

Evolution I Lab

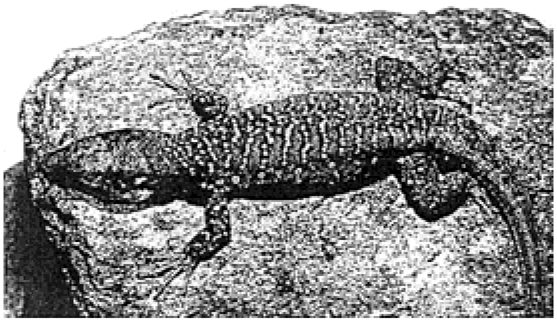
This week your lab looks at evolution. You will need a ruler, scissors, and tape, plus a clear work space. Since you are working on your own, and not in a team of four, I suggest that you pace yourself and do the work that would have been given to each team member at a separate mini-session, rather than trying to plow through the lab all at once. Just stay organized! Email me with questions.

ISLAND BIOGEOGRAPHY AND EVOLUTION: SOLVING A PHYLOGENETIC PUZZLE WITH MOLECULAR GENETICS

INTRODUCTION

Ever since Charles Darwin (hyperlink) formulated his hypothesis on how the finches of the Galapagos Islands evolved into 13 species, islands have been a prime target for the study of evolution. By their very nature, islands are isolated and are essentially a living laboratory of evolution. In this investigation, you should be familiar with the terms speciation, geographic isolation, gene flow, gene pool, and reproductive isolation. You will work with real data from real populations. The data will include observations of lizard morphology (body form), geological age estimates of various islands in the Canary Island Archipelago, geographic distances, and genetic distances based on nucleotide base differences in DNA between different populations of lizards.

Figure 1. Lizard, *Gallotia galloti* from Tenerife Island. (from Thorpe et al., 1989)

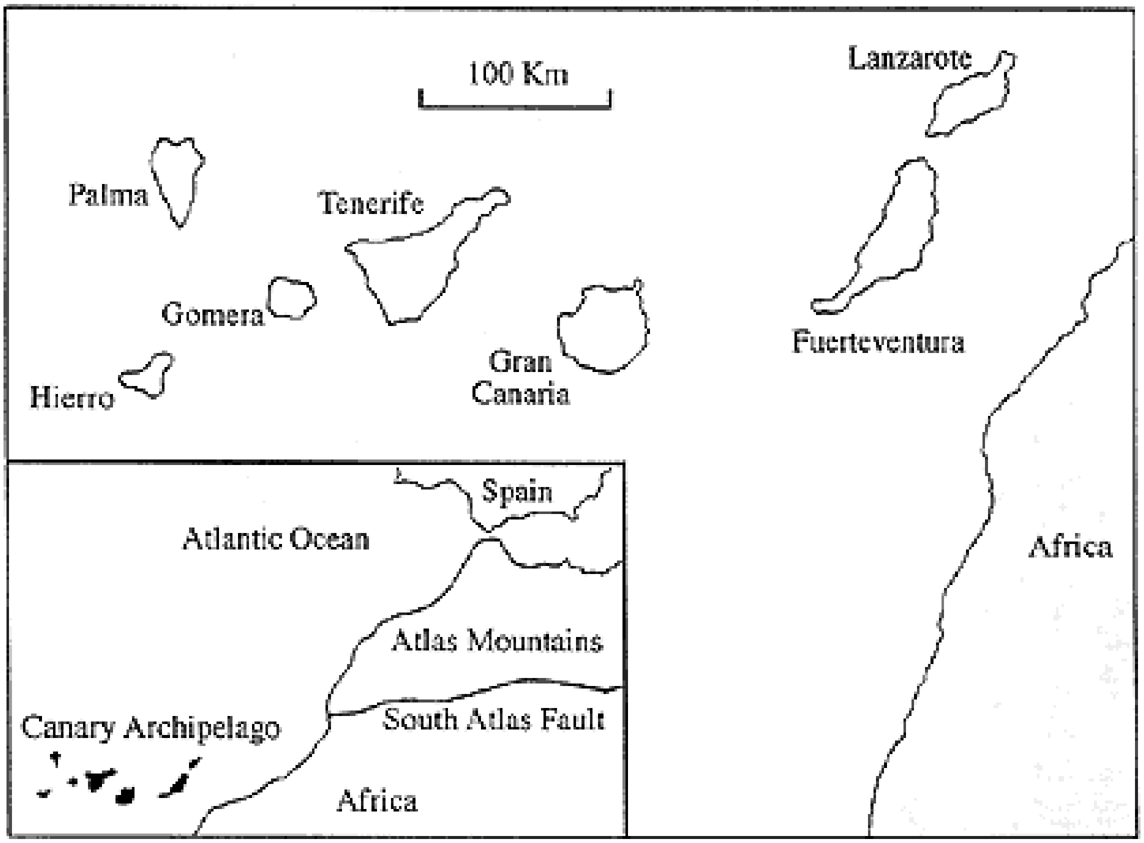


Background — Figure 1 (left) illustrates one of the many populations of lizards living on the Canary Islands. The Canary Islands form an archipelago of seven volcanic islands just west of the African continent (Map 1). The island chain starts about 85 km (50 miles) west of the continent, following a fault line of the Atlas Mountains in northern Africa. Geologists theorize that a geologic hot spot of upwelling magma has been drifting westward for the past 20 million years, gradually forming the islands as it moves. Thus the most eastern island, Lanzarote, is oldest, while the smaller western island, Hierro, is the youngest, about 0.8 million years old. Volcanic islands are particularly good laboratories for evolutionary science because they can be dated accurately using radioactive isotope decay and because they start out as lifeless masses of rock emerging from the sea.

The development of ecosystems on volcanic islands is somewhat unpredictable. However, ecological succession does occur first with pioneer organisms that gradually alter the environment until a stable climax community is established. What is unpredictable is what plant and animal species will colonize these new environments. Much of this is left to climate, proximity to other land masses, and of course, chance. This investigation deals with three species of lizards of the genus *Gallotia*, and within one of these species, *Gallotia galloti*, four separate island populations. The arrival of the *Gallotia* lizards was probably by rafting (SeeMap 1). Rafts of natural vegetation are often washed out to sea when high river levels cause river banks to collapse, carrying away both plants and clinging animals. Oceanic currents in this region vary with the seasons. Colonization by airborne organisms, such as insects and birds, usually occurs during storms. In any case, there are some general principles of island colonization:

1) The closer the island to another land mass, the higher the probability of colonization.
2) The older the island, the more likely it will be colonized.
3) The larger the island, the more species are likely to be established.
4) Geographic isolation reduces gene flow between populations.
5) Over time, colonial populations become genetically divergent from their parent population due to natural selection, mutation, and/or genetic drift.

Map 1. The Canary Islands Archipelago. (redrawn from Anguita et al., 1986)



Problem — Evolution biologists have been faced with an interesting problem. What is the phylogenetic history of the three species and seven populations of *Gallotia* lizards on the Canary Islands? Does the presence of four morphologically different populations of *G. galloti*on the four westernmost islands (Map 2) imply continuing evolution? In this investigation, you will use data from geography, geological history, morphology (body size), and molecular genetics to develop answers to these questions.

PART I: PHYLOGENY BASED ON GEOGRAPHIC DISTANCE

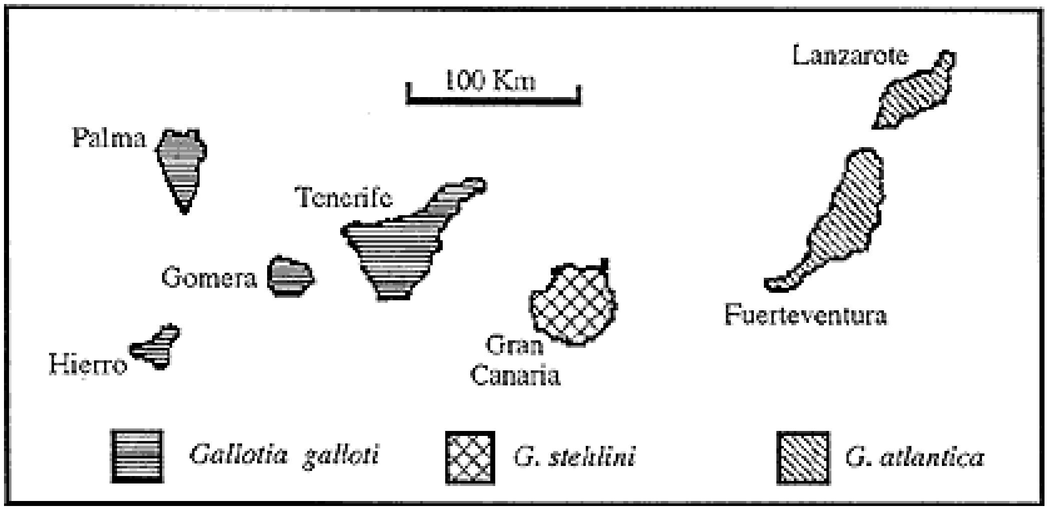
Procedure — Using Map 1measure the distance in kilometers of each island to the mainland (Africa). List these distances on a separate page. Include the following islands: Lanzarote, Fuerteventura, Gran Canaria, Tenerife, Gomera, Palma, and Hierro.

1) Which island is most likely to have been colonized first and which last? Tell why you think so.

2) Using Map 2 and your geographic reasoning, draw on a separate page a hypothetical phylogenetic (family) tree of the three species and the three additional populations of *G. galloti*. Label your end branches with the following population names:

atlantica *stehlini* *galloti* Tenerife *galloti* Palma *galloti* Gomera *galloti* Hierro

Map 2. Distribution of *Gallotia atlantica*, *G. stehlini*, and *G. galloti*. *G. galloti* has colonized the four westernmost islands and each population is morphologically distinct from the others. (redrawn from Thorpe et al., 1993)



PART II: PHYLOGENY BASED ON GEOLOGICAL HISTORY

Check your hypothetical phylogenetic tree against the geological data in Table 1.

The maximum age of each island was estimated by sampling volcanic rocks found on all islands. The ratio of radioactive potassium to its breakdown product, argon, was used to estimate the age of the rocks.

Table 1. Maximum age of the Canary Islands in millions of years. (Anguita et al., 1986)

Lanzarote & Fuerteventura	Gran Canaria	Tenerife	Gomera	Palma	Hierro
24.0	17.1	15.1	5.3	2.0	0.8

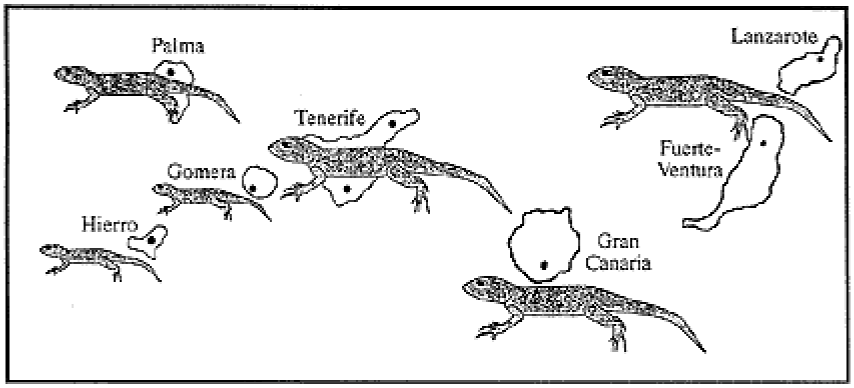
1) Explain how the data in Table 1 (above) support your phylogeny diagram? Or what changes should you make and why?

PART III: PHYLOGENY BASED ON MORPHOLOGY

Study the drawings from each lizard population in Figure 2 below. Compare and contrast their body size with the distribution on Map 2. To be sure differences were genetic, not environmental, researchers collected individuals from all island populations and bred and raised them in captivity. Their offspring still displayed differences according to their parental characteristics. Draw a new phylogeny chart based on morphological similarities and differences.

Compare your two phylogeny charts. Describe how they are different.

Figure 2. The relative sizes of typical lizards from each population are shown. (Redrawn from Thorpe et al., 1994.)



PART IV: PHYLOGENY BASED ON MOLECULAR GENETICS

Recent studies by Thorpe & Baez (1993) and Thorpe et al. (1994) have attempted to support various phylogenetic hypotheses by comparing genetic differences among the populations of the *Gallotia* lizards on the Canary Islands. The gene for cytochrome b, which is coded by DNA found in every cell's mitochondria, was used in this study along with DNA from other genes. Cytochrome b is an important substance for cell metabolism and has probably been around since the first prokaryotes. Changes in its nucleotide base sequence (A, T, C, and G) that do not disrupt the gene's function provide us with a kind of evolutionary clock. The rate of mutational changes due to pairing errors is relatively constant. The chances for such mutations are the same for any of these bases. This means that the more time, the more changes. When two populations are isolated and gene flow between them is restricted, the mutational differences accumulate over time. The longer the isolation the greater the difference.

Thorpe and his colleagues used restriction enzymes to cut the DNA, and gel electrophoresis to separate the fragments. Radioisotope tagging eventually led to the sequencing of the samples of DNA for each of the seven populations. Thorpe tested two populations on Tenerife to see if ecological differences were part of the story. He felt that because Tenerife is moist and lush in the north while arid and barren in the south, populations on that island might have some genetic differences. Also, he wondered if Tenerife was supplying colonizing lizards from two different directions. The results for Thorpe's tests appear on the last two pages of this investigation.

Your task is to count the differences between all pairings of the seven populations and use that data to construct a final phylogenetic tree based on genetic similarities and differences.

Procedure — There are 21 different pair combinations possible using seven populations. You should work in a team of four. Each person will be responsible for counting all of the base differences for five of the 21 pairs (see chart below). The pairings are listed on Table 2(download a pdf version). Note that the first pairing has been counted for you. Record your results in Table 2. When all teams are done, the data will be checked for agreement. The easiest way to make accurate counts is to cut the paper into four strips and tape them end to end in the correct order, A to D. You will then compare pairs of strips side by side to count the differences.

There are 21 possible pairings, each team member selects five pairings other than 1/2.

Student #1	Student #2	Student #3	Student #4
1/3	1/4	1/5	1/6
1/7	2/3	2/4	2/5
2/6	2/7	3/4	3/5
3/6	3/7	4/5	4/6
4/7	5/6	5/7	6/7

INTERPRETATIONS AND CONCLUSIONS

Use the data from Table 2 to guide you in redrawing your phylogenetic tree of the *Gallotia*lizards of the Canary Islands using both geographic and genetic information. Consider the two populations on Tenerife as a single population so that the phylogenetic tree contains six populations.

Low numbers express more genetic similarity and imply more recent common ancestry. Pairs with high numbers are said to have greater genetic distance between them. In other words, large numbers imply they are less genetically alike, have more distant ancestry, and have been separated longer. On a phylogenetic tree, early ancestry is expressed by low branches while more recently evolved are on the higher branches. Branches that are far apart imply greater genetic distance.

Table 2. Cytochrome b DNA sequence differences for the seven populations of *Gallotia*.

	1. *G. stehlini*	2. *G. atlantica*	3. *G. galloti* Palma	4. *G. galloti* N. Tenerife	5. *G. galloti* S.Tenerife	6. *G. galloti* Gomera	7. *G. galloti* Hierro
1. *G. stehlini*							
2. *G. atlantica*	36						
3. *G. galloti* Palma							
4. *G. galloti* N.Tenerife							
5. *G. galloti* S.Tenerife							
6. *G. galloti* Gomera							
7. *G. galloti* Hierro							

1) In Table 2, large numbers imply that pairs of populations are less related. Why is this?
2) Among the six populations, there are three species. How many base pair differences is the minimum to separate any two species of these lizards? (Remember, don't confuse populations with species.) Give an example to support your answer.
3) Which two populations are most closely related? Justify your answer.
4) Why should you expect the populations S. Tenerife (ST) and N. Tenerife (NT) to have fewer differences than other pairings?
5) Which population is least related to the rest? Why do you say so?
Refer to your last phylogeny chart using genetic similarities and differences found in Table 2. Compare it to the phylogeny chart you drew based on the geographic distances and geologic age of the islands.
6) What difference is there between the two phylogenies?
7) Which species, *G. stehlini* or *G. atlantica*, is the ancestor of the other? Explain your reasoning.
8) Predict what is likely to happen to the four populations of *G. galloti* on the four westernmost islands. State what conditions will support this prediction.

Table 3. Base-pair sequences from the mitochondrial genome for **cytochrome b** of *Gallotia* species and populations. Island codes in parentheses are P = Palma, NT = north Tenerife, ST = south Tenerife, G = gomera, and H = Hierro. Each sequence consists of four lines, eg., 1a+1b+1c+1d is the sequence for *Gallotia stehlini*.. (data from Thorpe et al., 1994).

1a *G. stehlini*--------TCACT TCTAG GACTC TGCCT AATCA TTCAA ATCAT CACAG GCCTC TTCCT AGCCA TGCAC TACAA
2a *G. atlantica*-------..... ....T ....T. .... T.... ....A ...T. ...A. ....
3a *G. galloti (P)*-----..... ....T ....T. .C... ..... T.... ....A ...T. G..A. .A... .....
4a *G. galloti (NT)*----..... ....T ....T. .... T.... ....A ...T. G..A. .A... .....
5a *G. galloti (ST)*----..... ....T ....T. .C... ..... T.... ....A ...T. G..A. ....
6a *G. galloti (G)*-----..... ....T ....T. .C... ..... T.... ....A ...T. G..A. ....
7a *G. galloti (H)*-----..... ....T ....T. .C... ..... T.... ....A ...T. G..A. ....
1b ***cont.*** CGCAG ACATT AACTC CGCAT TCTCA TCCAT TGCCC ACATC CACCG TGATG TCCAA CACGG ATGAC TCATT CGCAA
2b ***cont.*** .... .T... ..T.. T.... .T..C ..A..
3b ***cont.*** ....C .... C.... ....T ..T.. ...C. .... T.... .A..C ..A..
4b ***cont***. ....C .... C.... ....T ..T.. ...C. .... T.... .T... ..A..
5b ***cont.*** ....C .... C.... ....T ....C. .... T.... .T..C ..A..
6b ***cont.*** ....C .... C.... ....C. .... T..G. .T..C ..A..
7b ***cont.*** ....C .... C.... ....T ....C. .... T..G. .T..C ..A.. **1c** ***cont.*** TGTCC ACGCC AACGG CGCTT CACTA TTCTT CATCT GCATC TACGC GCATA TCGGA CGTGG CCTGT ATTAC GGCTC
2c ***cont.*** .A... .... A..C. ....T.. T.... ....AT ...C. .T... .... .C... .....
3c ***cont.*** .A... .... A..C. ....T.. T.... ....AT A..C. .T... ..G.. ....
4c ***cont.*** .A... ....T.. A..C. ....T.. T.... ....AT A..C. .T... ....A. .C... .....
5c ***cont.*** .A... ....T.. A..C. ....T.. T.... ....AT A..C. .T... ....A. .C... .....
6c ***cont.*** CA... ....T.. A..C. ....T.. T.... ....AT A..C. .T... ..G.. .T.A. ....
7c ***cont.*** CA... ....T.. A..C. ....T.. T.... ....AT A..C. .T... ..G.. TT.A. ....
1d ***cont.*** ATACC TATTT ACTGA AACCT GAAAC ATTGG AGTCC TCCTC CTTCT GCTAG TTATA GCCAC AGCCT TTATA GGCTA T
2d ***cont.*** ....T ..... GT... ...T. ....C.. ...A. .T..A ..A.. T.... .C... ....T. .C..G ..... .
3d ***cont.*** ....T .G... ....T ....A. .T..T ..C.. AT... .C... ....T. .C... ..... .
4d ***cont.*** ....T ....T ....A. .T..T ..C.. AT... .C... ....T. .C... ..... .
5d ***cont.*** ....T ....C.. ...A. .T..T ..C.. AT... .C... ....T. .C... ..... .
6d ***cont.*** ...T. ..... .T... ...A. ....T ..C.. ...A. .T... ..C.. A...G .C... ....T. .C..G ..... .
7d ***cont.*** ...T. .G... .T... ...A. ....T ..C.. G..A. .T... ..C.. A...G .C... ....T. .C..G ..... .

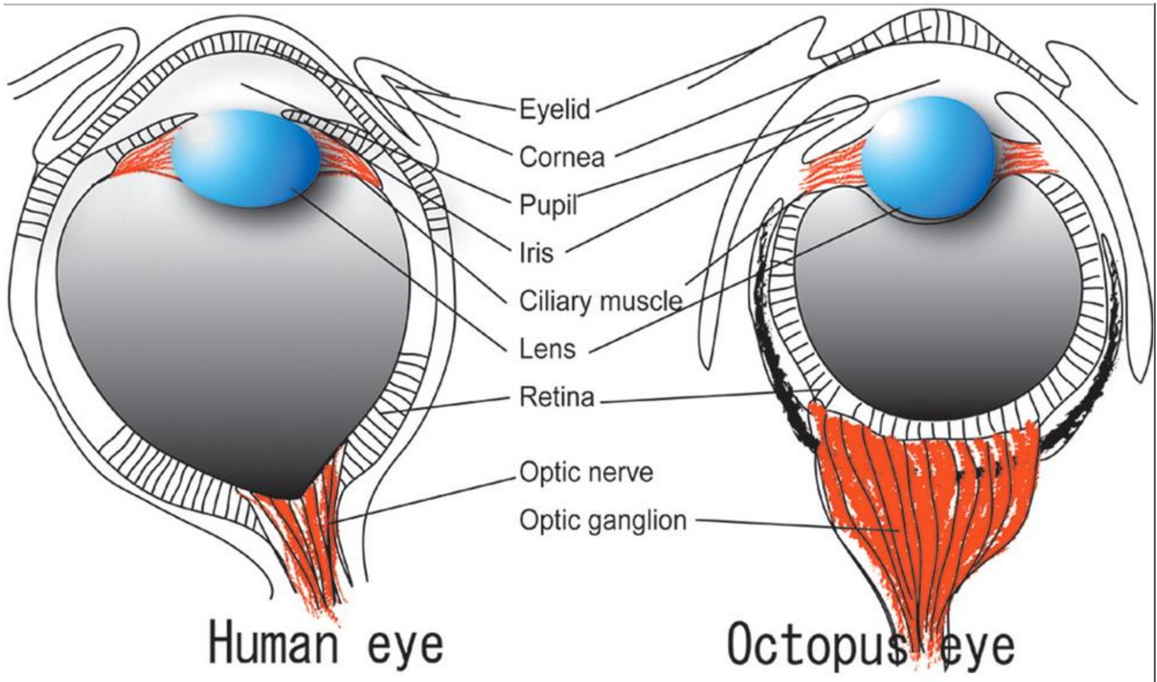
How could complex eyes have evolved?

(By Dr. Ingrid Waldron, Department of Biology, University of Pennsylvania, © 2011. A Word file for this Student Handout and Teacher Notes are available at http://serendip.brynmawr.edu/exchange/bioactivities/evoleye.)

In this activity we will investigate several key questions:

- How could something as complex as the human eye have evolved by natural selection? Could our eyes have evolved gradually through a series of many small improvements in the detection and processing of visual information?
- Since very little fossil evidence is available, how can scientists learn about the evolution of eyes?

This figure of the human eye illustrates some of the complexity and similarities of human and octopus eyes.



(Figure from http://genome.cshlp.org/content/14/8/1555/F1.expansion.html)

The similarities between the human and octopus eye include:

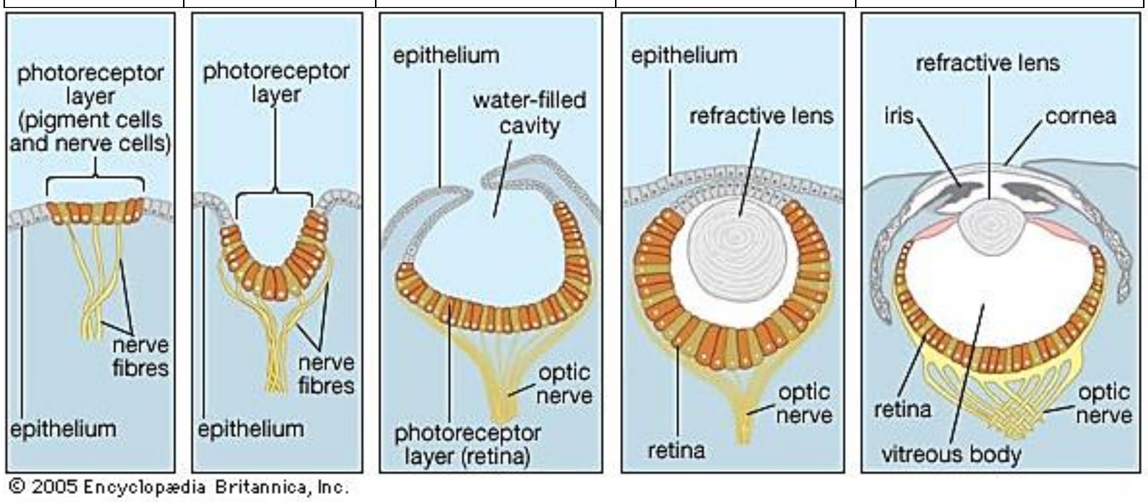
- the overall shape and structure of the eye
- the iris and pupil, which regulate how much light enters the eye
- the lens which focuses light to form an image on the retina
- the retina which contains photoreceptor cells that respond to light and send signals about visual information via the nerve cells
- light-sensitive molecules in the photoreceptor cells that consist of an opsin protein combined with retinal (a form of vitamin A).

Evidence from Comparative Anatomy – Evolution of Eye Shape

One way that scientists can develop hypotheses about how a complex structure like the octopus eye evolved is to compare the anatomy of different types of eyes in living evolutionary relatives (other mollusks such as snails, nautilus, and limpet). None of these living mollusks was an evolutionary ancestor of the octopus, but the different types of eye observed in these living mollusks suggests a possible sequence of intermediate steps that may have occurred during the evolution of the complex eye of the octopus. This evidence also indicates how each intermediate step in the evolution of a complex eye could have been useful and contributed to increased fitness (the ability to survive and reproduce).

The figure below shows the structure of eyes in several types of mollusks, and the table below describes the lifestyle of these mollusks. The light-sensitive molecules are called pigments because they are highly colored; therefore, the photoreceptor cells are sometimes called pigment cells and primitive types of eyes are called pigment spots or pigment cups.

Pigment spot (in limpet)	Pigment cup (in a snail)	Pinhole eye (in *Nautilus*)	Eye with primitive lens (in *Murex*)	Complex eye (in octopus)

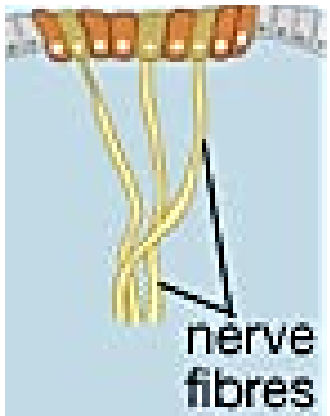


This limpet scrapes algae off of rocks and glides or creeps along, similar to a snail.	This snail feeds on sponges and moves by gliding or creeping along.	Nautilus swims in the open ocean and feeds on dead or dying prey.	This marine snail feeds on other snails, clams and barnacles (bores a hole to get at the soft tissues inside the shell).	An octopus is an active predator that relies on vision to hunt prey. It moves by swimming or using its arms for crawling.

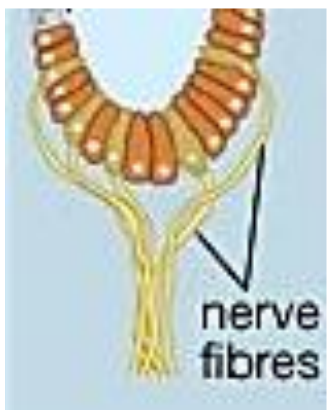
(figure from http://www.britannica.com/EBchecked/media/74661/Steps-in-the-evolution-of-the-eye-as-reflected-in)

1a. A pigment cup, but not a pigment spot, allows an animal to detect the direction the light is coming from. To demonstrate this, draw lines representing light coming from the left and from the right in the figures below and show how:

- light coming from either direction can stimulate all of the photoreceptor cells (pigment cells) in the pigment spot
- light coming from each direction can only stimulate certain specific photoreceptor cells in the pigment cup (remember that light travels in a straight line).



Pigment spot



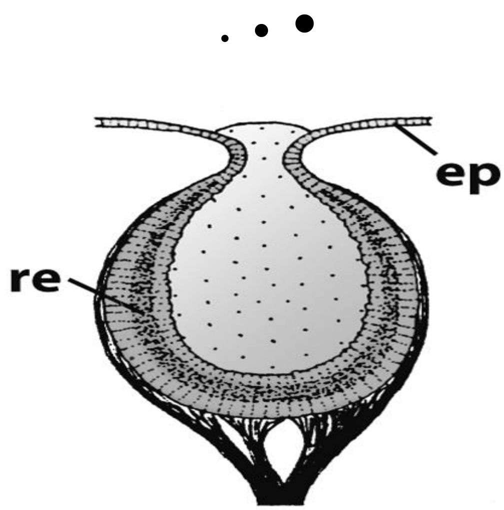
Pigment cup

1b. How could a snail benefit from being able to detect which direction light is coming from? In other words, how does a pigment cup contribute to increased fitness (the ability to survive and reproduce)?

1c. A pigment spot can detect light versus dark, but not the direction the light is coming from. How could a pigment spot contribute to increased fitness for a limpet?

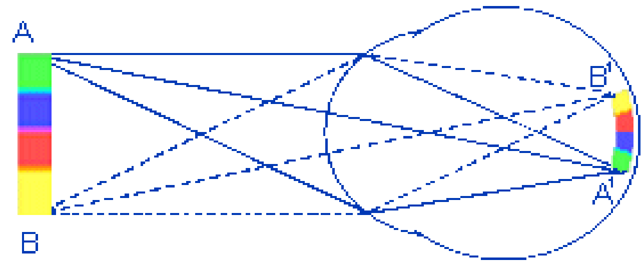
2. Explain how a visual stimulus can produce an image on the retina of a pinhole eye. Begin by drawing the pathway of light from the first and third dots in the visual stimulus in the diagram below in order to indicate which photoreceptors would be stimulated by light from each of these dots.

Visual stimulus: (from http://commons.wikimedia.org/wiki/File:Haliotis_pinhole_eye.png)



re = retina with photoreceptor cells; ep = epithelium

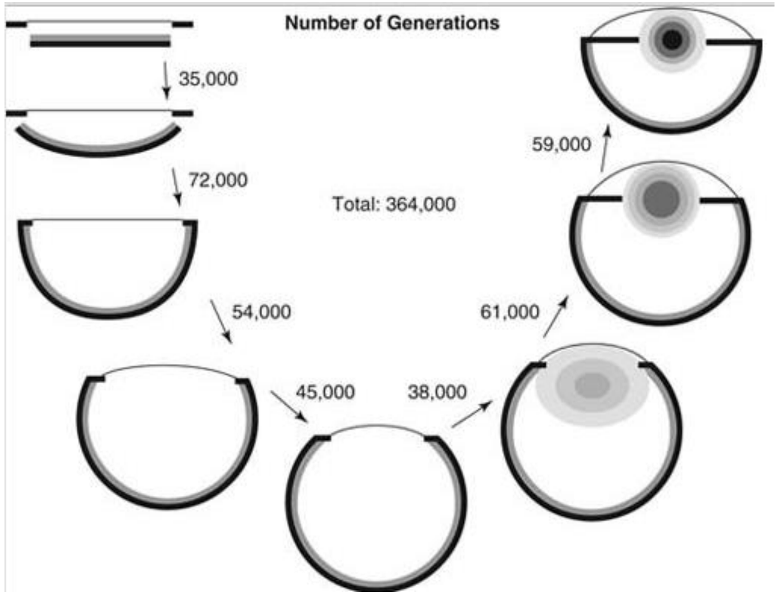
A major disadvantage of a pinhole eye is that very little light gets into the eye, so the image is dim. As discussed in the next section, an alternative evolutionary pathway avoids this disadvantage. Specifically, the evolution of a lens to focus light coming through a larger opening can result in a bright, sharp visual image. The figure shows how a lens that bends light can focus the light to produce a sharp image on the retina. (figure from http://webschoolsolutions.com/patts/systems/focus.gif)



Incoming light rays from each point on the object are bent by the cornea and lens so that (in normal vision) they come together at a single point on the retina. Note, however, the image is inverted. The brain ultimately interprets the image as rightside-up.

Results from a Mathematical Model of the Evolution of a Complex Eye

- Researchers have developed a mathematical model of a sequence of small changes by which natural selection could have produced an eye with the shape and lens observed in a human or octopus eye.
- This model begins with a three layer structure with a transparent protective layer on the outside, a layer of photoreceptor cells in the middle, and a layer of dark cells underneath.
- In this model, each small change results in slightly better spatial resolution (the ability of light coming from different parts of the environment to stimulate different photoreceptor cells). Improved spatial resolution results in a sharper visual image.
- The early steps in this model (shown in the left half of the figure) illustrate how selection for improved spatial resolution results in an increasingly spherical shape, with a sequence of steps similar to the pigment spot, pigment cup, and eyes with lenses in the comparative anatomy evidence
- The evolution of a lens begins with increasing concentrations of special transparent proteins in the region just behind the opening for light; these proteins increase the refractive index (so light bends as it passes through the lens). Each tiny increase in refractive index results in a small improvement in the ability to focus the light to produce a sharper image. Therefore, natural selection would favor the gradual development of a lens (as shown in the right half of the figure).
- Even with very conservative estimates, this model indicates that natural selection could produce the basic shape and lens of an octopus or human eye within less than 400,000 generations, which is a relatively short time in evolutionary terms. (Obviously, additional generations may be required to develop the additional features of complex eyes.)



(figure from http://musingsofscience.files.wordpress.com/2011/01/nilsson-pelger_model_of_eye_evolution.jpg)

3. What does this mathematical model contribute to our understanding of how complex eyes evolved?

4. Explain why the ability to form images would be more useful for an octopus than for a limpet.

Molecular Evidence – Evolution of Light-Sensitive Molecules

- Light-sensitive cells in all types of animals from jellyfish to humans use a fundamentally similar type of light-sensitive molecule that combines an opsin protein with a molecule like retinal (a form of vitamin A).
- The genes for the opsin proteins in a wide variety of animals have similar nucleotide sequences. This molecular evidence indicates that all these opsin protein genes are descended from an opsin protein gene that evolved very early in the evolution of animals (more than half a billion years ago, long before there were any mollusks or vertebrates).
- The molecular evidence suggests that a mistake during cell division resulted in duplication of a very ancient gene for a protein similar to opsin, and after that one of the copies of this duplicated gene had a mutation that changed a key amino acid to produce an opsin protein which can combine with retinal to form a light-sensitive molecule.
- This resulted in a very ancient animal that had two similar genes with different functions:

- the original gene that coded for the original protein (probably a receptor protein that responded to a chemical signal)
- the mutated gene that coded for an opsin protein in a light-sensitive molecule (this gene was the evolutionary ancestor for the opsin genes in all animals).

5. Explain why gene duplication can be a crucial initial step in the evolution of a new gene for a new protein with a new function (e.g. the opsin protein in light-sensitive molecules).

6a. When were the opsin proteins in light-sensitive molecules first observed in evolution?

____ in ancient animals that were the common evolutionary ancestor of mollusks and vertebrates

____ in more recent mollusks and vertebrates

6b. What evidence supports your conclusion?

6c. Are the similarities of the opsin-containing light-sensitive molecules in octopus and humans due to: ___ homology (similarity which results from common descent) or

___ analogy (similarity which results from convergent evolution, i.e. similar characteristics which evolved independently as a result of natural selection for a similar function)?

Concluding Questions

7a. Use the following evidence to decide whether the similarities between octopus and human eyes in shape and having a lens to focus light are due to:

___ homology (similarity which results from common descent) or

___ analogy (similarity which results from convergent evolution).

- Contemporary mollusks have a wide variety of types of eyes, including simple pigment spots or pigment cups in many types of mollusks. This indicates that the common ancestor of all mollusks almost certainly did not have spherical eyes with a lens. This in turn indicates that the common ancestor of mollusks and vertebrates did not have spherical eyes with a lens.

- Although the basic structure of human and octopus eyes is similar, there are some significant differences in structure which result from significant differences in the way that human and octopus eyes develop.
- The results of the mathematical model indicate that natural selection could produce the basic shape and lens of the octopus or human eye in a relatively short time (within 400,000 generations), which is much shorter than the roughly 500 million years since mollusk and vertebrate evolution began.

7b. Explain why you chose homology or why you chose analogy.

8. Complete the following table to describe the evidence for some likely steps in the evolution of complex eyes.

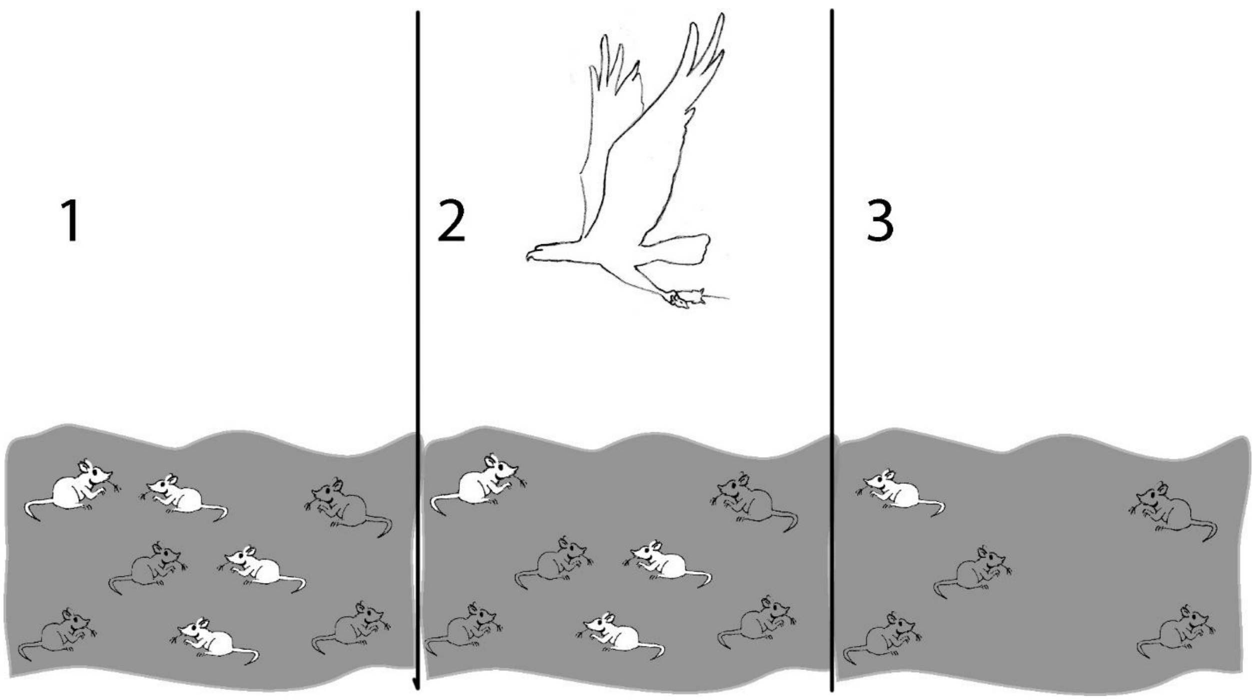
Steps in the Evolution of Complex Eyes	Evidence that Supports this Conclusion
Very early in the evolution of animals, light-sensitive molecules evolved by gene duplication and mutation.	
The shape of the eye probably evolved by gradual changes from a flat pigment spot to an indented pigment cup to a more spherical shape with an opening for light.	
The evolution of the lens probably began when increased concentrations of proteins behind the opening for light resulted in an increased refractive index which improved the ability to focus the light and form a sharp image.	

Evolution II Lab

Evolution by Natural Selection

Adapted from the University of California, Los Angeles Life Sciences 1 Demonstration Manual. Copyright 2011 by Drs. Jennifer Doherty and Ingrid Waldron, Department of Biology, University of Pennsylvania (Teachers are encouraged to copy this Student Handout for classroom use. A Word file (which you can edit if you want), *Teacher Preparation Notes, and other hands-on activities are available at* http://serendip.brynmawr.edu/sci_edu/waldron/. A shortened version of the Student Handout is available in the comments section at http://serendip.brynmawr.edu/sci_edu/waldron/#evolution)

★ Describe what is happening in figures 1-3. Is the population of mice different in figure 3 than in figure 1? Explain why.



Living things that are well adapted to their environment survive and reproduce. Those that are not well adapted don't survive and reproduce. An **adaptation** is any characteristic that increases **fitness**, which is defined as the ability to survive and reproduce.

★ For the mice in the figure, what characteristic was an adaptation that increased fitness?

The table describes four female mice that live in a beach area which is mostly tan sand with scattered plants.

Characteristics of each female mouse	Color of Fur			
	Black	Tan	Tan and Black	Cream
Running speed	8 cm/sec.	6 cm/sec.	7 cm/sec.	5 cm/sec.
# pups produced by each female	0	11	5	4
Age at death	2 months	8 months	4 months	4 months

★ According to the definition given above for fitness, which mouse would biologists consider the fittest? Explain why this mouse would be the fittest.

★ If a mouse's fur color is generally similar to its mother's color, which color fur would be the most common among the pups?

A characteristic which is influenced by genes and passed from parents to offspring is called **heritable.** For the mice on the tan sand, fur color was a heritable characteristic. As you saw, tan fur was a heritable adaptive characteristic which became more common in the pups.

In general, individuals with heritable adaptive characteristics survive longer and have more offspring which have similar adaptive characteristics. Therefore, a heritable adaptive characteristic will tend to become more common in the population. This process is called **evolution by natural selection**.

Evolution by natural selection leads to adaptation within a population. The term evolution by natural selection does <u>not</u> refer to individuals changing, only to changes in the frequency of adaptive characteristics in the population as a whole. For example, for the mice that lived on tan sand, none of the mice had a change in the color of their fur; rather, due to natural selection, tan fur was more common for the pups than for the mother mice.

Questions

1. Explain why a heritable characteristic which helps an animal to live longer will generally tend to become more common in subsequent generations as a result of evolution by natural selection.

2. Suppose an unusual heritable characteristic helped animals to live longer but made them sterile so they could not have any offspring. Explain why this heritable characteristic would not become more common in subsequent generations as a result of evolution by natural selection.

Simulation of Natural Selection

We will now play a simulation game to demonstrate how natural selection works. A **simulation** is a good way to mimic and simplify the process so we can observe how evolution by natural selection may work in a real population. This simulation involves pom poms that can reproduce. These pom poms live out their lives on a Black Forest or Red Grassland habitat in the classroom. The only concern our pom pom creatures have is the presence of ravenous hunters (that's you!). If you cannot find pom poms, you can use Goldfish ™ crackers instead.

The simulation will have the three necessary conditions for evolution by natural selection.

1. **Variation in characteristics**: For natural selection to occur, different individuals in a population must have different characteristics. In our simulation, pom poms vary in color; they are black or red. The hunters vary as well; hunters have two distinct types of feeding structures: forks and spoons.

2. **Differences in fitness**: For natural selection to occur, the different characteristics of different individuals must contribute to differences in fitness (i.e. differences in ability to survive and reproduce). For example, variation in pom pom color may influence the probability that a pom pom is snatched up by a hungry hunter. Also, different feeding structures may vary in their success in capturing pom poms. These differences contribute to survival and therefore success in reproducing.

3. **Heritability of characteristics**: For natural selection to occur, the characteristics that affect fitness must be heritable (i.e. passed by genes from one generation to the next). In our simulation, a pom pom that is born into the pom pom population is the same color as its parent and a hunter that is born into the hunter population has the same feeding structure as its parent.

Here is what you will do:

1. Your class will be split into two groups which will carry out the simulation on two different habitats: Black Forest (represented by a rough black material such as faux fur) and Red Grassland (represented by a red fleece material).

2. Pom poms come in two colors: black and red. Your teacher will scatter an equal number of each color on the Black Forest and on the Red Grassland. Which color pom pom do you think will be more likely to survive in each habitat?

   Black Forest:

   Red Grassland:

   Why do you think that?

3. There are two different types of feeding structures: forks and spoons. Your teacher will distribute these feeding structures so that half the hunters in each habitat have forks and half have spoons. Complete the first and second rows of this table for the hunters in your habitat.

Hunters in ______________________________ Habitat	Spoon	Fork
Generation 1 - Number who have this feeding structure		
Generation 2 - Number who have this feeding structure		
Generation 3 - Number who have this feeding structure		

You will also be given a cup. This cup will serve as your “stomach”. To capture a pom pom, you must use only your fork or spoon to lift the pom pom from the habitat and put it into your cup. Which feeding structure do you think will do better in each habitat?

Black Forest:

Red Grassland:

Why do you think that?

4. At your teacher’s signal, start feeding. Don’t be shy about competing with your fellow hunters. However, once a pom pom is on a fork or spoon it is off limits. When your teacher calls time, **STOP** feeding.

5. Now count how many pom poms you have eaten and line up with your classmates who were feeding on the same habitat, from fewest pom poms eaten to most pom poms eaten. The hunters with the fewest pom-poms did not eat enough to survive; if you are in the bottom half of the number of pom-poms in your group, return your feeding structure to indicate that you have died. Each hunter who died will be reborn as the child of a hunter in the top half of the group who ate enough to survive and reproduce. Each child will receive the same feeding structure as his/her parent. After each hunter who died has been reborn, record the results in the generation 2 line of the above table.

6. Your teacher will record how many pom poms of each color were eaten, calculate how many pom poms survived, and help the surviving pom poms reproduce. Only the pom poms that were not eaten will reproduce.

7. <u>While your teacher is busy</u> preparing for the next round of feeding, <u>discuss the following questions</u> with your group:
   - Which feeding structure contributed to greater fitness (ability to survive and reproduce)?
   - What characteristics of forks and spoons increased or decreased fitness?

8. You will run through the simulation one more time. Complete the last row in the table on page 3.

9. Propose an explanation for any changes in the number of spoon vs. fork feeding structures from generation 1 to generation 3.

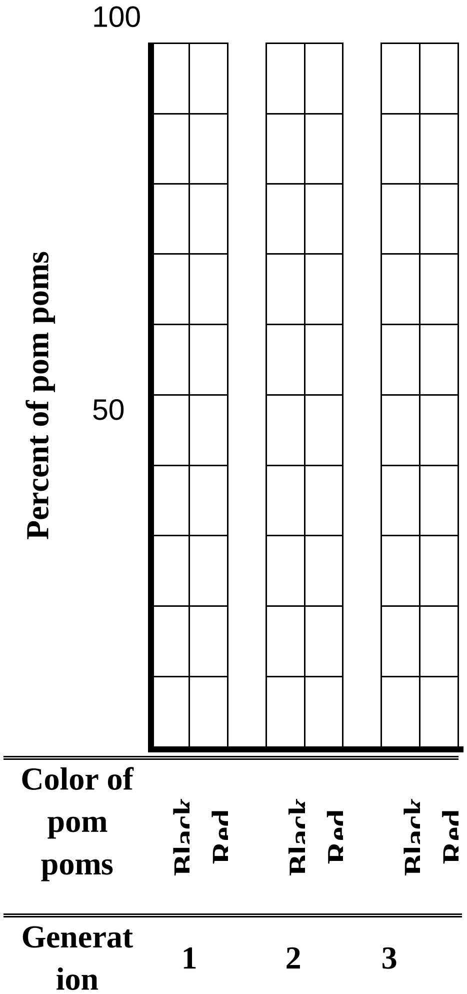
10. Your teacher will post on the board the numbers of pom poms of each color and hunters of each type at the beginning of the simulation (generation 1) and at the end of each cycle (generations 2 and 3). Copy these numbers in the table below. Then, for each generation of pom poms in each habitat, calculate the percent that are black or red. Similarly, for each generation of hunters in each habitat, calculate the percent that have spoons or forks as their feeding implement.

	Black Forest					
	Pom poms			Hunters		
	Black	Red	Total	Spoon	Fork	Total
Generation 1 Number						
Percent			100%			100%
Generation 2 Number						
Percent			100%			100%
Generation 3 Number						
Percent			100%			100%

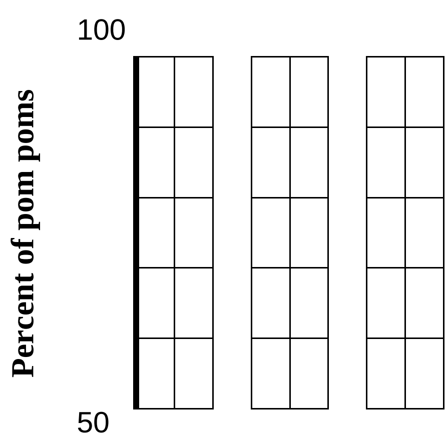
	Red Grassland					
	Pom poms			Hunters		
	Black	Red	Total	Spoon	Fork	Total
Generation 1 Number						
Percent			100%			100%
Generation 2 Number						
Percent			100%			100%
Generation 3 Number						
Percent			100%			100%

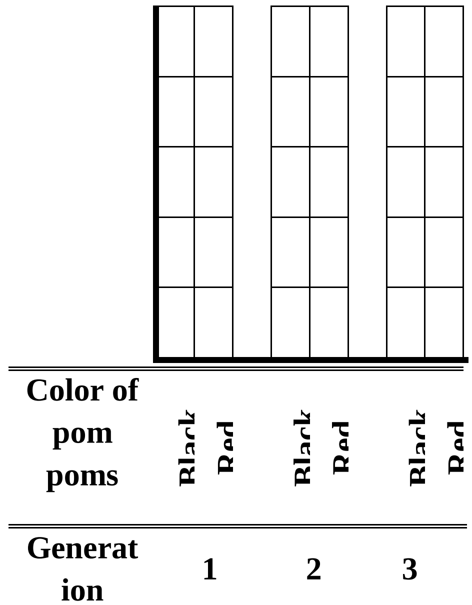
11. Use the data to complete the following bar graphs. This will help you to see the trends in the percent of pom poms of each color and hunters with each type of feeding implement over the three generations in each habitat.

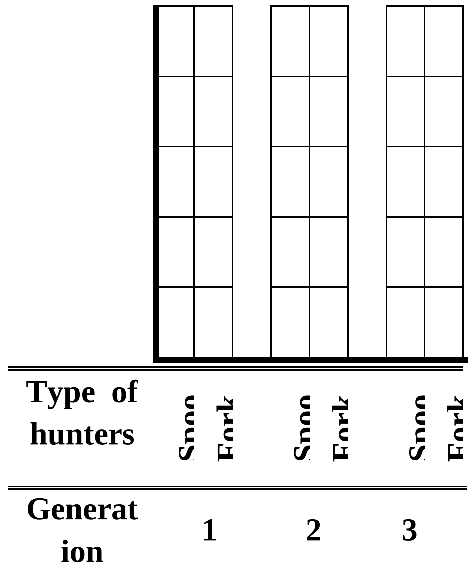
Pom poms in the Black Forest



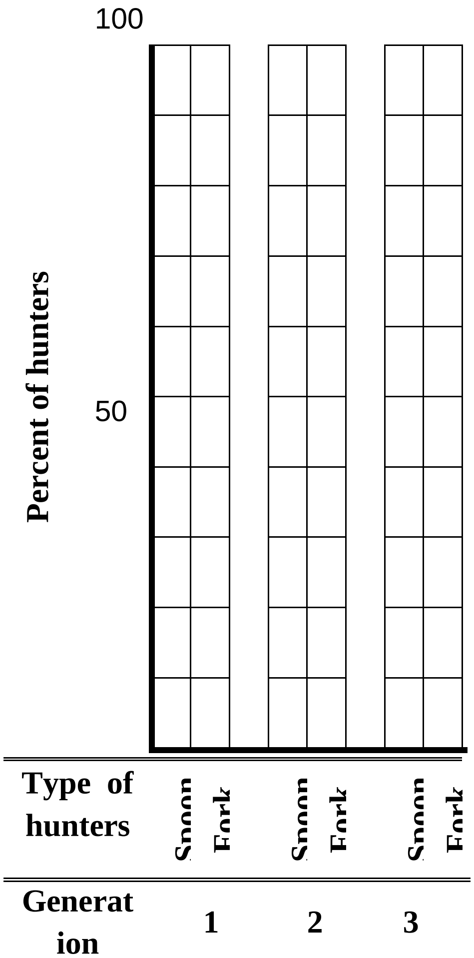
Pom poms in the Red Grassland



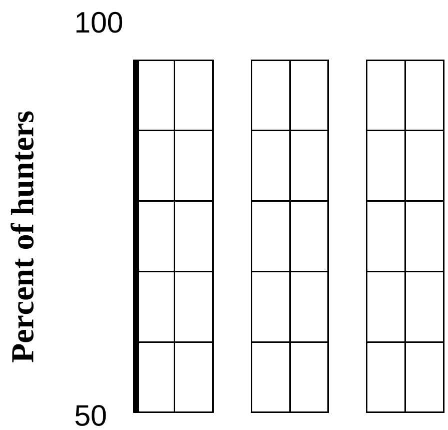




Hunters in the Black Forest



Hunters in the Red Grassland



Questions

1. Did evolution by natural selection occur in each pom pom population? In other words, did one pom pom color become more common over time while the other color became less common?

   Black Forest:

   Red Grassland:

   What traits contributed to the survival of pom poms that survived to reproduce?

Remember that the pom pom populations were the same on the Black Forest and Red Grassland at the beginning. Explain why the trends differ in these two different habitats and the two populations of pom poms end up so different.

2. Did any individual pom poms change color or adapt? If not, then why did the colors of the pom poms in the final population differ from the colors of the pom poms in the original populations?

3. For each population of hunters, did one type of feeding structure become more common while the other type of feeding structure became less common? Explain the reasons for any trends in the type of feeding structure.

   Black Forest:

   Red Grassland:

   Explain the reasons for any differences in trends between the two habitats.

4. If we ran the simulation for 50 more generations, what would you predict about the colors of the pom poms in each habitat?

   Black Forest:

   Red Grassland:

5. What do you think would happen to the pom pom population if the black forest experienced a prolonged drought so all the trees died and the habitat became red grassland? First, make your prediction of what would happen if the population of pom poms in the black forest at the beginning of the drought included both red and black pom poms.

Next, suppose that natural selection over many generations had resulted in only black pom poms surviving in the black forest, and then a prolonged drought resulted in this habitat turning into a red grassland. Would natural selection for pom pom color occur? Why or why not?

Based on this example, explain why evolution by natural selection can not occur if there is no variation in a characteristic.

6. Suppose that all the hunters in the simulation were blind-folded and could only find pom poms by touch. Would you expect evolution by natural selection in the color of the pom poms? Why or why not?

Explain why evolution by natural selection can not occur if the variation in a characteristic does not contribute to differences in fitness.

7. The following example illustrates a more complete definition of fitness as the ability to survive and produce offspring who can also survive and reproduce. According to this definition of him fitness, which of the four male lions described below would biologists consider the "fittest"?

Name	George	Dwayne	Spot	Tyrone
Age at death	13 years	16 years	12 years	10 years
# cubs fathered	19	25	22	22
# cubs surviving to adulthood	15	14	14	19
Size	10 feet	8.5 feet	9 feet	9 feet

(Adapted from Michigan State University, Occasional Paper No. 91, Evolution by Natural Selection: A Teaching Module by Beth Bishop and Charles Anderson, 1986)

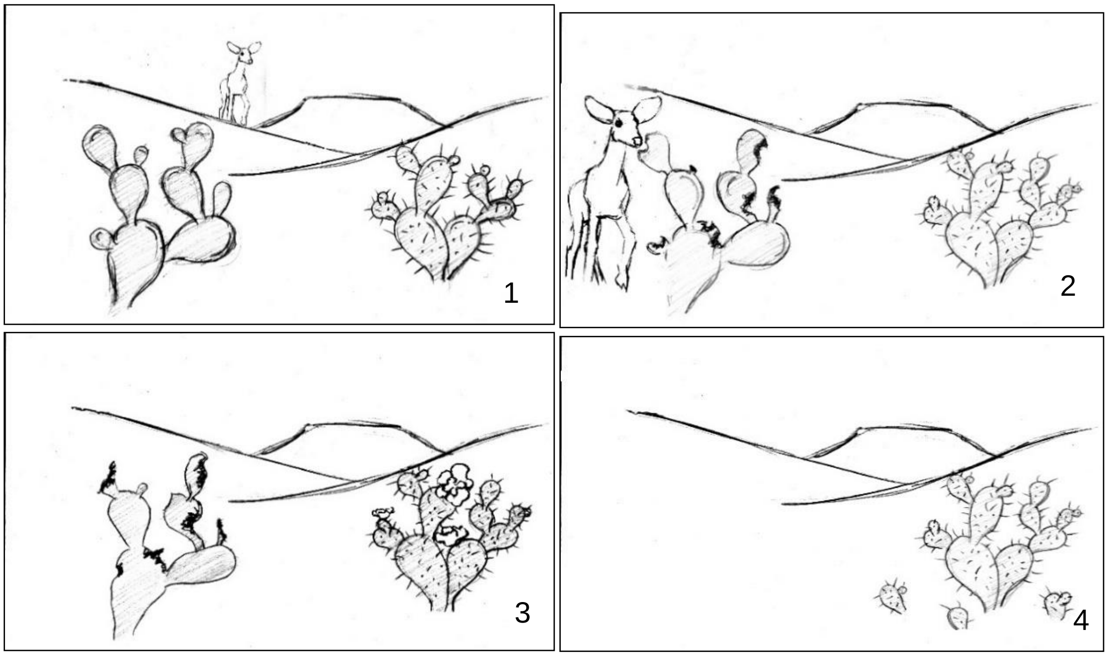
Explain why Dwayne was not the fittest even though he lived the longest and fathered the most cubs.

Complete the following table.

If the reason why more of Tyrone's cubs survived was:	Would the offspring of Tyrone's cubs inherit characteristics that increased their chances of surviving to adulthood? Explain why or why not.
Tyrone had heritable characteristics that increased resistance to infections, and many of his cubs inherited these characteristics.	
Tyrone happened to live near a farmer whose children liked watching lion cubs, so for ten years the farmer put out meat with antibiotics for Tyrone's cubs.	

Use this example to explain why natural selection does not operate on a characteristic which affects fitness but is not heritable.

8. This series of pictures shows natural selection in a population of cacti. Pictures 1 and 2 show what happened when a deer came to eat, picture 3 shows the cacti a few weeks later (notice the flowers on the right-hand cactus), and picture 4 shows the situation a few months later.



Complete the following table to describe how this cactus example illustrates the three necessary conditions for evolution by natural selection.

Necessary Condition for Evolution by Natural Selection	How does the cactus example illustrate this condition?

9. "Survival of the fittest" is a common expression. What do you think most people mean by this expression?

How would you explain this expression to help someone understand how natural selection actually functions?

To view case studies used in the laboratory section of the course, please view on the National Center for Case Study Teaching in Science (http://sciencecases.lib.buffalo.edu/cs/) the following cases:

“Why Sex is Good” by Clyde Freeman Herreid

“Man’s Best Friend? Using Animal Bones to Solve an Archaeological Mystery” by Elizabeth Scharf

“I’m Looking Over a White-Striped Clover: A Case of Natural Selection” by Susan Evarts, Alison Krufka, Luke Holbrook, and Chester Wilson.

APPENDIX E

INTERVIEW QUESTIONS

These questions were used for individual and focus group interviews.

1. I've reviewed your laboratory summary about your perceptions towards the simulations/at-home kits. I think these were the big ideas you were expressing in that summary. Can you look at this word cloud from your summary and see what you think?
2. Why did you write about these words in your ecology summary?
    a. Is there a connected or bigger idea you wanted to covey? For instance, if I were writing about bears, wolves, and Denali National Park, I might really want to connect to the ideas of communities, apex predators, or how we manage those populations. How often you write a word doesn't tell me the whole story, so what else do you want me to know about this?
3. What do you think you learned from the ecology lab activities? Does this word cloud capture what you learned?
4. Do you think those activities were effective in helping you learn? Why or why not?
5. Why did you write a lot about these words in your evolution summary?
    a. Is there a connected or bigger idea you wanted to covey? For instance, if I were writing about stickleback fish, the *Pax-1* gene, and armored plating, I might really want to connect to ideas of how scientists use models to describe and explain genes we find in many species. How often you write a word doesn't tell me the whole story, so what else do you want me to know about this?

6. What do you think you learned from doing the evolution lab activities? Does this word cloud capture what you learned?
7. Do you think those activities were effective in helping you learn? Why or why not?
8. Can you describe the environment around you when you were doing your labs? Did anyone help you with your labs?
9. What else would you like me to know about your experience with labs?