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Testing the Efficacy of Merrill's First Principles of Instruction in Improving Student Performance in Introductory Biology Courses

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TESTING THE EFFICACY OF MERRILL'S FIRST PRINCIPLES OF INSTRUCTION IN IMPROVING STUDENT PERFORMANCE IN INTRODUCTORY BIOLOGY COURSES

by

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ABSTRACT

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One learning problem is that public understanding of science is limited. Many people blame at least part of the problem on the predominant lecture approach for students' lack of science understanding. Current research indicates that more active instructional approaches can improve student learning in introductory undergraduate biology courses. Active learning may be difficult to implement because methods and strategies, ranging from in-class collaborative problem-solving to out of class multimedia presentations, are diverse, and sometimes difficult to implement. Merrill's First Principles of Instruction (hereafter referred to as "First Principles" or "First Principles of Instruction") provides a framework for implementing active learning strategies.

This study used First Principles of Instruction as a framework for organizing multiple active learning strategies in a web-based module in an introductory biology course. Participants in this exploratory study were university students in Life Sciences

1350, an introductory biology course for nonscience majors. Students were randomly assigned to use either the module using First Principles of Instruction (hereafter called the First Principles module) or the module using a more traditional web-based approach (hereafter called the traditional module) as supplementary instruction.

The First Principles module implemented several active learning strategies and used a progression of whole problems and several demonstration and application activities to teach the topic of “microevolution,” defined as the study of how populations evolve and change over time. The traditional module implemented a more traditional web-based approach, providing information and explanations about microevolution with limited examples. This exploratory study’s results showed that the learning gain from pretest to posttest at the remember level was significant for the traditional group at alpha = .05 and was significant for the First Principles group at alpha = .1. In addition the pretest to posttest gain at problem solving for the First Principles group was significant at alpha = .05. When students rated their confidence in solving future problems, those in the First Principles group were significantly more likely to predict future success at alpha = .1.

(266 pages)

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Joel Lee Gardner

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CHAPTER I

INTRODUCTION

Public Understanding of Science

One current societal problem is a general lack of understanding of science concepts. Over 25 years ago, Volpe (1984) called public science understanding “appalling” and wrote that “The public continues to be naive and unconversant with the limits and accomplishments of science” (p. 433). Now, a quarter of a century later, many are still concerned about this lack of understanding of general science concepts (Halpern & Hakel, 2002; Michael, 2006). At a time when U.S. students struggle to compete with their international counterparts in understanding science concepts (National Center for Education Statistics [NCES], 2006a, 2006b), it is imperative that educators analyze why this problem persists and what can be done to overcome it.

Traditional Lecture Inhibits Science Understanding

Many blame predominant instructional approaches for this lack of science understanding and specifically cite traditional lecture as a culprit, because teachers using this format present science as information to be merely remembered instead of actively used (Halpern & Hakel, 2002; Michael, 2006; Volpe, 1984). In a traditional lecture approach to teaching, information is disseminated directly from professors to students with minimal additional learning activities. In addition to in-class lab activities, students are then expected to study class notes, slides, or the course textbook out of class to learn the materials presented. However, the fundamental assumption behind the use of lecture in instruction is that the content can be distilled to facts that must be transferred to the minds of students (Mayer, 1992). This approach stands in contrast to the view that "...learning is not about committing a set of facts to memory, but requires the ability to use resources to find, evaluate and apply information" (DiCarlo, 2006, p. 291) and that learning science is "a constructive process that requires active participation by both the student and teacher" (Ebert-May, Brewer, & Allred, 1997, p. 601). Unfortunately, science concepts are still often presented in lecture form as a compilation of facts for students to study and memorize (Michael, 2006). While some science courses offer a laboratory in conjunction with a lecture class, thereby potentially providing meaningful experience to students, several such courses taught at Utah State University (USU) do not implement a lab. To effectively learn, students must be able to construct their knowledge using scientific reasoning. Unfortunately, the lecture format is used in many biology courses, including several at USU, and laboratory work is not required in many introductory biology courses. Students, therefore, continue to have poor performance, resulting in high student failure rates (Freeman et al., 2007; Greg Podgorski, personal communication, November 13, 2009).

Active Learning to Improve Student Learning

Current research on biology instruction indicates that more active, constructivist approaches can increase student understanding of science concepts because they facilitate student learning processes (Michael, 2006; Prince, 2004). Active learning in undergraduate biology courses means having students engage in activities that involve them in gathering information, thinking, and solving problems (Collins & O'Brien, 2003). Having students participate actively in learning helps students be involved more fully in the learning process instead of passively acquiring knowledge as in a lecture. Many active learning strategies, such as collaborative problem solving and the use of student response systems to engage students in the material, have been shown to bring about increases in student learning (Michael, 2006; Prince, 2004).

One interesting body of research on active learning investigates the use of web-based educational technologies to improve student learning in undergraduate biology courses, both in class and as out of class activities. This research has found that the use of computer animations can improve student performance in class and reduce student misconceptions about biology concepts (Kiboss, Ndirangu, & Wekesa, 2004; Reuter & Perrin, 1999; Sanger, Brecheisen, & Hynek, 2001). For example, Sanger and colleagues found that students who were shown animations depicting molecular processes were less likely to retain misconceptions of molecular process than those who received traditional instruction. In addition, engaging students in web-based problem-solving activities can significantly improve student understanding of science concepts (Dori & Belcher, 2005; Riffell & Sibley, 2005).

Student use of web-based assignments is an effective way to increase active learning because the assignments can be used as out-of-class activities that supplement and enhance larger lecture-based courses. In addition, engaging students in these activities outside class does not require the extensive resources needed to use active learning strategies in class (Smith et al., 2005). Therefore, from the standpoint of the classroom teacher, they can be an efficient method for actively involving students.

Although these strategies can improve student learning, active learning strategies are difficult to define and can be difficult to incorporate in an effective, systematic strategy for teaching biology courses. Kumar (2005) concluded that “active learning refers to the application of any teaching strategy in which students actively participate in academic exercises rather than passively listen to an instructor’s lecture” (p. 324). This definition is vague enough that it leaves educators wondering how to implement an active learning strategy. Researchers have suggested several strategies to implement an active learning approach. But several questions remain. Should this variety of strategies be used to implement an active learning approach? Or is there some combination of strategies that can be more effectively used? If so, how can such combination be best determined? In this study, I test the effectiveness of several active learning strategies for teaching in an undergraduate biology module, including First Principles of Instruction as a framework for active learning strategies (Merrill, 2002).

Using Merrill’s First Principles in Undergraduate Biology Instruction

To investigate the integration of multiple active learning strategies into an undergraduate biology course at Utah State University, in this paper I propose a study using Merrill’s First Principles of Instruction (Merrill, 2002) as a framework. First Principles of instruction provides a clear framework and prescriptions for utilizing active learning strategies, including research-based instructional strategies. For simplicity’s sake, from the remainder of this paper, I will use the terms “First Principles” or “First Principles of Instruction” to refer to Merrill’s First Principles of Instruction. First Principles are based on an extensive review of research-based instructional best practices (Merrill, 2002). According to First Principles, instructional activities should be centered on real-world problems or tasks (Merrill, 2002, 2006a). Furthermore, instruction should follow a four-phase cycle of instruction that activates students’ previous knowledge, demonstrates new knowledge to the students, has the students apply their new knowledge, and encourages them to integrate that knowledge into their lives (Merrill, 2002, 2006a).

The First Principles approach provides a useful framework for incorporating active learning because it supports and incorporates many active learning strategies. It also provides a systematic process for implementing these strategies. In addition, a growing body of research shows support for these principles, suggesting that the use of First Principles may increase student learning if implemented into a teaching strategy in undergraduate biology courses (Frick, Chadha, Watson, Wang, & Green, 2007; Merrill, 2006b; Thomson, 2002).

This study will compare the performance of students receiving traditional web-based supplementary instruction, with students receiving supplemental instruction incorporating Merrill’s First Principles of Instruction.

Overview of Upcoming Chapters

In Chapter II, I describe in more detail the problems related to poor student understanding of science, particularly biology. I also review in greater detail the research related to active learning in undergraduate biology courses, including several themes in the active learning literature. I then describe First Principles of Instruction as a potential framework for using active learning strategies and demonstrate how these principles easily integrate into a cohesive instructional process. Finally, I present the research questions for this study. In Chapter III, I describe the instructional strategies used in the two modules used in this study. I also describe the process used for developing the modules. In Chapter IV, I describe the quantitative approach used to address the research questions. Participants in this exploratory study were drawn from a class of undergraduate students studying microevolution in USU 1350, an introductory life sciences course. I compared the effectiveness of a web-based module using First Principles of Instruction with a web-based module using traditional methods. In Chapter V, I present the results, which include the main effect of student performance at the "remember" and "understand" levels of learning as well as student ability to solve problems. I also present several additional effects of interest. In Chapter VI, I first review the introduction, literature review, and method. Then I discuss the major findings, in light of the current literature. I then present implications for research on instructional strategy in undergraduate biology courses. Finally, I discuss the limitations of the study and make suggestions for future research.

CHAPTER II

REVIEW OF LITERATURE

Goals of Undergraduate Biology Instruction

Recently there has been a call to restructure undergraduate biology education to make it more accessible to students (Labov, Reid, & Yamamoto, 2010; National Research Council [NRC], 2003) and to help biology students better understand the world and the nature of science (Woodin, Smith, & Allen, 2009). The common phrase used in the literature to describe these newly stated goals of undergraduate biology teaching is the goal of enabling students to become "scientifically literate" (American Association for the Advancement of Science [AAAS], 2009). While this label has many meanings, scientific literacy has been broken down into two major areas: student understanding of core concepts and understanding of the science processes. Each of these areas is discussed in greater detail below.

The first major goal for undergraduate biology courses is to help students understand several core ideas in biology. In a national conference organized by the AAAS, members described the following as core concepts that every student should understand "evolution; pathways and transformations of energy and matter; information flow, exchange, and storage; structure and function; and, systems" (AAAS, 2009, p. 3). In keeping with this goal, this study will work specifically with a core concept of evolution—microevolution.

Microevolution is generation-to-generation changes in allele frequencies in a population. It drives macroevolution. There are four main forces of evolution: mutation, gene flow, genetic drift, and natural selection. *Mutation* is a permanent, heritable change in the genetic makeup of an individual in a population. For example, a random mutation of genes could cause the child of brown beetles to have a green coloration. *Gene flow* is the movement of gene forms from different populations of a species. For example, some individuals from a population of beetles with genes for brown coloration might join a population of beetles with genes for green coloration, making the green population more similar to the brown population. *Genetic drift* is the process of change of a population due to chance or random events. For example, if a population of beetles had both green and brown and colorations, and the green beetles passed their genes to offspring more successfully due to randomness, the population's genetic composition would be different than the previous generation. The final force of evolution is *natural selection*, the process in nature by which organisms that possess certain characteristics are more likely to survive than organisms with less favorable characteristics. For example, if a population of brown and green beetles lived on the leaves of trees, the green beetles would be more likely to survive hunting from predators and would be naturally selected to survive more than the brown beetles.

The second major goal for undergraduate biology courses is to help students understand the processes scientists use to acquire and use biological knowledge. Students in introductory biology courses should gain the ability to use the scientific process to interpret and solve problems in their lives. Students should

> develop an understanding of the nature of science and the scientific process so that when they confront issues that involve science and technology, they can solve

> every-day problems and use evidence and logic to reach sound conclusions. (AAAS, 2009, p. 5)

This study focused on one aspect of the scientific process—forming a hypothesis.

Traditional Lecture Inhibits Biology Understanding

Traditionally, lecture is used as a primary method for teaching biology, but there has been a growing awareness that traditional lecture-based instruction in introductory biology courses does not produce adequate student understanding of biology concepts (Alters & Nelson, 2002; Armbruster, Patel, Johnson, & Weiss, 2009; Crowe, Dirks, & Wenderoth, 2008; Francom, Bybee, Wolfersberger, & Merrill, 2009). Nelson (2008) wrote:

> For at least three decades, the evidence has been quite strong that traditional teaching is not very effective in college and university classes in science…the problem is that while traditional methods are "not ineffective" and work for some, they are not nearly as effective as some well-documented alternative approaches. (p. 213)

Traditional teaching is primarily lecture-based instruction in which a teacher provides information to students verbally in class and includes few or no additional learning activities or teaching strategies as part of the course. In many courses taught at USU, lecture is the primary method for teaching students. For example, in USU 1350 Life Sciences, the introductory biology course associated with this study, lecture is the primary instructional method. This course does not include a laboratory. Unfortunately, a lecture-based approach does not bring about meaningful student learning (Merrill, 2006b). Meaningful learning can be defined as learning at higher levels of Bloom's Taxonomy of Learning Objectives, such as the ability to apply or use the knowledge learned (Anderson, Krathwohl, Airasian, & Samuel, 2001). Lecture most often presents information to be memorized and repeated and targets the lowest level of student learning—the remember level (Anderson et al., 2001). Unfortunately, students who merely remember what they are told often cannot apply their learning in meaningful ways. Perhaps this is why Volpe (1984) wrote that "the major contributor to society's stunning ignorance of science has been our educational system" (p. 433).

For decades the evidence has been quite strong that traditional teaching is not very effective in enabling higher levels of student learning in undergraduate science classes, including the newly framed goals of undergraduate biology courses (AAAS, 2009). This problem appears to have persisted. More recently, Halpern and Hakel (2002) wrote that "it would be difficult to design an educational model that is more at odds with current research on human cognition than the one that is used in most colleges and universities" (p. 4).

The lack of student understanding of biology concepts is reflected in poor student performance in undergraduate biology courses. In a typical introductory biology course for students planning to major in biology, 19.6% of students do not receive the minimum grade to qualify to proceed to higher levels of biology courses and nearly half do not perform well enough to declare a biology major (Freeman et al., 2007). This poor student performance is also seen in an introductory biology course at Utah State University, with nearly 40% of students receiving a D or an F in the course (Greg Podgorski, personal communication, November 13, 2009). Freeman and colleagues noted,

> High failure rates in “gateway” courses are unacceptable for two reasons: they contribute to low graduation rates and extended time-to-graduation for the institution as a whole, and they have a disproportionately large impact on URMs (underrepresented minorities) and other students from disadvantaged backgrounds. (p. 132)

When biology is taught using traditional lecture methods, students not only fail their introductory courses more often, but they also often come to view biology as a collection of facts instead of useful knowledge (DiCarlo, 2006). DiCarlo wrote that “…learning is not about committing a set of facts to memory, but requires the ability to use resources to find, evaluate and apply information” (p. 291). But traditional lecture does not effectively enable students to do so, resulting in poor understanding. Americans now rank very poorly in science understanding when compared to their contemporaries in other developed countries (NCES, 2006a), and poor student performance in undergraduate biology courses indicates a need for change in teaching strategies in undergraduate science classes.

Active Learning to Improve Student Learning

In the recent past, there has been a call to “take biology out of the realm of the abstract and relate it to the real world” (AAAS, 2009). Many have advocated a shift from the traditional lecture approach to active learning (Alters & Nelson, 2002; Freeman et al., 2007; Michael, 2006; Smith et al., 2005). This means creating “dynamic student-centered experiences that engage students in research-oriented learning” (DiCarlo, 2006, p. 290). The active learning approach is closely associated with constructivist approaches to teaching and learning, which emphasizes problem solving as an important component of student learning (Duffy & Cunningham, 1996).

Collins and O'Brien (2003) defined active learning as "The process of keeping students mentally, and often physically, active in their learning through activities that involve them in gathering information, thinking, and problem solving" (p. 4). This learning "emphasizes interactions with peers and instructors and involves a cycle of activity and feedback where students are given consistent opportunities to apply their learning" (Armbruster et al., 2009, p. 203). Active learning activities facilitate the student learning process of selecting, organizing, and using science content (Armbruster et al., 2009).

But what exactly are these activities, and how effective are they at improving student learning? To gain a deeper understanding of current literature and research on active learning teaching strategies, I reviewed active learning literature related to teaching in undergraduate science courses. To gather articles related to active learning, I searched for articles using Google Scholar and the ERIC and Education Full Text Databases using the keywords "active learning," "biology," and "undergraduate." I selected articles that addressed teaching strategies in undergraduate biology and other science courses. I chose articles that identified the instructional strategies used in the article as an active learning teaching strategy. This search resulted in 17 relevant articles.

One striking pattern among the research is that active learning is a term that is applied to several different strategies, technologies and mediums. This makes it difficult to organize these strategies into a coherent framework. To organize the active learning literature, I frame my discussion of active learning according to several themes that emerged during the review. These themes are highlighted and discussed below, followed by a discussion of how these kinds of reforms are difficult to implement.

Problem Solving

Many authors recommended basing biology learning activities around problem solving (e.g., Armbruster et al., 2009). Case studies and associated biology problems are an effective tool for increasing students' active attention and interest in the learning process (Smith et al., 2005). Case studies and problems are promoted by many as the foundation of all student activities because of their ability to help students identify important information and organize it. Making instruction problem-based has been reported to decrease course failure rates in introductory undergraduate biology courses (Freeman et al., 2007).

Freeman and colleagues (2007) studied the effectiveness of having biology students regularly answer complex questions and problems during face to face biology courses. These questions were designed to test student ability to apply the content learned to a new situation or analyze an aspect of the topic being learned. Students responded to questions using a student response system and were given feedback on their responses. Freeman, *et al*. found that the course failure rate decreased significantly when this method was used.

DiCarlo (2006) promoted having students learn biology in the same way that science is practiced. This problem-based approach should present a problem and have students work in groups to solve these problems. Biology instruction should focus on having students use scientific thinking and critical thinking to solve content-related problems (Nelson, 2008). Many other researchers describe the need for having students solve biology related problems (e.g., Ebert-May et al., 1997; Smith et al., 2005).

Collaboration and Discussion

Student to student collaboration and discussion is also an important aspect in active learning. This is because collaboration and discussion allow students to learn from each other. Collaboration and discussion have been shown to increase course passing rates (Dori & Belcher, 2005) and increase student learning (Michael, 2006), including student understanding of the biology content being taught (Ebert-May et al., 1997).

Including student discussion as a part of an active learning teaching strategy in an undergraduate biology course helped increase student understanding of the content being taught (Ebert-May et al., 1997). DiCarlo (2006) found that having students collaborate in working to solve content-related biology problems promotes student success and improves student learning.

Discussion and collaboration have been shown to be effective in other introductory science courses, as well. Dori and Belcher (2005) described how having introductory physics students work together in teams to conduct desktop experiments was an integral part of an active learning strategy. In addition, based on his review of active learning literature, Michael (2006) concluded that meaningful learning in physiology courses is facilitated by having students articulate explanations about what they are learning.

Animations

Animations are another important aspect of active learning. Based on a summary of over 40 studies on effective methods for teaching using multimedia and visual demonstrations, Clark and Mayer (2008) found that when multimedia including computer animations are presented to students using appropriate methods, student learning and ability to use content knowledge increases significantly.

The use of animations to teach biology concepts has been researched in active learning literature. “Innovative teaching is also facilitated by multimedia productions” (DiCarlo, 2006, p. 293) and computer animations are one way multimedia have been used to improve student understanding of biology concepts. Reuter and Perrin (1999) found that using a dynamic web-based model in an introductory biology course significantly increased student understanding of concepts. In a study testing the effectiveness of what they called Computer-Mediated Simulations at improving student learning of cell division in an undergraduate biology course, Kiboss and colleagues (2004) found that computerized simulations helped undergraduate biology students learn and understand cell division more effectively than lecture alone.

In a similar study, computer animations were used to teach biology students diffusion and osmosis concepts. Students who were shown animations depicting molecular processes exhibited less misconceptions about molecular processes than students who received traditional instruction (Sanger et al., 2001).

Web-Based Assignments

In addition to research on computer animated demonstrations of science knowledge, one study investigated the effect of online assignments on student learning in undergraduate biology courses. Riffell and Sibley (2005) tested the effectiveness of a web-based module that had students answer biology content-related problems. Students also manipulated java-based models to complete some assignments. Course test scores improved for all students, and the improvement was significant for upperclassmen in the course (Riffell & Sibley, 2005). These results showed that repeatedly solving well-designed problems in a web-based environment can improve student learning of biology concepts.

Technology-Enabled Active Learning

One comprehensive use of active learning strategies to teach physics was reported by Dori and Belcher (2005; Dori et al., 2003), who described how they used technology enabled active learning (TEAL) in a freshman physics course at the Massachusetts Institute of Technology (MIT). TEAL incorporated many strategies described above and included student interaction with software that included web-based visualizations, three-dimensional illustrations and animations, and shockwave visualizations. Faculty members also worked with students to perform collaborative desktop experiments and web assignments.

Based on a multi-year study, Dori and Belcher (2005) found that TEAL instruction improved students' conceptual understanding of the physics subject matter to a significantly higher extent than their control group peers. In addition, student failure rates in the experimental groups were less than 5%, compared to 13% in the traditional setting. Although this research took place in a physics class, the findings are encouraging and support the use of multiple active learning strategies and web-based educational technologies in undergraduate biology courses.

Summary of Active Learning

This review of teaching strategies for promoting active learning shows that these strategies effectively improve student learning. It also reveals some innovative approaches to instruction. For example, there is overall agreement among active learning researchers that having students solve problems increases meaningful learning significantly (Armbruster et al., 2009; DiCarlo, 2006; Ebert-May et al., 1997; Freeman et al., 2007; Michael, 2006; Nelson, 2008; Smith et al., 2005). The evidence also shows that demonstrating biology phenomena using a variety of web-based multimedia increases student understanding of biology concepts (DiCarlo, 2006; Kiboss et al., 2004; Reuter & Perrin, 1999; Sanger et al., 2001). Having students answer questions and solve problems in a web-based environment also appears to improve student ability to solve problems and understand biology content (Riffell & Sibley, 2005).

While research appears to support the use of active learning strategies to increase learning, it is important to note that active learning does not happen without careful instructional design (Michael, 2006). Learning activities must be carefully incorporated into a teaching framework that implements these strategies effectively. Furthermore, it is clear that these kinds of changes take several years to effectively implement into a science program or department (Wyckoff, 2001). Smith and colleagues (2005) acknowledged that incorporating an active learning approach in a large biology course requires a large teaching team, including biology faculty, graduate teaching assistants, undergraduate teaching assistants, and education and technology consultants. The time and resources required for creating courses using active learning is one reason that introductory science courses often continue to use a lecture-based approach (Michael, 2006).

Another reason that active learning research may be difficult to implement is that the methods and strategies are diverse, ranging from in-class collaborative problem-solving to out of class multimedia presentations. Interestingly, few studies I reviewed implemented more than one or two strategies described in this review. Perhaps this is because it can be difficult to incorporate several of these strategies into a cohesive teaching strategy that works together to increase student learning. For active learning to be most successful, it must incorporate and integrate many of the methods reviewed in this proposal (Michael, 2006). The following section describes how these strategies can be effectively organized using a research-based framework for organizing instruction.

A Framework for Organizing Active Learning

Teaching should incorporate multiple strategies to maximize the effectiveness of active learning strategies. Two frameworks that integrate the use of active learning strategies are the 5E Learning Cycle Model (Bybee et al., 2006) and First Principles of Instruction (Merrill, 2002). In the following section, I will briefly describe the 5E Model. I will then describe First Principles of Instruction and discuss why it has been selected as the framework for this study.

One framework for organizing student learning activities is the 5E Learning Cycle Model (Bybee et al., 2006). The model is based around a series of activities that move students through several phases of inquiry, each phase designed to move the students to a deeper understanding of the subject being taught. Phases in the model include: (a) *engagement*, in which learners are engaged in the learning; (b) *exploration*, in which students learn new knowledge and skills through different learning activities; (c) *explanation*, in which students demonstrate their conceptual understanding and skills; (d) *elaboration*, in which students deepen and broaden their understanding by conducting different activities; and (e) *evaluation*, in which students and the teacher assess student understanding and abilities.

There is a body of research that supports the use of the 5E Learning Cycle (Bybee et al., 2006), and many authors have described methods for implementing this cycle (e.g., Orgill & Thomas, 2007; Urey & Calik, 2008). However, this model appears to rely heavily on students solving problems without prior demonstration of problem solving. A growing body of research supports the practice of demonstrating worked examples of problem solving activities to students and slowly transitioning to student problem solving that becomes increasingly complex (Kirschner, Sweller, & Clark, 2006). This is because individuals who are new to a field or a concept benefit greatly from demonstrations of how to use the content, which provide a framework or a reference point for future learning (Kirschner et al., 2006).

Because novice students need an approach that will provide effective demonstration of problem solving, in this study First Principles of Instruction (Merrill,

2002) is used as a framework for organizing active learning instruction in introductory biology courses. This framework provides a logical, systematic method for implementing research-based methods of instruction. In this section I define First Principles of Instruction, show how teaching strategies for active learning fit within this framework, and review previous research related to First Principles.

First Principles of Instruction

Based on an analysis of several instructional theories, models, and best practices, Merrill (2002) proposed that effective teaching implements five fundamental, "First Principles" of instruction. He hypothesized that when these principles are used in instruction, student learning is increased. The following bullets are a synthesis of his prescriptions. Merrill (2002, 2006a, 2007) wrote that student learning is increased when:

1. Instruction is based on a progression of whole **real-world problems** or **tasks**
2. Learners **activate** relevant cognitive structures by recalling, describing or demonstrating relevant prior knowledge and experience, sharing previous experience with one another, and/or recalling or acquiring a structure for organizing new knowledge
3. Learners observe a **demonstration** of the skills to be learned from the instructor and/or peers and are guided to relate general information or the organizing structure to specific instances
4. Learners **apply** their new knowledge and receive feedback and coaching that is gradually withdrawn; application can include having students engage in peer-collaboration
5. Learners **integrate** their new knowledge by reflecting on, discussing,

presenting, or defending their new knowledge.

Merrill (2002) converted these principles to a systematic cycle of instructional phases. These phases should be based on a real-world problem or task and begin with activation, followed by demonstration, application, and integration. Figure 1 represents these principles and phases of instruction.

First Principles of Instruction can be a powerful framework for organizing and incorporating active learning strategies because it advocates strategies that are very similar to active learning strategies. This section describes the similarities between active learning strategies and First Principles. This section also highlights some of the instructional and learning theory supporting these principles. Table 1 summarizes this section and shows the relationship between active learning strategies and First Principles of Instruction.

Problem-centered. Centering instruction on authentic problems provides students with a context for the content they are learning (Duffy & Cunningham, 1996; Merrill, 2002, 2006b). The effective use of problems includes demonstrating the solution of real-world problems (Merrill, 2002) and having students solve real-world problems (Duffy &

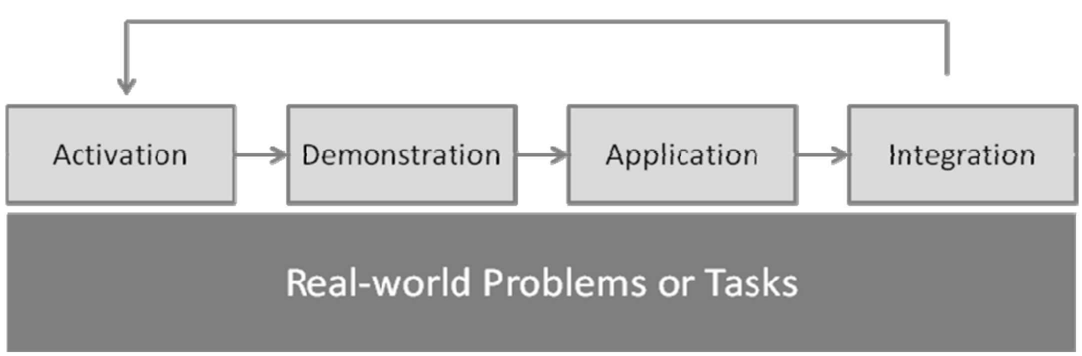

Figure 1. Merrill’s (2002) First Principles of Instruction.

Cunningham, 1996; Merrill, 2002). These problems should be increasingly complex, meaning the first problems presented should be less difficult or complex and subsequent problems should be more difficult or complex as time goes on. The problem-centeredness principle is discussed in greater detail in the “Demonstration” and “Application” sections below.

Several instructional and learning theorists recognize student problem solving as a key component of good teaching. The purpose of centering instruction around problems is to promote students’ ability to solve authentic problems outside of school (Jonassen, 1999). To facilitate learning, these problems should increase in difficulty and complexity as students solve more and more problems (Merrill, 2002, 2006a, 2006b, 2007; Schwartz, Lin, Brophy, & Bransford, 1999) and become increasingly independent (Keller, 1987). In undergraduate biology courses, having students solve increasingly difficult problems using biology content enables students’ understanding of the content and likely facilitates student ability to use it later in life.

Sugrue (1995) reviewed several comprehensive research-based models of problem solving and found that they emphasized several similar themes. In an attempt to synthesize prior research, Sugrue identified three predictors of successful problem solving: (a) domain specific knowledge, including principles, concepts and procedures related to the target problem (b) metacognition, or the ability to plan and monitor problem-solving, and (c) motivation, including perceived self-efficacy, perceived task difficulty, and perceived task attraction. These elements will form the foundation of how I measure problem solving in this study. Later sections of this dissertation will describe how these elements will be measured.

Activation. As illustrated in Figure 1, First Principles can be converted to a cycle of instruction implementing several strategies. In the first phase in this cycle of instruction, prior knowledge is activated. Activation is accomplished by having students describe or demonstrate relevant prior learning related to the subject being taught (Merrill, 2002). Activation is an important strategy because it probes students' prior knowledge and organizes their thinking for what they are about to learn (Ebert-May et al., 1997). Schema theory suggests that the mind is organized into schema, or abstract structures of information (Anderson, 1984), and any newly acquired knowledge is encoded into these mental structures. One assumption of learning theory is that all new learning "depends primarily upon the combining of previously acquired and recalled learned entities" (Gagné, 1968, p. 189). Activating prior knowledge allows students to recall their own knowledge and even how it is structured, which potentially makes it easier to acquire and assimilate new information into that structure.

Having students list and discuss prior knowledge that relates to the problem they are solving also activates prior knowledge and primes the students to learn more about the subject (Allen & Tanner, 2003). This activation of prior knowledge prepares students to gain new knowledge because it helps students recognize what they already know and facilitates the assimilation of the new knowledge within their own mental knowledge structures.

Activation also involves providing an organizing structure to the knowledge being presented (Merrill, 2002). This is important because providing students with a conceptual model of the information structure can help them organize information they receive (Collins, Brown, & Holum, 1991). This can be accomplished in several ways; for example, providing students with a simple analogy primes students with something they can understand and provides a structure for the new knowledge to be acquired (Mayer, 1999). Another method might include providing organization to a learning module which explicitly structures the information to match the content being learned (Mendenhall, Caixia, Suhaka, & Mills, 2006; Merrill, 2002). Whatever method is used, giving students a structure for what they will learn can help them to organize and integrate new knowledge into their existing knowledge (Mayer, 1999).

Demonstration. In the second phase of instruction, students should be given a demonstration of what is being taught (Merrill, 2002). Giving students a case on which they can build their knowledge is important because people tend to solve problems by referring to previous similar experiences and knowledge (Kolodner, 1997). Because student reasoning is based on previous experience (Kolodner, 1997, p. 58), instruction can engender that reasoning by providing several example cases to learners so that they have some experience (if only by proxy) to base their decisions on (Schank, 2001). Providing examples and cases to students allows them to reason with those cases (Kolodner, 1997).

Providing information to students in the form of a problem and solution facilitates student learning of that problem. Mayer (1992) proposed a basic model for how individuals construct their own knowledge. This model includes three basic processes: Selecting information, organizing that information, and integrating it into existing knowledge structures. Providing an appropriate problem-centered demonstration facilitates student selection of the information related to that problem and organization of information related to the context in which the problem takes place.

Effective demonstration includes two major parts: (1) demonstration of a real-world problem being solved, and (2) demonstration designed to help students acquire knowledge and skills used to solve that problem (Merrill, 2002, 2007). For example, instruction that teaches students how to analyze how microevolution is working in a population should provide a demonstration example of a person solving the problem that overviews the entire process of analyzing the population. It should then provide detailed demonstration and explanation of the activities and knowledge used each of the steps in that process. In this way, students are provided with a context for the task being learned (analyzing microevolution in a population) and specific instruction of how to accomplish each of the steps (Mendenhall et al., 2006).

Active learning research and literature highlights the importance of demonstrating knowledge to students in both of these ways. For example, demonstrating to students how to do a content-related task before having the student attempt to do a similar task is key (Michael, 2006). In addition, using web-based computer animations representing biology phenomena is a form of demonstration that enables student understanding of the content (DiCarlo, 2006; Kiboss et al., 2004; Reuter & Perrin, 1999; Sanger et al., 2001).

Application. In the next phase in the cycle of instruction, students should apply their new knowledge in meaningful ways (Merrill, 2002). This application includes having students apply their knowledge by solving real-world problems using the content they are learning and applying knowledge by answering content-related questions. Student application of knowledge is important because people think about how to act based on experience (Kolodner, 1997), and providing students with relevant experience will increase the ability to act appropriately in the future.

Several active learning researchers use strategies that have students apply their knowledge in both of these ways (Ebert-May et al., 1997; Nelson, 2008; Smith et al., 2005). For example, having students regularly answer complex questions and problems in class increases student learning and decreased course failure rates (Freeman et al., 2007). This problem solving can include presenting students with a problem and having them work as groups to solve these problems (DiCarlo, 2006). It is worth noting that having students solve multiple problems and questions in web-based modules improves student understanding of biology content (Riffell & Sibley, 2005). It is clear that having students apply their knowledge improves their learning.

Integration. In the final phase of instruction, it is important to encourage students to integrate their knowledge into their lives (Merrill, 2002). This can be done by having students discuss, debate, and reflect on what they are learning. These strategies are important because “small group discussion and debate... enhances problem solving and higher order thinking and promotes shared knowledge construction” (Hmelo-Silver, 2004, p. 246). Providing opportunities for reflection can also enhance integration of new knowledge (Perkins & Unger, 1999). Using debriefing activities can help students to consolidate and internalize the key concepts learned during the instruction; in addition, having students relate what they are learning to their future goals can improve student motivation to learn more and use it in the future (Keller, 1987).

There are several strategies from the active learning literature that appear to incorporate this principle. Having students articulate explanations about what they are learning (Michael, 2006) or discuss and reflect on course content (Brewer, 2004) can increase student learning. Ebert-May and colleagues (1997) reported that including student discussion as a part of an active learning teaching strategy helped increase student understanding of the content being taught. Having students engage in extensive discussion about their solution to the problem promotes student reflection on the problem solving process (Allen & Tanner, 2003). Having students articulate their scientific reasoning can also increase student learning (Wyckoff, 2001).

First Principles and Active Learning

It is clear from this review that there is a strong parallel between First Principles of Instruction and active learning teaching strategies. Table 1 summarizes these relationships.

Merrill's (2002) cycle of instruction based on these principles provides a framework into which active learning strategies can be integrated. For example, when beginning active learning instruction for teaching microevolution, students' previous knowledge of what evolution is and what a population is should be activated. Students should also receive a structure for organizing the new knowledge they will learn (e.g., a three step process for analyzing the population). Students should then view a demonstration of biologists analyzing microevolution in a population. This demonstration should show students how to solve real-world problems and can include cases or

Table 1

Active Learning and First Principles of Instruction

First principles of instruction	Strategies used in active learning
Problem-Centered	Base learning activities around problem-solving (Armbruster et al., 2009)
	Have students work as groups to solve problems (DiCarlo, 2006)
	Have students use scientific and critical thinking to solve content-related problems (Nelson, 2008)
Activation	Ask a question to probe student prior knowledge and organize their thinking for what they are about to learn (Ebert-Ma et al., 1997)
	Have students list and discuss prior knowledge related to the problem they are solving (Allen & Tanner, 2003)
Demonstration	Use case studies and associated problems to engage students in the learning process (Smith et al., 2005)
	Show students computer animations and models to represent biology concepts (Kiboss et al., 2004; Reuter & Perrin, 1999; Sanger et al., 2001)
Application	Have students answer complex questions and problems during class (Freeman et al., 2007)
	Have students answer questions and solve problems using web-based technologies (Dori & Belcher, 2005; Riffell & Sibley, 2005)
Integration	Allow students to discuss and reflect on their learning (Ebert-May et al., 1997)
	Have students articulate explanations about what they are learning (Michael, 2006)

multimedia presentations. Students should then be given the opportunity to solve real-world problems collaboratively with other students and answer questions that help them apply their knowledge. Finally, students should have the opportunity to discuss, reflect on or present their new knowledge.

Not only do First Principles provide a framework for active learning strategies, they can potentially increase their effectiveness. For example, active learning research indicates that computer animations can increase student learning. But how should these animations be developed and presented? First Principles synthesizes research and best practices to provide very clear descriptions for the most effective use of visual demonstrations (Merrill, 2006a), thereby potentially enhancing active learning strategies. I hypothesize that using First Principles of Instruction as a framework to organize and enhance active learning strategies will yield significant learning increases for students in undergraduate biology courses.

First Principles of Instruction have been called a “lesson framework with a more constructivist appearance” (Molenda & Boling, 2008, p. 112). Bednar, Cunningham, Duffy, and Perry (1991) wrote that from a constructivist perspective, ‘the learner is building an internal representation of knowledge, a personal interpretation of experience…. Learning is an active process in which meaning is developed on the basis of experience” (p. 91).

One of the implications of the constructivist approach is that instruction should use problems as a stimulus for authentic activity (Duffy & Cunningham, 1996, p. 190). Problem-based instruction has the potential to allow students to construct knowledge that can be used in the real world. This construction of knowledge is often viewed as personal to the learner, and the focus on experience in real-world contexts supports the idea that students should engage in problems they will likely encounter in the real world, which would facilitate the construction of knowledge that is useful in real-world contexts.

This section highlights the relationship between active learning strategies and First Principles of Instruction. It also demonstrates how active learning strategies can be incorporated into a cycle of instruction based on these principles. I hypothesize that the use of these principles will enhance the use of active learning strategies because they integrate research-based best practices for implementing these strategies. In the following section, I review research supporting First Principles of Instruction.

Research Support for First Principles of Instruction

To identify previous research related to First Principles of Instruction, I conducted a review of literature discussing research using First Principles of Instruction. Google Scholar, as well as The ERIC and Education Full Text databases were searched using the keywords “first” and “principles” and “instruction.” In addition, David Merrill, Anne Mendenhall, and Max Cropper, all knowledgeable in research on First Principles of Instruction, were contacted directly and asked for any articles or publications related to this subject. Articles were included if they reviewed or included research related to First Principles of Instruction.

The results of this search produced six articles. Two were articles describing cases in which First Principles of Instruction were used in higher education. Two studies researching First Principles of Instruction as a whole were found. Finally, two articles were found that synthesized research conducted on the individual First Principles of Instruction.

Cases reporting on First Principles. Two authors described how First Principles of Instruction have been used in undergraduate courses. One case, reported by Mendenhall and colleagues (2006), described how a hybrid entrepreneurship course utilizing First Principles of Instruction used real-world tasks to teach the process and skills of starting and managing a business. This report described a web-based module that provided students with real-world examples of former students starting and managing businesses and had students practice parts of these tasks in an interactive FLASH environment. The description of the strategy used is innovative and useful and will be considered when the module for this study is designed and developed. However, there is no report of how effective this approach was compared with traditional strategies.

Francom and colleagues (2009) described a peer-interactive, problem-centered instructional strategy used in an introductory biology course. This case described how an instructional cycle of demonstrating worked examples of problem-solving followed by team problem-solving activities were employed to increase the depth of biology learning. The results of this study are positive and showed high levels of student satisfaction, with 76% of students indicating that they preferred this method of teaching to other general education teaching methods they had been exposed to. While this study incorporated a full instructional strategy for an entire biology course, it also failed to compare student achievement results with traditional instruction. This kind of data would provide us with a greater understanding of the degree to which a problem or task-centered strategy can improve student learning at different levels such as those described in Bloom's revised taxonomy (Anderson et al., 2001; Krathwohl, 2002).

Research on First Principles of Instruction as a whole. Frick and colleagues (2007) surveyed 140 students at 89 institutions of higher education to discover the correlation between academic learning time (student time and effort spent learning in a course) and First Principles of Instruction and student mastery of course objectives. The results of this study indicate that students were nine times more likely to report that they had mastered course learning when First Principles were reported in the student survey to have been used and when students spent much time and effort learning course materials. This correlation between the use of First Principles of Instruction and student perceived class success provides some support for their implementation in courses in higher education. Interestingly, no studies reported the impact of First Principles on student learning when compared with traditional instruction in higher education.

One study conducted by the NETg Corporation compared a web-based module using First Principles of Instruction to teach Excel with traditional web-based instruction (Thomson, 2002). The results of the study indicate that students in the First Principles of Instruction group performed significantly better than students exposed to traditional e-Learning at solving real-world problems using Excel. The use of First Principles of Instruction resulted in a 30% improvement in accuracy over the traditional e-Learning instruction, as well as a 41% improvement in time spent solving the problems. While the Thomson study shows a significant improvement in the performance of students taught to use Excel through First Principles of Instruction, there is still a need to test the effectiveness of First Principles of Instruction in the university setting.

Research on individual principles. There have been many studies on each of the individual First Principles of Instruction. Merrill (2006a) reviewed a number of authors who provided empirical support for the individual principles of instruction. See Table 2.

The authors cited in Table 2 provide support for the individual principles of instruction, adapted from Cropper (2007). In addition to the research cited, Cropper

Table 2

Authors Supporting First Principles of Instruction

Author	Problem-centered	Activation	Demonstration	Application	Integration
Andre (1997)		X	X	X	
Clark (1994)	X		X	X	
Clark & Mayer (2008)	X	X	X	X	
Dembo & Young (2003)			X		
Marzano, Pickering, & Pollock (2001)	X	X	X	X	X
Mayer (2003)			X		
Rosenshine (1997)	X	X	X	X	

identified and reviewed seven meta-analyses that provide support for these principles individually (Bennett, 1986; Bransford, Brown, & Cocking, 1999; Ellis, Worthington, & Larkin, 1994; Friedman & Fisher, 1998; Marzano, 1998, 2003; Marzano et al., 2001) and concluded that there is significant evidence for each of the individual principles. Specifically, one meta-analysis supported the problem-centered principle, six supported activation, seven supported demonstration, seven supported application, and three supported integration. These meta-analyses provide further support for these individual principles of instruction.

Although these principles appear to have growing support, current instruction still often includes only the presentation of information while implementing very few of these principles (Barclay, Gur, & Wu, 2004; Cropper, 2007; Merrill, 2006b). The information-only lecture approach is still employed in many undergraduate biology courses, resulting in poor higher-order learning and poor performance on assignments and exams in those courses (Alters & Nelson, 2002; Crowe et al., 2008; Francom et al., 2009; Freeman et al., 2007; Michael, 2006; Wyckoff, 2001). In addition, few studies have specifically implemented First Principles as a cycle of instruction and tested them as a whole. Because First Principles of Instruction provides a framework for employing active learning strategies and teaching knowledge and skill in the context of real-world problems, they can be used to enable student construction of knowledge.

Purpose and Objectives

Based on the above review, it appears that active learning strategies increase student learning. However, much current research on teaching for active learning in undergraduate biology courses does not integrate active learning ideals into a cohesive strategy. In addition, no research has been conducted to investigate the effectiveness of First Principles of Instruction in increasing student learning in undergraduate biology courses. Therefore, the purpose of this study is to investigate how effectively active learning strategies using First Principles of Instruction as an organizing framework improve student learning in an introductory undergraduate biology course.

Research Questions

This study investigated the following research questions.

1. Compared to students receiving traditional web-based supplementary instruction, do students receiving supplemental instruction incorporating Merrill's First

Principles of Instruction perform better at the “remember” and “understand” levels of Bloom’s Taxonomy?

2. Compared to students receiving traditional web-based supplementary instruction, do students receiving supplemental instruction incorporating Merrill’s First Principles of Instruction perform better at solving content-related problems?

CHAPTER III

DESIGN OF THE MODULES

Treatments

The independent variable for this study was the type of instructional strategy employed. There were two versions—the web-based FLASH module using First Principles of Instruction (hereafter called “First Principles module”) and a web-based FLASH module using more traditional approach (hereafter called “traditional module”). The instructional strategies used in these modules are described in detail below. The process used to design these modules is also described.

First Principles Module

This module followed the cycle of instruction described by Merrill (2002) in which activation, demonstration, and application strategies were employed based on the real-world tasks of analyzing microevolution in several populations. The first section of the module provided a video overview of the topic to be covered and a preview of the sequence of the module. The video also oriented students to the organizing structure of this course, which served as an activation strategy (Merrill, 2002, 2006a). In this case, the organizing structure consisted of tabs across the top of the module that related to the three whole tasks to be performed in the module. It also consisted of tabs on the left-hand side of the module that related to the three component strategies included within each whole task. When students viewed content related to each of the component steps in the problem solving process, the tab for that step was highlighted on the left of the content display. Figure 2 shows the layout of the organizing structure. The tabs across the top display the whole tasks in the module and the tabs on the left correlate to the three component strategy steps. The tabs on the left become highlighted with that particular component strategy step is being taught or applied. The content is presented in the middle of the screen, and Figure 2 shows a still capture of a video introducing the organizing structure.

Whole Tasks

As mentioned above, students worked through three separate whole tasks during this module. Each task consisted of an overview that provided students with the facts necessary to complete each component strategy step in the problem solving process. The tasks included biologists studying microevolution in populations of (a) moths, (b) people

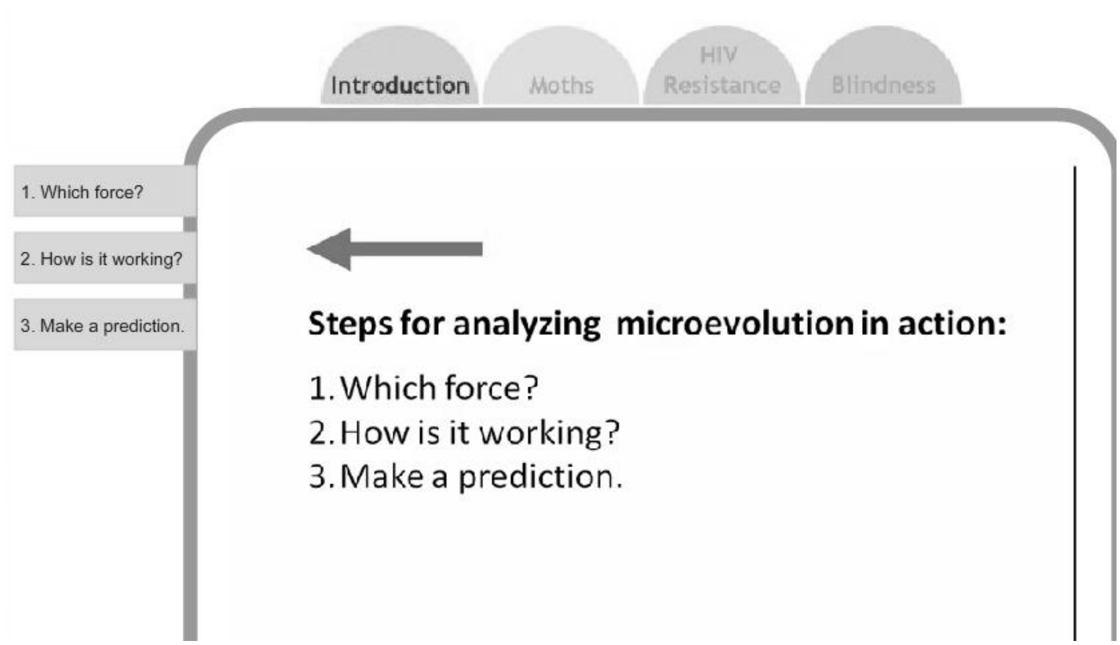

Figure 2. Organizing structure layout.

experiencing genetic blindness, and (c) people experiencing HIV resistance. Students then were shown a demonstration of biologists completing each component strategy, as well as a summary video that summarized the whole task. As students progressed through the module, they assumed more and more responsibility for each component strategy and performed each strategy on their own. Table 3 summarizes the strategies used in the First Principles module. For example, in task one, the three component strategies or steps were taught with pure demonstration (column 2). Then after the first task was demonstrated, students received additional instruction on how to perform component step 1, including detailed demonstration and application of step 1.

The design of the First Principles module for this study (described in detail below) primarily supports students' domain-specific knowledge related to problem solving. Problems in this module focus on the real-world task of hypothesizing which forces of evolution are at play in a population and how those forces are affecting the population. Biologists studying microevolution often study different populations of a species, and a fundamental task or problem performed by these scientists is hypothesizing

Table 3

Strategies Used in the First Principles Module

Module	Task1	Task 2	Task 3
Component 1	Demonstration	Application	Application
Component 2	Demonstration	Demonstration	Application
Component 3	Demonstration	Demonstration	Application
Additional instruction	Component 1 detailed demonstration Component 1 detailed application	Components 2 and 3 detailed demonstration Component 2 and 3 detailed application	

which forces of evolution are at play and predicting what will happen to the population based on these forces (Gregory Podgorski, personal communication, May 9, 2010). Students using this module will go through several real-world tasks in which this ability is demonstrated to and applied by the students. Table 4 demonstrates Sugrue's (1995) domain specific knowledge constructs and describes how these categories organize the general components skills associated with being able to effectively analyze a microevolution problem. The column on the left includes the problem solving components described by Sugrue and the column on the right describes how these components are used in microevolution problem solving.

Task One

The first task described a scenario in which biologists analyzed a population of peppered moths to understand how microevolution was affecting it. Students were first shown an overview video that provided details related to the problem to be solved (see Figure 3).

Table 4

Components of Microevolution Problem Solving

Components of domain specific knowledge construct in problem-solving (Sugrue, 1995)	Problem-solving abilities in microevolution (Personal Communication, Gregory Podgorski, March 6, 2010).
Concepts	Hypothesize what specific force of evolution is at play in the problem given.
	Hypothesize how this force of evolution is acting on the population.
Principles	Predict what will happen to the population in the future based on the microevolution taking place.

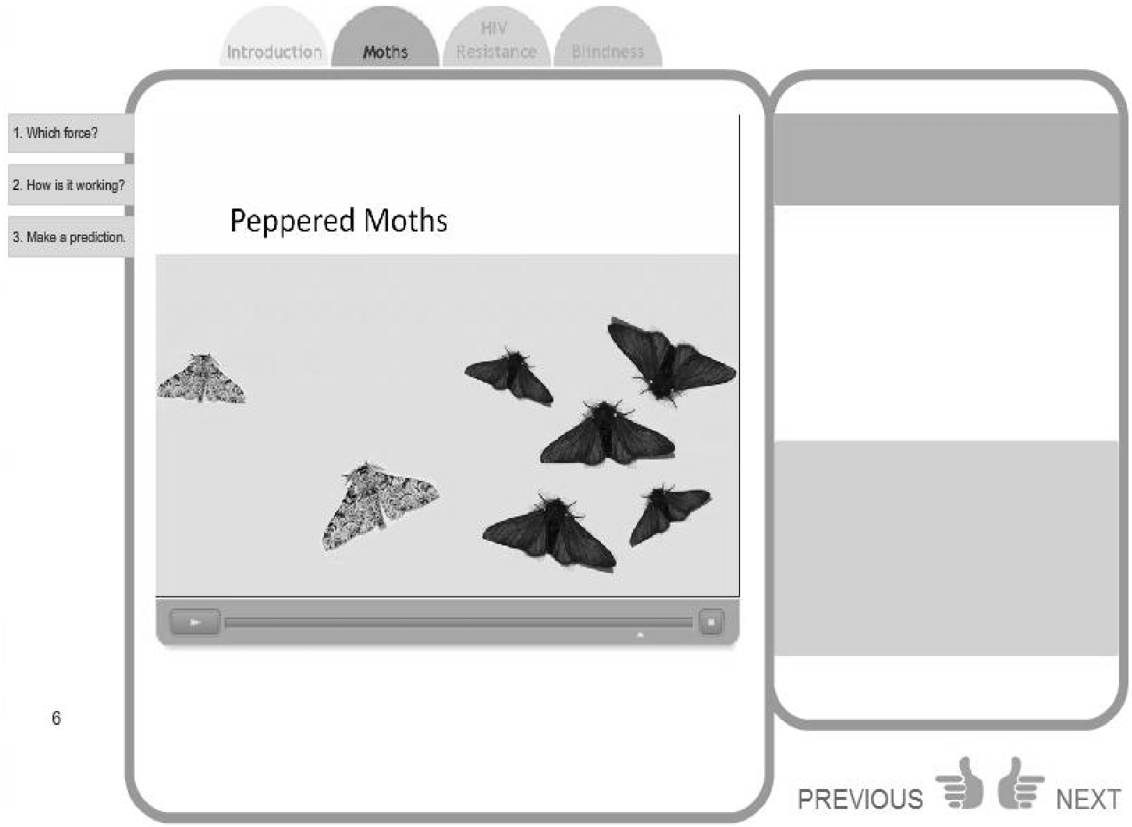

Figure 3. Problem introduction—peppered moths.

After viewing the introduction, students were taught each of the component strategies for analyzing microevolution in the population. The component strategies were taught using video demonstrations in which general information was displayed on the left, and the specific instance of that knowledge was demonstrated on the right. For example, as shown in Figure 4, natural selection is defined on the left side of the video screen and a general definition of how it works is provided. Then students are shown on the right of the video screen how this force is at play in the population of peppered moths. This same pattern was followed for component strategies two and three: general information is portrayed on the left and a specific instance of the information is displayed

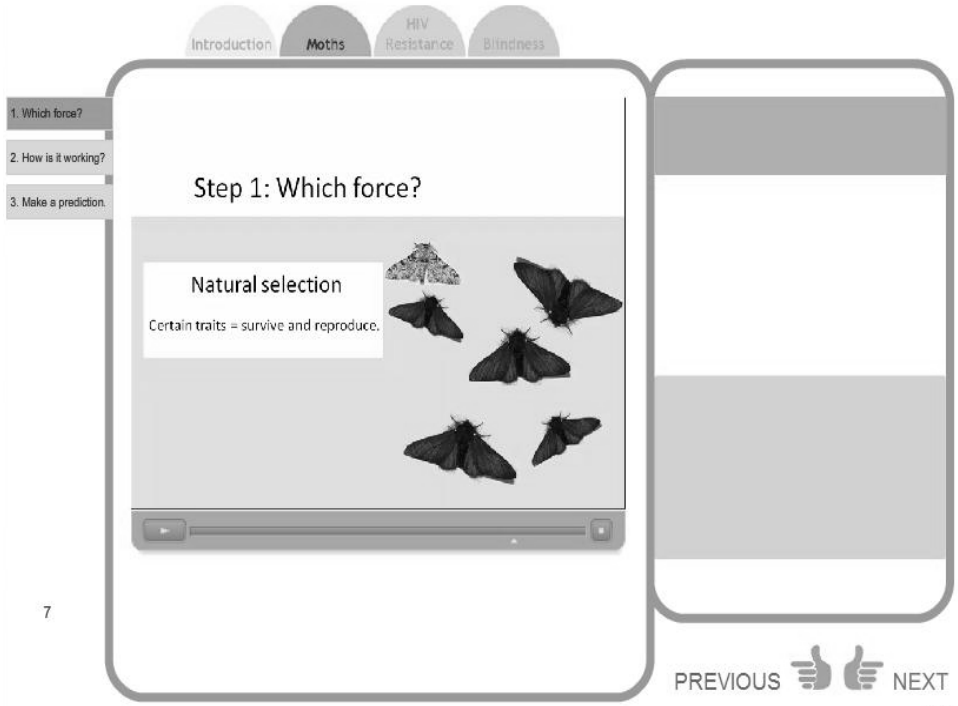

Figure 4. Step 1 demonstration—peppered moths.

on the right. After viewing videos describing how and why biologists hypothesized microevolution was acting on the population, students viewed a video summarizing the three step process. Figure 5 shows a still capture of the video summarizing the steps.

After the demonstration of the first whole task, students were directed to view a more detailed demonstration of how to perform the first component strategy: identifying which force of evolution is acting on the population. In this case, the students watched four short videos that described how each of the four forces of evolution acts on a population. See Figure 6 for an example of a demonstration of the force mutation.

In each video, a short definition of the force of evolution was provided on the left side of the screen, and then an example was given that showed how this force of evolution works in a population of beetles. As this demonstration was given, the narrator

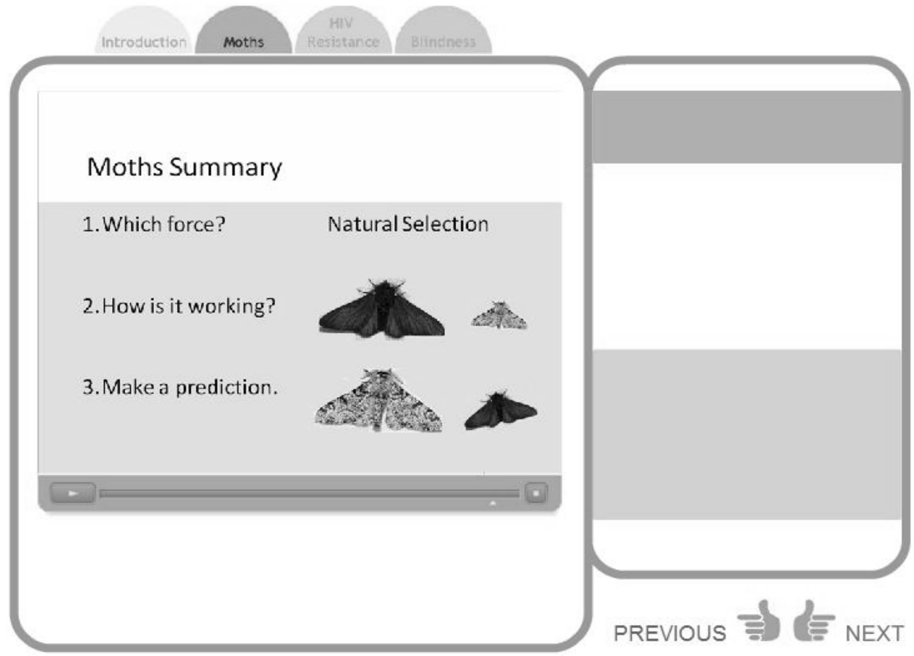

Figure 5. Summary of steps—peppered moths.

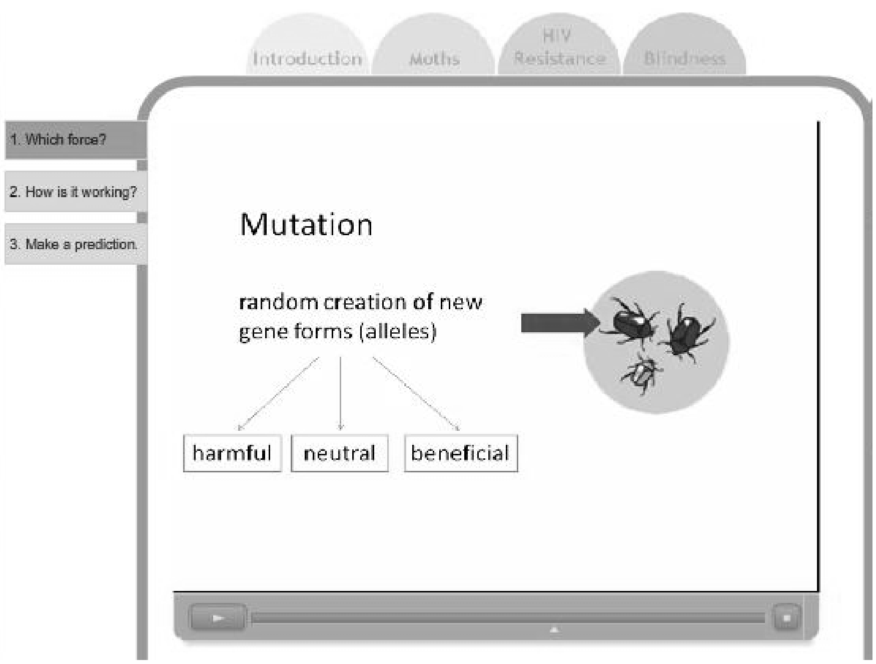

Figure 6. Component one demonstration—beetles.

described how biologists performed step one in the problem solving process for analyzing microevolution in a population. It coached students on the thinking behind each step as well, showing students how a biologist would approach the specific problem. In each of these videos, I attempted to utilize sound multimedia principles as described by Clark and Mayer (2008). For example, as shown in Figure 6, arrows were used to focus the students' attention on specific elements of the display at the time those elements were being discussed. In addition, content on the screen would appear as it was being discussed to assist in focusing student attention.

After viewing videos teaching the four forces of evolution, students were given the opportunity to apply what they had learned to four different cases of microevolution. Students were given scenarios in which microevolution was taking place and were asked to identify which force was acting on the population by selecting that force from a list provided on the right. When students made a selection, they were provided with text giving feedback on their selection. If the incorrect selection was made, they were informed why their selection was incorrect and were given the opportunity to select another force. When students selected the correct answer, they were provided with a brief explanation of why that selection was the correct answer. See Figure 7 for an example of how students were given the opportunity to apply component strategy 1. Feedback was provided in text in the bottom-right hand side of the screen.

Task Two

After learning in detail how to perform the first component strategy and applying that knowledge to several real-world scenarios, students worked through the next whole

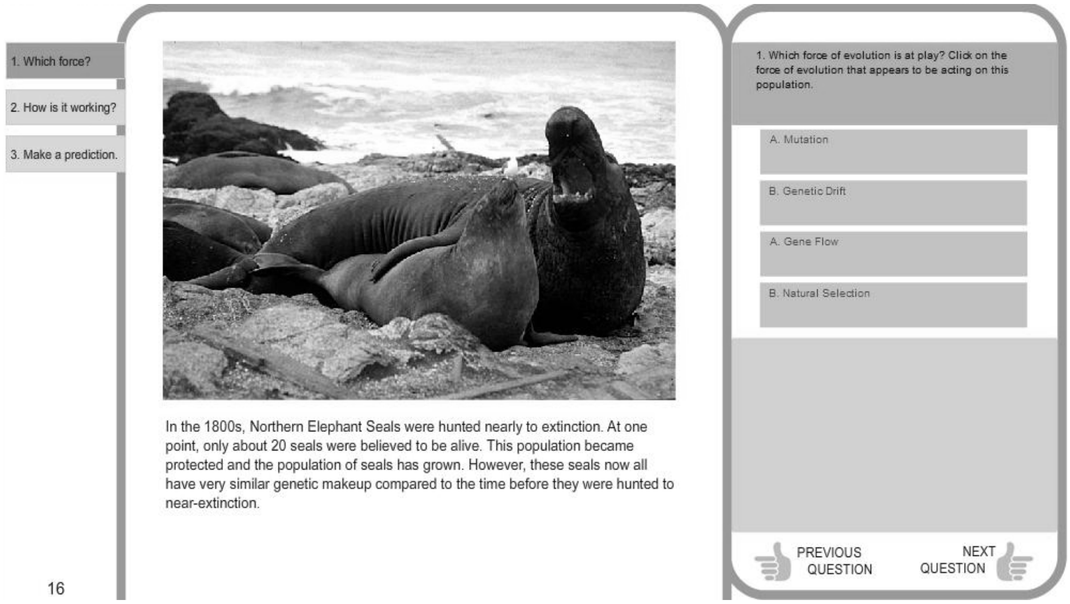

Figure 7. Component one application—seals.

task, which described how some people in a population had developed a resistance to HIV. In this task, students were shown an overview video providing them with the givens of the task as shown in Figure 8. Students were then asked to perform the first step of the task, identifying which force of evolution was likely acting on the population, shown in Figure 9. This application strategy followed the same pattern as described above, and students were provided with clear feedback on their responses.

After performing the first component strategy, students watched videos describing how biologists performed the second and third component strategies for task two. These videos followed the same strategies described above- students observed how biologists would approach the t ask of analyzing microevolution in the population of people. They then watched a video summarizing task two, which followed the same pattern as shown earlier in Figure 5.

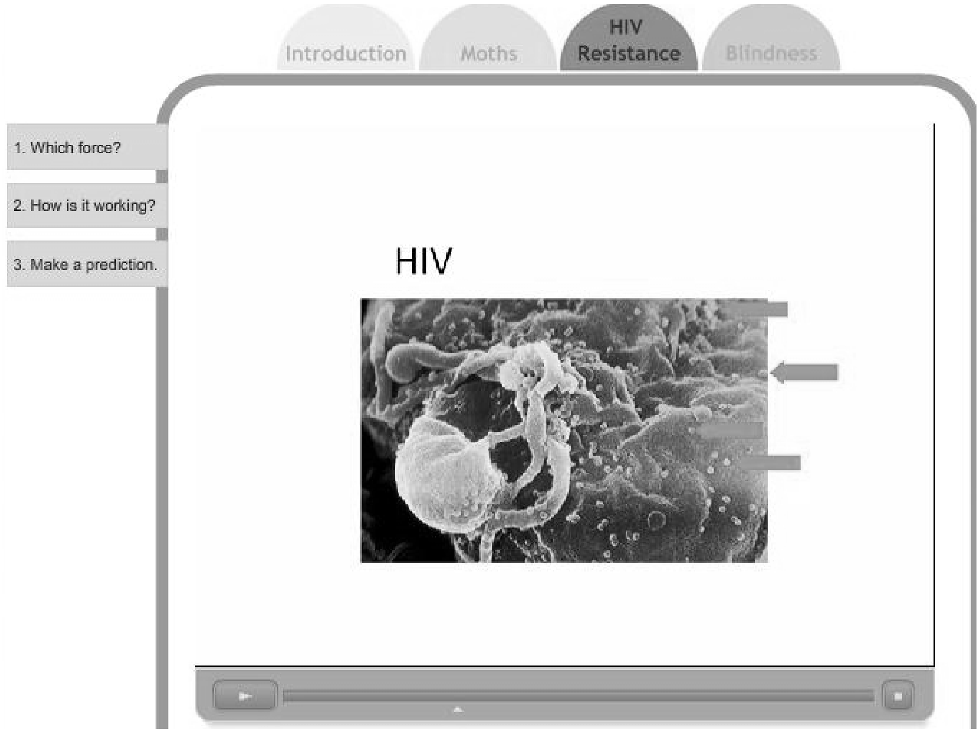

Figure 8. Introduction—HIV resistance.

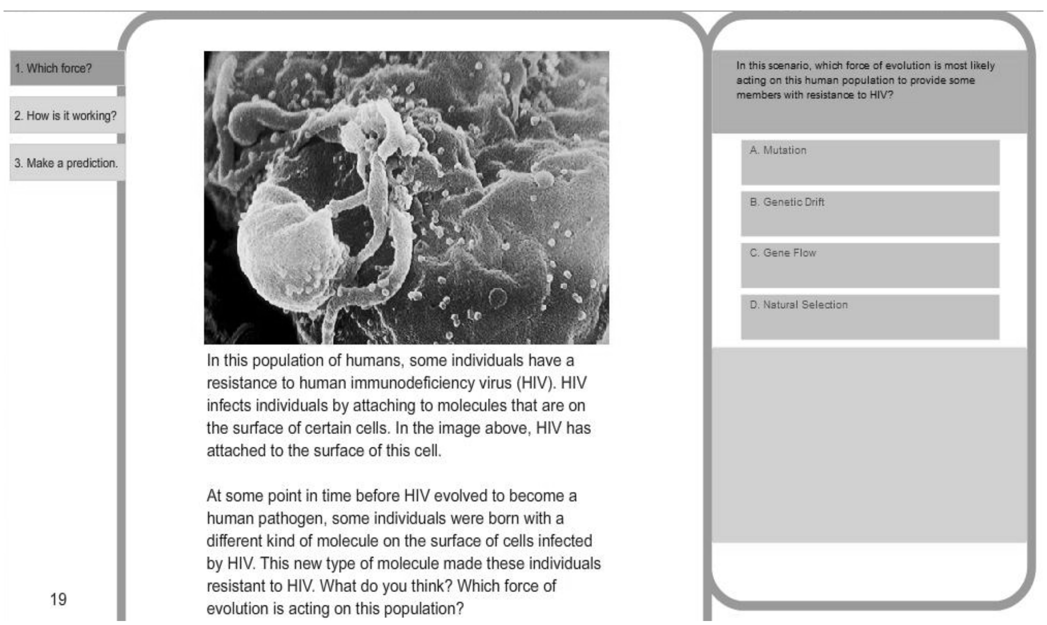

Figure 9. Component one application—HIV resistance.

After the second whole task, the module provided more detailed demonstration and application activities for the second and third component strategies: hypothesize how this force is acting on the population and hypothesize how the population might change over time. These demonstration and application strategies followed the same strategy as those used for the first component strategy taught after Task 1 (see Figures 6 and 7). Students watched several videos demonstrating how the force interacted with a population of beetles and then applied what they knew to several real-world scenarios.

Task Three

In the third whole task, students were asked to analyze how evolution was acting on a population of people with high incidence of genetic blindness. Students watched an overview video that provided them with the givens of the task similar to that shown in Figure 3. Students were directed to perform the entire task including all three problem solving components. The application format was the same as shown in Figure 7. Students performed each component strategy in sequence and were provided with feedback on their application. Task Three ended with a video summarizing the three components.

Cycle of Instruction

Instruction accompanying each task followed the First Principles framework of instruction (Merrill, 2002). The first phase of instruction was activation, in which students were provided with the organized structure described above. Students were also oriented to the module through a short video describing how the module functions and progresses.

The second phase of instruction, demonstration, presented students with a biology problem and demonstrated how biologists analyzed microevolution in a population of peppered moths. Demonstrations in this module utilized the multimedia principles highlighted by Clark and Mayer (2008). The initial problem provided students with more demonstration than application, while later tasks provided a decrease in demonstration and an increase in student application. The demonstration phase included a presentation of the problem solving skills as well as a presentation of information related to the problem.

The application phase of instruction allowed students to apply what they learned to new problems. The module gave students increasing responsibility to apply their knowledge as the module progressed. In the first problem, students primarily watched a demonstration of how to solve the problem of analyzing microevolution in a population. For the second task, students watched a demonstration of how the task was performed but also helped perform a portion of that problem solving. Finally, in the third task, students solved the entire problem by performing all three component strategy steps and answering questions related to the problems presented and the component skills associated with the problem. Each time a student applied new knowledge, they were given feedback on that application.

Design Process for First Principles Module

This module was designed using the "pebble-in-the-pond" approach for designing task-centered instruction (Merrill, 2002, 2006). The pebble-in-the-pond model guides the creation of task-centered instruction and utilizes six phases or ripples in the design process. These ripples begin with the initial phase and ripple out to the remainder of the phase. These ripples include: (a) specify a real world task, (b) identify a progression of tasks, (c) specify component knowledge and skill, (d) specify and instructional strategy, (e) develop the interface, and (f) produce the instruction. This section describes the process used for designing the First Principles module.

Specify a Real-World Task

The first ripple in the model is to specify a real-world task. Over the course of several weeks, I met with Dr. Greg Podgorski to discuss what tasks biologists perform related to microevolution. Because we were planning to teach a very complex subject matter to novice learners, we chose to work with a very simple real-world task. In this case, the real-world task consisted of analyzing and hypothesizing how microevolution is affecting a specific population. Forming a hypothesis is a crucial step in the scientific process, and hypothesizing how microevolution is working on a population is an important real-world task.

Identify a Progression of Tasks

To identify a progression of tasks, I searched through several resources to identify real-world examples of microevolution that might be used as real-world tasks. Dr. Podgorski provided several reference sources including slides from his classroom lectures. I also performed several online searches to find relevant examples of microevolution.

Over the course of several days, Dr. Podgorski reviewed the identified tasks and helped to select those real-world examples that would best fit the task. After several reviews, whole tasks were selected, as well as the real-world examples used to teach component strategies.

Specify Component Knowledge and Skill

Based on the whole tasks identified, Dr. Podgorski suggested three component strategies to be included in the whole task. These included: (a) hypothesize which force of evolution is acting on the population, (b) hypothesize how this force is affecting the population, and (c) predict how this population will change over time based on what you know.

Specify an Instructional Strategy

After identifying the tasks and component skills, I developed an instructional strategy based on First Principles of Instruction described above. This strategy was developed into a storyboard that included a script and a description of the images and interactions for the module. An example storyboard frame can be seen in Figure 10 and the full storyboard can be found in Appendix Q. The storyboard was created in PowerPoint in which each slide represented a screen or frame within the module. In addition, each frame within the storyboard contained text describing the audio, written text, questions, answers and feedback associated with a particular screen. Over the course of three weeks, Dr. Podgorski reviewed the scripts and text and provided valuable feedback on improving the accuracy and effectiveness of the materials. He also helped

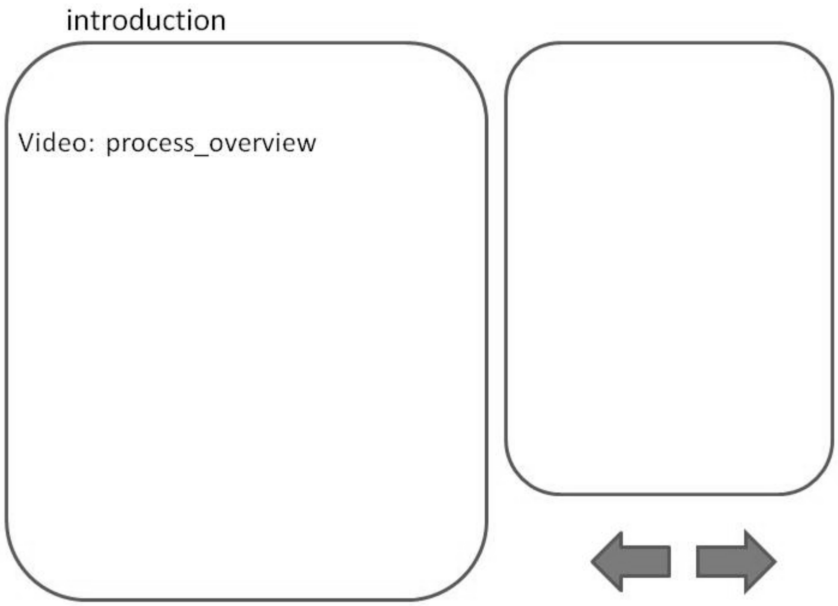

Figure 10. Example storyboard screenshot.

create and refine application questions, answers and answer feedback. After finalizing the instructional strategy, text, and scripts for the module, David Merrill, creator of First Principles of Instruction, reviewed the instructional strategy and provided me feedback and guidance on how to improve the strategy. He provided insights on how to improve the organizing structure of the module and recommended using a three-tab structure to the left of the module so that students would know which component strategy they were learning or applying. Merrill also clarified effective methods for creating high quality multimedia presentations. Specifically, he recommended providing general information on the left of the presentation screen and specific examples on the right when teaching component skills. This feedback and guidance was incorporated into the development of the FLASH interface, as well as the video presentations.

Develop the Interface

The development of the module included the creation of several instructional videos, which were developed using PowerPoint and Camtasia. The visuals for the presentations were created in PowerPoint using text and images to orient students to the relevant information being presented. As described and illustrated above, these videos presented general information (definitions, explanations) on the left side of the video screen and specific examples of this information on the right.

I used Camtasia to record audio related to these videos. After recording the videos, additional animations were provided which were intended to focus student attention on the topic being discussed. For example, if an image was being discussed, it would appear on the screen at the time it was introduced and arrows would point to specific parts of the images as those parts were being described. An example of this can be found in Figure 6 above.

The FLASH interface was designed and developed by two Faculty Assistance Center for Teaching (FACT) coworkers, Rebecca Clark and Tae Jeon, and myself. Most of the FLASH interface for this and the comparison module were previously developed during the fall 2009 and spring 2010 semesters. However, as mentioned above, one new interface change was included: the three tab structure on the left side of the module which was designed to orient students to which component strategy is being demonstrated or applied in a given instance.

Module Production

After the videos were developed and the text finalized, the module was produced in the FLASH interface. The text, images, videos, question, answers, and feedback were implemented into the interface. The production was executed by Clark and went through several iterations based on formative evaluation feedback.

The module underwent several formative evaluations. The first were two formative evaluations in which I reviewed the module and identified navigation problems. The next formative evaluation was a one-on-one evaluation in which an undergraduate student used the learning module as if participating in the study. I observed the student using the module and noted problems with navigation and minor errors in the instructional text, the application questions, and the application feedback.

Typical problems identified in formative evaluations included spelling errors, content implemented into the incorrect section of the module, missing or incorrect application feedback, and frustrating or unconventional navigational functions. I noted these problems and created a detailed list of revision tasks describing how to correct and improve content and navigational problems. The revisions were completed by the developer and the next formative evaluation was then executed. This development, evaluation and revision process lasted two weeks.

Traditional Web-Based Module

To offset the variable of time spent studying materials, students in the comparison group spent about 45 minutes studying using a traditional web-based module. This module was designed to be similar to typical instructional modules that provide information to learners efficiently with some demonstration of examples. Traditional modules typically include an information-only approach to instructional design (Barclay et al., 2004), and in this module, students viewed and listened to short video lectures, read information related to microevolution, participated in drag-and-drop learning activities and answered information-related questions. The comparison group studied for the same length of time as the experimental group to maintain a balance of time spent studying the materials during the experiment. The organization of and activities in this web-based module are described in greater detail below.

The traditional module was organized using a topic-centered approach. Five major sections were included in the module: introduction, mutation, genetic drift, gene flow, and natural selection. In the introduction, students were provided an overview of the subject area, which began with definitions of microevolution and how it relates to the study of evolution. Students were then introduced to the four forces of evolution, which were taught in greater detail in later sections of the module. The four sections following the introduction provided information about and description of each of the four forces of evolution and gave examples of these forces. Figure 11 demonstrates the organization and layout of the traditional module, including the five tabs across the top, representing the five sections of the module.

Introduction

Students first viewed an introductory video, which provided them with an overview of the four forces of evolution. The video organized the content visually in the form of a concept map to provide some structure for information. A screenshot of this video is included in Figure 11.

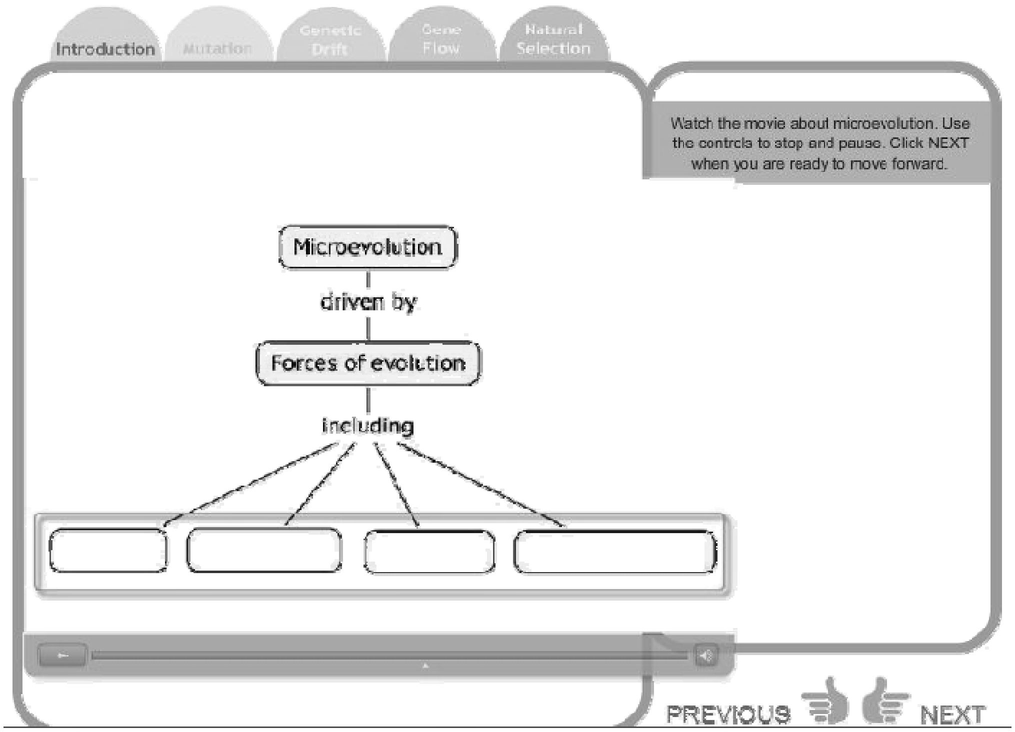

Figure 11. Introduction video.

After viewing the introduction video, students were given definitions and simple examples of the four forces of microevolution. These introduced each of the forces further and provided an increase in information about each force. Figure 12 shows how mutation, one of the forces of evolution, was taught in the introduction. This format was repeated for each of the other forces during the introduction.

After reading definitions and simple examples of the four forces of microevolution, students were provided with a mouse-over activity as shown in Figure 13. The purpose of this activity was to reinforce the definitions of the forces. Students were directed to move the cursor over the different components of the map. As they moused over the components, the definition of each concept would pop up, as displayed in Figure 13.

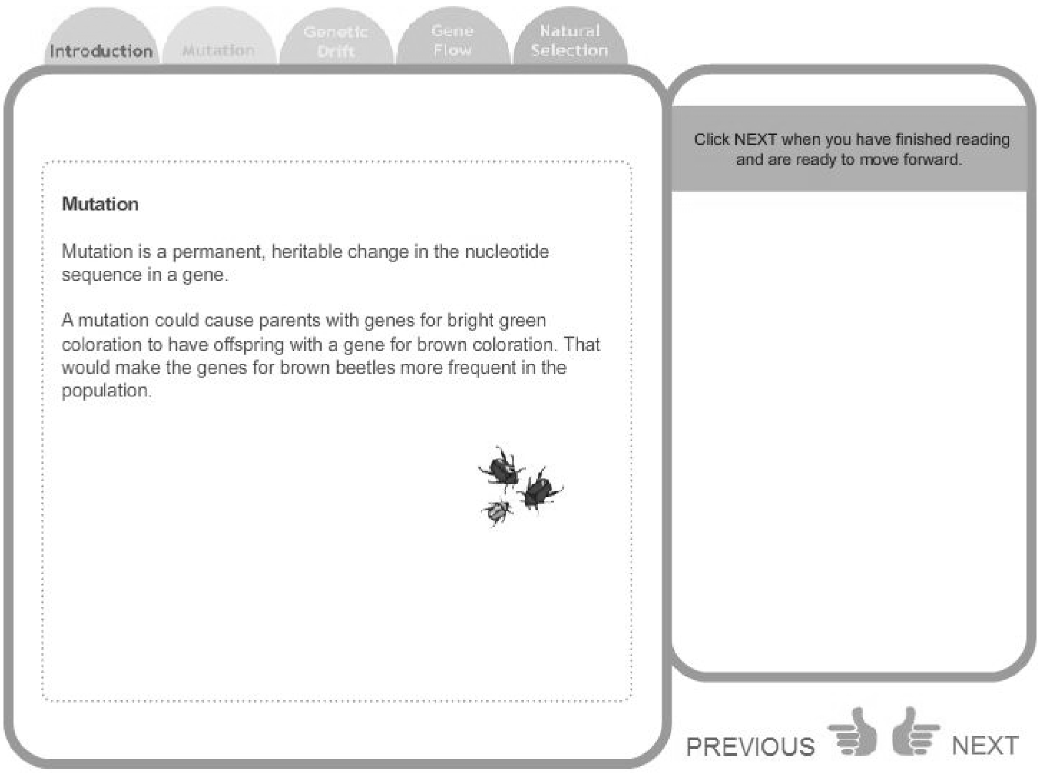

Figure 12. Introduction mutation overview.

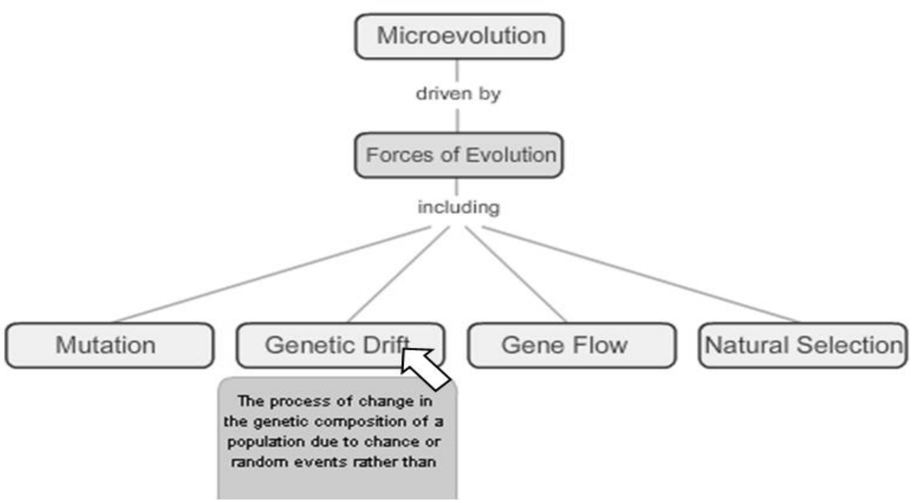

Figure 13. Overview mouse-over activity.

After completing the mouse-over activity, students were directed to participate in a drag and drop activity as shown in Figure 14. Students were directed to drag the components of the concept from the panel on the right to the appropriate place on the map. Students were given feedback based on their actions.

After the drag and drop activity, students were quizzed on the information presented in the introduction as shown in Figure 15. The concept map was displayed on the left as an aid for the student during the quiz. The questions and answer options were displayed on the right and feedback for correct and incorrect responses was displayed on the bottom of the panel on the left side of the screen.

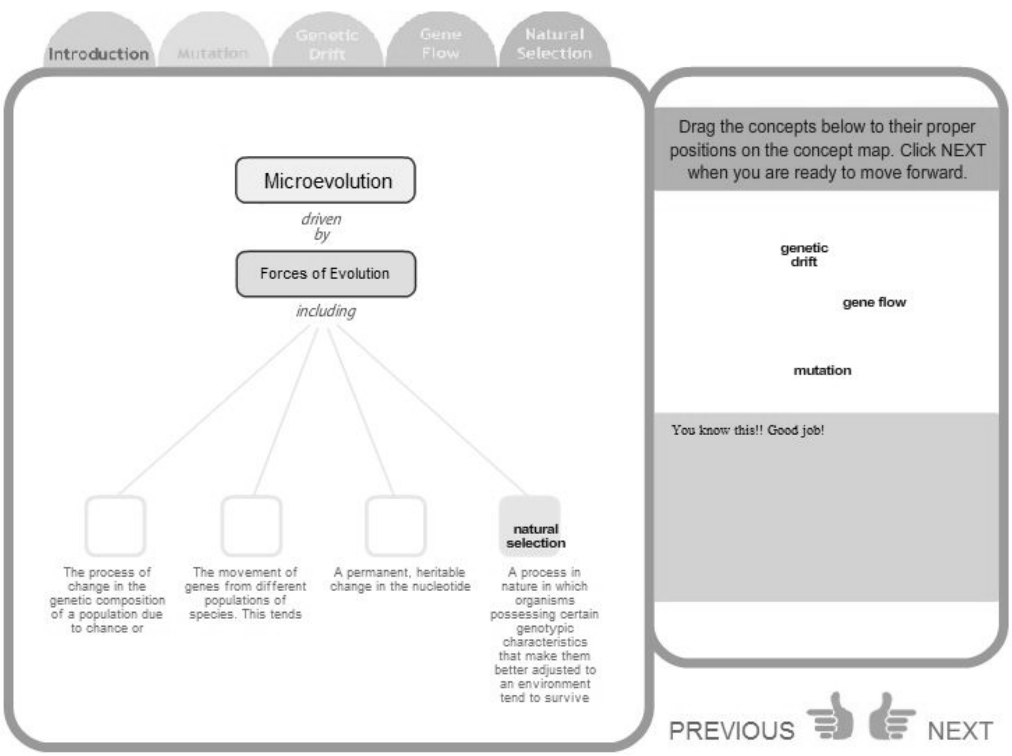

Figure 14. Drag and drop activity.

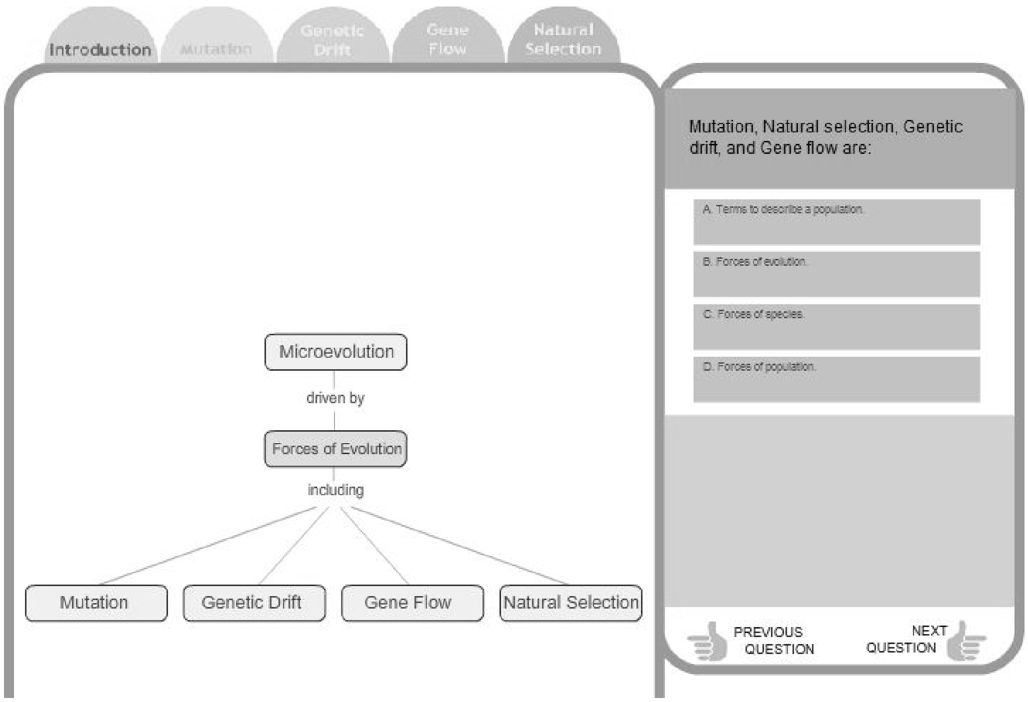

Figure15. Introduction quiz.

Mutation Section

After completing the introduction section described and illustrated above, the students were directed to study mutation, the first of the four forces of evolution presented in the module. Note that the same pattern was followed for each of the forces of evolution. To reduce unneeded repetition, I will only show screen shots of the mutation section.

Students were first provided with text and images that described and provided simple examples of the force being taught. In Figure 16, more information about mutation is provided and several additional text and image-based screens beyond this screen are accessed by the students.

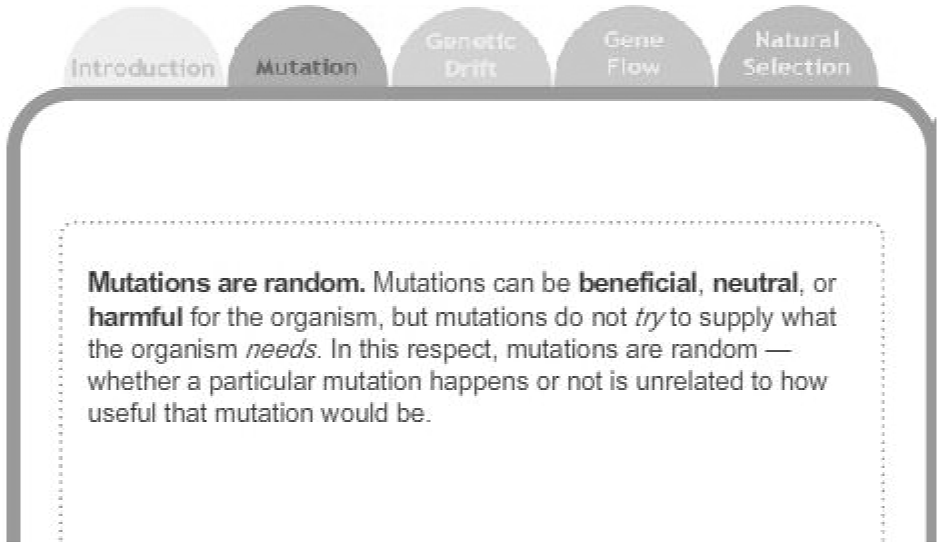

Figure 16. Mutation text.

After reading text describing mutation, students watched a video introducing the concept of mutation in greater detail. As can be seen in Figure 17, the video used the same structure as that used in the introduction video. Students then interacted with a mouse-over activity that utilized the concept map dealing specifically with mutation concepts. The activity followed the same methods as in the introduction concept map activity, described above (see Figure 18).

After the concept map mouse-over activity, students were directed to another drag and drop activity (see Figure 19). Mutation-related terms were found in the panel on the right and students were directed to drag those terms to the appropriate place on the map. After the drag and drop activity, students were directed to take a quiz covering the content taught in the mutation section of the module (see Figure 20). This activity was administered using the same methods in the introduction quiz, as described above.

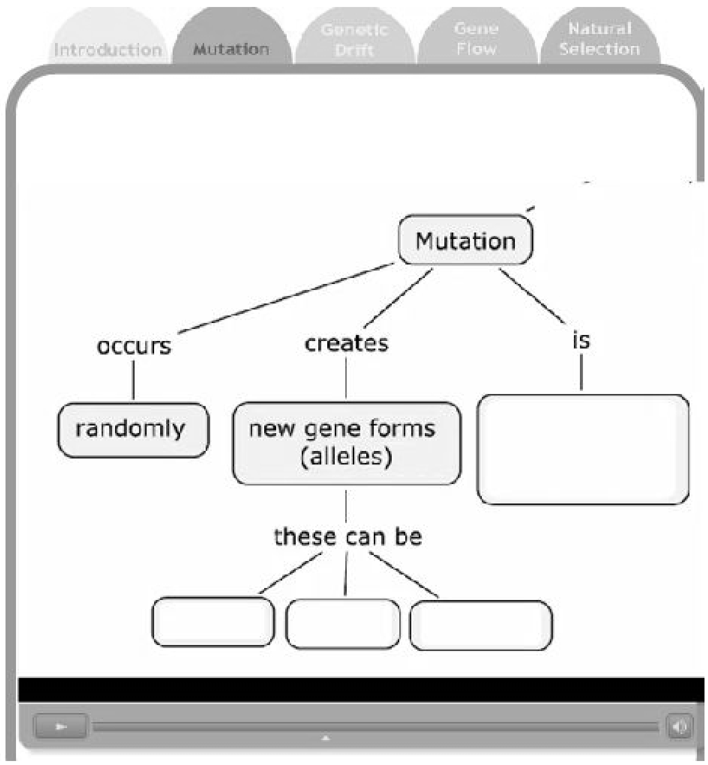

Figure 17. Mutation video.

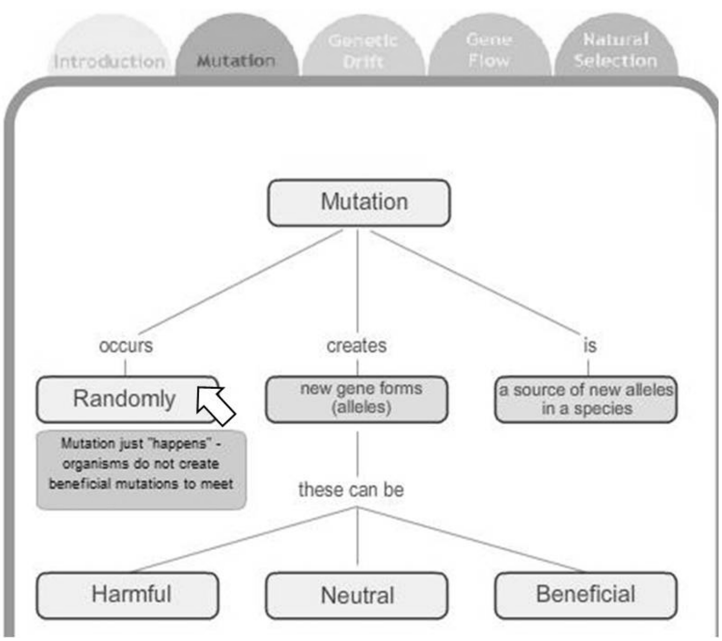

Figure 18. Mutation concept map mouse-over activity.

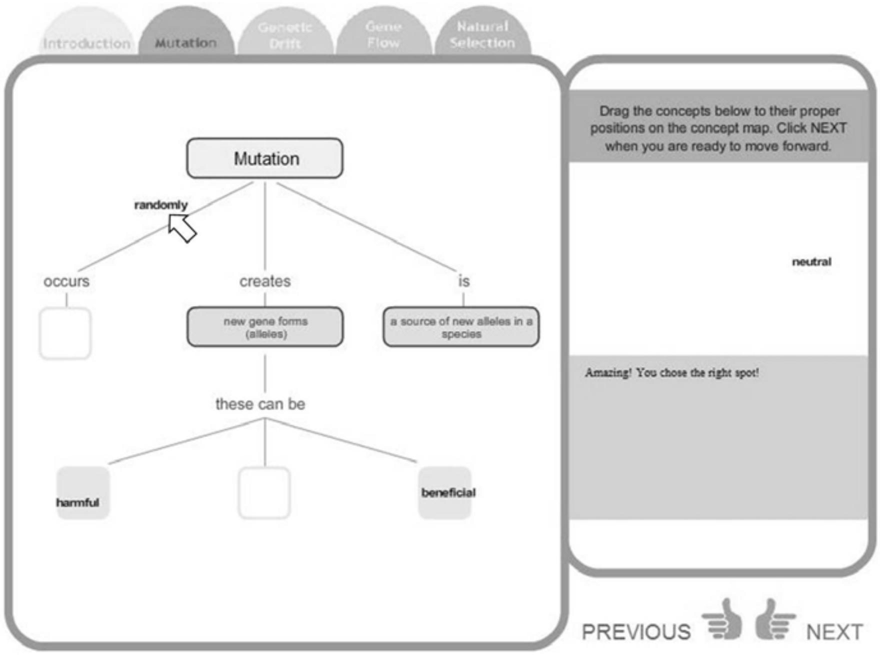

Figure 19. Mutation drag and drop activity.

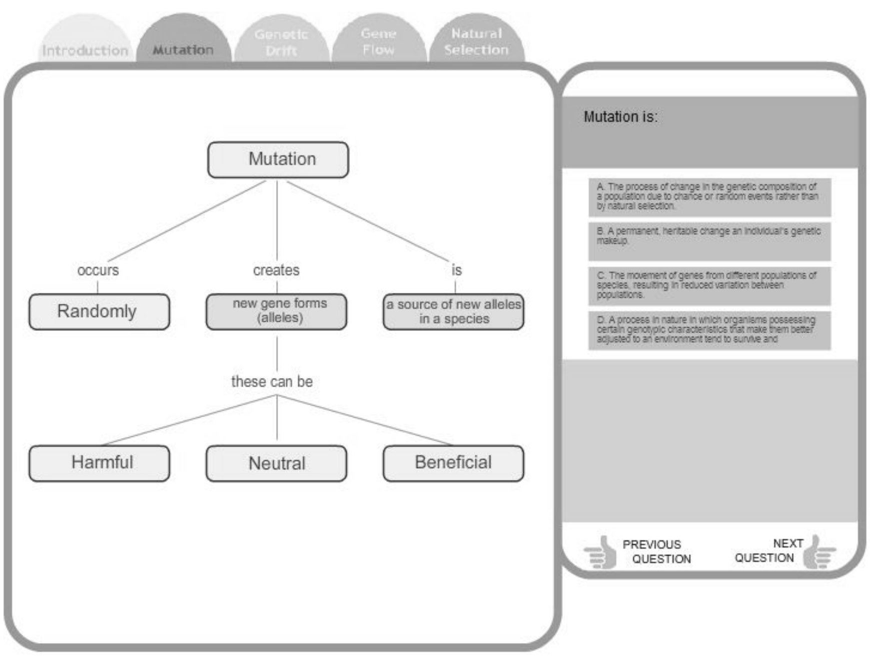

Figure 20. Mutation drag and drop activity (Part 2).

Genetic Drift, Gene Flow and Natural Selection Sections

The same pattern as that used in the mutation section was used for the remaining three sections: genetic drift, gene flow, and natural selection. Students read text, looked at related images, watched videos, did mouse-over activities, dragged concepts to the map, and took quizzes.

After completing all five sections of the module, students were directed to take a quiz that repeated all of the questions asked throughout the module (see Figure 21). Again, the quiz was administered using the same methods as all previous quizzes.

Design Process for Traditional Module

This module went through several steps in the design process. As mentioned above, formative evaluation of the functionality of the FLASH environment was

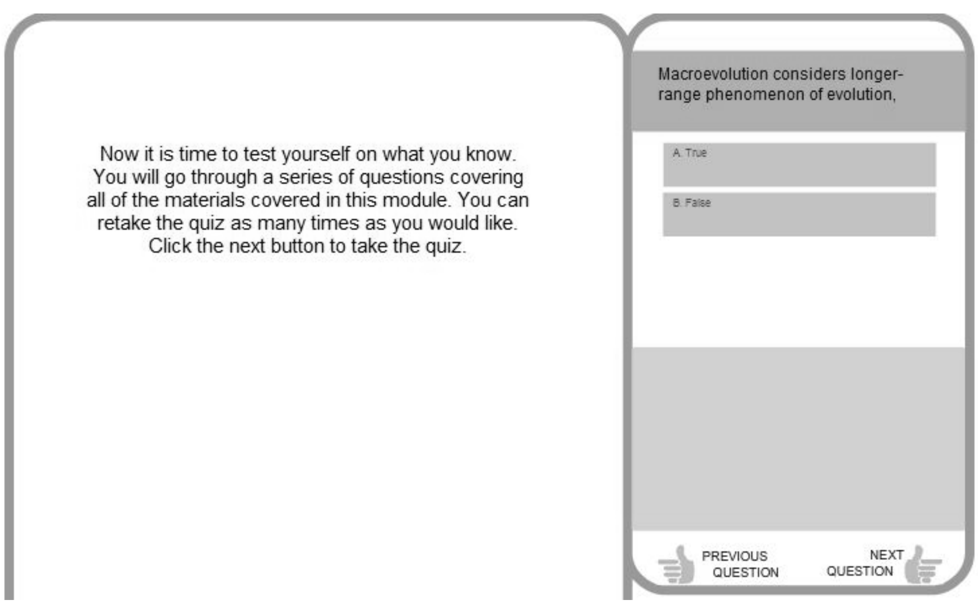

Figure21. Final module quiz.

completed during the Fall 2009 and Spring 2010 semesters. During these formative periods, the module underwent several formative evaluations with students using the module, as well as formative feedback from several instructional designers at FACT.

In preparing the content for this module, the initial content was provided by Dr. Greg Podgorski who created the concept map, concept definitions, and recorded the short videos described above. This content was developed and included in an earlier version of the web-based module.

To balance the amount of content included in the modules, more content was needed in the traditional module. Great care was taken to select content that taught the concepts being discussed in a way that meshed well with the previously developed materials. Based on Dr. Podgorski's recommendation, this content was taken primarily from Evolution 101, a well-known freely accessible web-based module teaching microevolution that is hosted by UC Museum of Paleontology's Understanding Evolution (http://evolution.berkeley.edu). A copy of the letter of permission for using this site content is included in Appendix P. The content was reviewed by Dr. Podgorski and then included in the traditional module.

During the development process, this module underwent several formative evaluations. First, I reviewed the module and identified several problems. The majority of problems appeared to be navigational in nature, and the feedback was given to the developer, along with a detailed list of steps for improving the module's effectiveness. In addition to this evaluation, I observed a graduate student at USU who used the learning module as if participating in the study. During his use of the module, the student noticed some additional navigation problems and gave some suggestions for making the instruction more appealing, including the use of images to illustrate concepts being taught. He also gave suggestions on how to organize the text by adding paragraph breaks and images reinforcing the content being taught. Based on this feedback, I collected open source images describing the content being taught and sent these, along with detailed suggestions for improving the layout of the text, to the developer.

As the time to implement the study approached, there were still several minor navigation and content errors to be corrected. To facilitate revision of the module, Tae Jeon, an instructional designer at FACT assisted with the refinement of the traditional module. At this time, I formatively evaluated the module and provided Jeon with steps for improving and refining the content.

Comparing Modules

Rating the Modules

To clarify the differences between the two modules used, I will describe the specific strategies used in each module. I have evaluated each module using a form of Merrill's e3 Rating Rubric (Merrill, 2007) as a standard. The categories listed across the top of the rating form are based on specific instructional strategies outlined in Merrill's First Principles of Instruction (Merrill, 2007). An X was placed to indicate that a strategy was used in the module.

The first four categories, tell, ask, show and do are the most fundamental strategies. *Tell* strategies are verbal delivery of the content. *Ask* strategies direct students to recall and repeat the verbal delivery. *Show* strategies are a demonstration of how to use the content. And *do* strategies direct the students use the content. The purpose of the ratings in these categories is to distinguish between instruction that represents content as information or as portrayal. *Tell* and *ask* strategies present content as information and *show* and *ask* strategies present content as portrayals.

The next five categories include information about, parts of, kinds of, how to, what happens, and whole task. These categories are based on the five different kinds of learning outcomes as described by Merrill (2007). *Information about* outcomes include student recall of the description of an entity or recognize a described instance of an entity. *Parts of* outcomes include recall of the names and descriptions of parts of an entity or the location of these parts on an entity. *Kinds of* outcomes include student recall of the definition and properties of an entity and the classification of entities into categories. *How to* outcomes ask students to remember the steps of and sequence of an action or to perform the steps of a sequence. *What happens* outcomes require students to remember the conditions and consequences of a process or predict an outcome based on a process.

When rating the modules, I treated each screen within the modules as a course component. For each screen, I indicated which strategies were used by placing an X in the appropriate column. For example, if a screen contained text describing a force of evolution, I marked the screen focused on the outcome of *information only* and as using a *tell* strategy. If the screen asked students to predict how a population would change over time based on the influence of a specific force of evolution, I marked that screen as a what happens outcome using a *do* strategy (predicting what will happen based on a situation). Each screen was evaluated according to these categories and Table 5 summarizes those ratings.

According to Merrill's hypothesized levels of instructional strategy (Merrill, 2006b), the traditional web-based module is a level 1 module. It provides extensive information to the students and gives some limited examples of some of the concepts being taught. I evaluated the traditional module using a form of Merrill's e3 rubric (Merrill, 2007). The materials are presented as primarily information-only with some examples; therefore, I rate this as a level 1. Row 2 of Table 5 summarizes my evaluation of the components in the traditional web-based module. It is clear from this summary that the module focuses primarily on providing information and limited examples to the learner and only directs students to take part in information-related application. Appendix D includes the full evaluation of the traditional web-based module.

In contrast to the traditional web-based module, the First Principles module includes demonstration and application as a part of a problem-centered strategy. This module utilizes three examples of problems associated with microevolution and provides worked examples of how expert biologists solve these problems. This module also has

Table 5

Comparing Strategies in Traditional and First Principles Modules

Summary of module use of First Principles of Instruction	Tell	Ask	Show	Do	Info about	Parts	Kinds	How to	What	Whole	Structure	Feedback	Guidance	Coaching
Traditional module	X	X			X							X		
First Principles module	X		X	X	X		X	X	X	X	X	X		

students apply these problem solving skills to real-world problems. Row 3 of Table 5 summarizes my evaluation of the First Principles module. It is clear when compared with Row 2 that this module contains different instructional strategies that are based more on First Principles of Instruction. Appendix G includes my full evaluation of the traditional web-based module. Appendix F includes my full evaluation of the First Principles module.

Narrative Comparison of Modules

In addition to this evaluation of the two modules, I have provided a narrative description of the differences between each of the modules. Because of its size, I have placed this description in Appendix H. It is clear when comparing the different strategies for each module that the First Principles module is focused on task-centered instruction, providing multiple real-world tasks and student application of those tasks, while the traditional module is focused on information and example-based instruction, providing definitions and simple examples with simple quizzes testing the content.

CHAPTER IV

METHOD

Setting

In this study, I utilized an exploratory design to compare the effectiveness of study materials using First Principles of Instruction with traditional web-based materials.

The study was conducted in conjunction with USU Life Sciences 1350, an introductory biology course for undergraduate nonmajors at Utah State University, a large land-grant university in northern Utah, in the summer semester of 2010. This study was originally intended to be conducted with a large introductory biology course in the Spring semester of 2010. However, because of time restraints, USU Life Sciences 1350, a class with a smaller population of students was selected for this study. This resulted in a smaller sample of students, making this study more exploratory in nature. This face-to-face course had an enrollment of about 58 students and the students in this course were given the opportunity to participate in the study.

Participants

Participants in the study were mostly traditional-aged students; 75% of students were 20 years old or younger or 21 to 23 years old. Of the participants in the study, 35% were freshman and 35% sophomore, both typical for an introductory biology course. Fifty-six percent of participants were male and 44% female. Most students, 50%, reported a grade-point average of 3.6 to 4.0, and 77.5% of students expected to receive an

A in the course, the remaining 22.5% expecting to receive a B. Tables 6 through 10 summarize the demographic results of the survey.

Students in both groups spent about 45 minutes studying these materials. Before participating in the study, students were randomly assigned to one of the two groups using the group randomization tool found in Blackboard Vista. They were then given access to the appropriate module when they arrived at the study session. Great care was taken to ensure that time on task did not vary much between the two treatments.

The majority of students participating in the study were either Freshmen or Sophomores. Only 30% of the participants were upper-classmen. The majority of the participants in the study were of a traditional age, 23 years old or younger. Most participants reported a grade point average of 3.6-4.0. There were slightly more male participants than female participants in this study. All participants expected a high grade in the course, USU Life Sciences 1350.

Access to the Course

To gain access to the course, I contacted Dr. Brian Warnick, the instructor for the course, who agreed to allow me to recruit students in the course. Participating students were given a small amount of extra credit for participating in the study and were entered into a drawing to receive one of six $10 gift cards to the university bookstore. Participants were randomly assigned to the comparison or the experimental group using the group randomization tool available in the Course Management System Blackboard Vista.

Data and Analysis

Sample Size Estimation

A statistical power analysis was performed for sample size estimation, based on data from the Thomson (2002) study that compared the difference in problem solving ability between a control group and an experimental group using First Principles, in a manner similar to this study. The effect size (ES) was 1.16, considered extremely large using Cohen's (1988) criteria. With a one-tailed alpha = .05 and power = 0.80, the projected sample size needed for this ES is approximately (N = 20) for the simplest between group comparison. For the proposed study, in order to allow for the possibility of a more modest but still large effect for problem-solving ability and a likely lesser effect for the remember and understand level outcomes, I attempted to recruit 50 participants through several classroom visits. At end of data collection, a total of 40 participants had participated in the study.

There are two levels of the independent variable used in this study: the First Principles module and the traditional module. Students were randomly assigned to either the First Principles or the traditional modules. More detail on these modules, including their use of instructional strategies, can be found Chapter III.

Data Collection

Multiple choice pretest and posttest. To compare student performance at the remember and understand levels of Bloom's Taxonomy, this study compared results of a 10 multiple choice question pretest and a 10 multiple choice question posttest. See

Appendix A for the pretest items and Appendix B for posttest items. Dr. Podgorski, an expert in microevolution content, was consulted extensively during the development of these questions. Each question for both the pretest and posttest was worth one point with a total of 10 points possible.

Each test (both pretest and posttest) consisted of five questions at both the "remember" and "understand" levels of Bloom's taxonomy (Anderson et al., 2001; Krathwohl, 2002), with a total of 10 questions. For example, one multiple choice question at the remember level read "____________ is a random fluctuation in allele frequency due to chance events." Student memory of the definition is really all that was required for this question. In contrast, understand questions required students to understand the concept being tested. For example, one multiple choice question at the understand level asked "Why would individuals in a population have a variety of sizes?"

During the process of developing and refining these tests, all questions went through a formative evaluation over an 8-week time period. During this period, I presented the question items to several professional instructional designers for rating of the questions according to the levels. The initial rating was done by Dr. Lianna Etchberger, a biology professor in the Department of Biology at USU. Sandy Durtchi, an instructional designer in FACT at USU also reviewed these questions, offering clarifying suggestions for improvement. These initial reviews helped me identify nine questions that needed to be changed. I then met with Dr. Greg Podgorski who assisted in the revision of these questions. After changing these questions, Tae Jeon, another instructional designer at FACT rated the questions. Based on these ratings, I identified eight questions to revise further. The questions were revised and approved by Dr. Podgorski.

To ensure that these questions were consistent with the remember and understand levels, the question items were ranked according to the levels by two PhD students in the Department of Instructional Technology and Learning Sciences at Utah State University. The reviewers were asked to rate these questions according to the levels within Bloom's Revised Taxonomy. Raters were sent an email with an attached list of the questions including a space to indicate which level the question is ranked as. Raters completed their rating and returned their completed forms to me. According to these ratings, eleven questions were ranked at the desired level, and nine were ranked by one or both of the raters at a level different than that desired. I then revised these questions based on the ratings and with the assistance and approval of Dr. Podgorski. The revised questions were resent to the raters who rated the items again. Based on these ratings, three questions were identified which were not ranked at the appropriate level by one of the two raters. I revised these questions once again with the approval of Dr. Podgorski. Because of time restraints and the numerous revisions made to the question items, these revised questions were those used in the study. Of the final questions used in the study, 13 were agreed upon by both raters, five were not agreed upon fully but received at least one desired rating, and two were rated differently by both raters. However, each of these questions was revised based on feedback from raters.

Content validity testing (Gall, Gall, & Borg, 2007) was also performed on the pretest and posttest items. To perform the content validity test, two instructors in the department of biology reviewed the questions to indicate whether they were representative of the content being taught. I prepared a document listing the several subjects in the module. This list is found in Appendix I. I also prepared a document containing the 20 multiple choice test items from the pre and posttests. For each test item, a rating scale was created in which a rater could indicate how representative the test item is of the content. The raters were asked to rate how representative each test item was of the content. The heading for the rating form read “Representative of content?” and below were three options: (1) no; (2) partially; and (3) yes. This form was sent to Dr. Thayne Sweeten and Dr. Jessica Habashi, both instructors in the Department of Biology at Utah State. Of the 20 multiple choice items rated, 16, or 80%, of the questions received a rating of (3), indicating total alignment and representativeness for those questions. The other four questions received a rating of (2) from either one of the raters and a rating of (3) by the other rater, indicating that all questions are at least partially representative of the content being tested and that every question included in the pre and posttests was representative of the content.

The reliability of the pre and posttest items was also tested. Cronbach’s alpha for the pretest for the sample of students participating in the study was 0.655, considered just below the rule of thumb for a reliable scale. Cronbach’s alpha for the posttest for the students participating in the study was 0.762, considered a reliable scale.

To ensure that the pretest and posttest were of a similar difficulty level, I performed a formative evaluation of their difficulty level. Four students with little prior knowledge of microevolution were asked to take each test sequentially without receiving any intervention. After these students took these tests, I tallied the number of correct answers for each test. Table 6 summarizes the total number of correct answers according to the different question types for four participants.

For questions at the remember level, students scored slightly higher on the pretest than the posttest. To manage this discrepancy, a question on the pretest was switched with a question on the posttest to balance the scores at 13 for each test. For questions at the understand level, the number of correct responses were similar, only off by two points. These questions were left as they were because switching questions would not result in more similar scores. For problem-solving questions, the pretest appeared to be slightly more difficult than the posttest. To offset the difficulty of the pretest, I slightly modified one of the posttest questions based on the approval of Dr. Podgorski to increase its difficulty. Based on these adjustments, these two tests were more similar in difficulty and these adjusted pre and posttests were used in the study.

Problem solving assessment. In addition to the multiple-choice questions assessing student learning at the remember and understand levels, the pre and posttest included problem solving assessment questions. This section describes the methods used for assessing students' ability to solve microevolution problems.

Table 6

Formative Pretest and Posttest Scores

Question type	Correct pretest questions	Correct posttest questions
Remember level	15	11
Understand level	19	17
Problem solving questions	8	11

Methods for assessing problem solving. There are many ways to assess student ability to solve problems (Belland, French, & Ertmer, 2009). Sugrue (1995) categorized these assessment methods into three major categories: selection, generation, and explanation. In *selection* assessment, students are presented with a problem and are directed to select the appropriate answer from a set of given options. These answers are designed to be discrete options that can be measured in clear ways. An example is the use of a multiple-choice question to test student ability to select an appropriate response to a content-related question. In *generation* assessment, students create predictions or solutions. In an example generation task, students describe their solution to a specific problem. Finally, in *explanation* assessment, students explain their solutions or describe why they selected or generated a specific solution.

Each of these methods has strengths and weaknesses. A selection strategy provides a way to test problem-solving ability in a discrete, clear way (right or wrong), though it does not provide rich data on student ability to solve problems. Generation strategies provide researchers with rich data about student problem-solving strategies; however, it can be difficult to quantify that strategy. Explanation strategies also provide rich data about student reasoning, but they are also difficult to quantify and evaluate.

Problem solving assessment methods used in this study. To assess student ability to solve microevolution problems, I used *selection* and *explanation* assessment strategies (Sugrue, 1995). As part of the posttest, students were presented with a real-world microevolution problem. Students answered three *selection* strategy, multiple choice questions designed to assess their domain-specific knowledge related to the problem.

Specifically, they were asked questions directly matching the three component strategy steps associated with analyzing microevolution in a real-world population. For example, after being presented with a scenario in which microevolution was taking place in a population of Northern Elephant Seals, students were asked "Based on what you know about this population of seals, how is this force of evolution acting on this population?" Students then selected the answer that seemed most appropriate. Questions for pretest and posttest problem solving can be found in Appendix J and Appendix K.

Student reasoning assessment. Students also answered an open-ended *explanation* strategy question designed to determine the level of sophistication of student reasoning for choosing the response selected. Students were asked to describe their reasoning for answering a question the way that they did. For example, after indicating which force of evolution is acting on a population of Northern Elephant Seals, students are asked, "Please explain your thinking for your answer to question (above). Why did you select the force you did?" In this way, student reasoning is measured. The pretest microevolution problem solving questions are found in Appendix J. The posttest microevolution problem solving questions are found in Appendix K.

Students explained their problem solving reasoning by explaining why they thought a particular force of evolution was acting on the population in question. After answering problem solving questions, students were asked "Please explain your thinking for your answer to question _. Why did you select the force you did?" To analyze student reasoning explanations, I first created a simple three point scale for categorizing student reasoning. A rating of 1 was given to student responses with an incorrect answer and incorrect reasoning. A rating of 2 was given to student responses with partially correct reasoning including some good reasoning. Finally, a rating of 3 was given to student responses that were totally correct with good reasoning. I then met with Dr. Podgorski who analyzed several student responses and created a set of rules for analyzing the students' written responses. The rules included the following:

- If the answer has correct reasoning and the answer was correct, it receives a rating of 3.
- If part of the answer is wrong and part is right, then it receives a rating of 2.
- Brief correct answers with little explanation receive a rating of 2.
- No answer written receives a rating of 1.
- Correct answer with no explanation receives a rating of 1.
- If the reasoning is totally bad, it receives a rating of 1.

Motivation toward problem solving assessment. Another way to test problem solving is to assess students' motivation level related to the problem-solving task (Sugrue, 1995). After answering these domain-specific questions, students rated themselves on their own motivation related to solving the problems. These questions can be found in Appendix L. Students rated (a) their self-efficacy in solving the problem (b) the difficulty of the problem, and (c) their enjoyment of solving the problem, with one question used to test each form of motivation. Questions included the following three questions: (1) "How often can you succeed at answering these kinds of questions without help?" (2) "Do you enjoy yourself when answering questions of this kind?" (3) "How difficult were these questions for you to answer?"

Using the questions above, I measured the extent to which using First Principles of Instruction affected the students' attitudes about problem solving. There were three motivation-related questions used, one question for each of the categories listed above. Scales used in this strategy were based on Boekaert's (1987) methods for evaluating student motivation.

Delayed posttest. To measure long-term retention of learning gain at the remembering, understanding and problem solving levels, students answered questions about microevolution on the course mid-term. Three questions were included: one at the remember level, one at the understand level, and one asking students to solve a component of a real-world problem. These questions used *selection* strategies similar to the questions on the pretest and posttest. These question items were based on questions included in the pre and posttests. Question items for the delayed posttest are found in Appendix M.

Additional measures. Additional measures used in this study are described in detail below.

Demographics survey. Before taking the pretest, students filled out a survey designed to gather basic demographic data about the students (see Appendix C). This survey gathered data on student demographics such as student class (freshman, sophomore, etc.), student self-reported GPA, and student sex. This data provided insight into the demographics of students taking the course and participating in the study. To establish validity evidence for these items, Dr. Nick Eastmond and Dr. Brian Belland reviewed the question items for face validity concerns and gave a few minor suggestions for improving the clarity of the questions. Cronbach's alpha for the demographics survey for the sample of students participating in the study was 0.57.

Student reaction survey. After studying with the module, students filled out a reaction survey, found in Appendix D. This survey tested student reaction to the study materials used in the study. Because a high level of student satisfaction is desired for these modules, the survey included the question "How would you rate the usefulness of this study session in helping you learn about evolution?" as well as a Likert-type question to gather student response. The survey also included two short answer sections gathering data on what they liked about the materials and whether they believed they learned from their studies. The student reaction survey underwent validity testing using the same procedures used to test the demographics survey. The survey was reviewed by Dr. Brian Belland and Dr. Nick Eastmond for face validity concerns and was revised based on their feedback.

Data Analysis

Main effect. In the original proposal for this study, I intended to utilize a more comprehensive model for the data analysis for study. Specifically, a plan was originally made to utilize an analysis of covariance (ANCOVA) with the posttest as the dependent variable, and the group as the independent variable, controlling for pretest score to maintain focus on the posttest scores as a measure of success. I also originally planned to implement *t* tests on learning gain (posttest score—pretest score) to help further quantify gain differences between groups. However, because the study took place during the summer semester, the limitation of a much smaller sample size than anticipated reduced the power for the study. This change in sample size made the nature of the study more exploratory in nature, with the goal of searching for trends and effects that warrant the conduction of larger studies. The analysis of data was performed as described below.

To examine the primary learning outcomes for research question 1, at the remember and understand levels, *t* tests were performed to determine mean learning gain from pretest to posttest within each group and to compare differences in mean learning gain between the groups. In addition, effect sizes were calculated using Cohen's *d*. The same analyses (*t* tests and effect sizes) were performed to test learning outcomes for research question 2 at problem-solving. In addition, additional problem solving measures were used as described below.

Additional problem solving measures. Secondary learning outcomes, included student description of problem solving reasoning (rated on a 3-point scale) and problem solving motivation scales (rated on a 4-point scale). The measures used for these outcomes, which are described above and can be found in Appendices K and L, were examined using a chi-square statistic. For all measures, when distribution assumptions were not met, a nonparametric method was used. Normality assumptions were not met for some comparisons, and a non-parametric method was used for the following tests: test for problem solving learning gain scores, pretest to posttest comparison for First Principles group, pretest to posttest comparison for traditional group, and delayed posttest comparisons for all three measures.

I rated all student responses and Dr. Podgorski rated 25% of the student responses. Ratings for this 25% were compared and all ratings were given the exact same rating from both raters, indicating perfect interrater reliability.

Additional measures. The student reaction rating question, described in detail above and found in Appendix D, was also analyzed using chi-square. In addition, student comments on what they liked about the module and student recommendations for improvement were analyzed using thematic analysis to determine themes and patterns associated with each of the instructional modules. Themes were developed from common trends in student comments. For example, several students mentioned that they liked the repetition in the First Principles module. Therefore, “repetition” became a theme and student comments within that theme were analyzed. Comments from each group (control and experimental) were compared to further clarify any differences in student reaction to the modules. These comments were also compared to quantitative findings to determine any potential trends.

At the end of the study, to examine the outcome of retention of knowledge, a repeated measures ANOVA was used to examine pre-, post-, and delayed posttest score differences between groups.

Procedures

Data gathering period. Data were collected the week of June 14th through the June 19th. Delayed posttest data were collected two weeks later on July 1st. On the 14th of June, I visited the class to invite students to participate in the study. It was the first day of class, and the course instructor, Dr. Brian Warnick, introduced me to the class. I described the study and then passed out several sign-up sheets, a blank copy of which can be found in Appendix E. The sign-up sheet directed students to write their name, their email address, and to select a time from the sessions available to participate in the study. Attached to the signup sheets was the Institutional Review Board (IRB) Letter of Information, which can be found in Appendix N and describes the study. There were three study sessions planned for each day the remainder of the week in which the study took place, Tuesday through Friday. A total of 12 study sessions took place, and the number of students in each session ranged from 1 to 16. The night before each study session, I contacted each student who had signed up for the sessions the next day by email to remind them about the study and to remind them of the location and of what would be happening. This email also included the letter of information as an attachment.

Study environment. This study was conducted in a laboratory environment to control the variables of time spent using the module and taking tests, internet connection speed, and other potential distractions to student study. Study sessions took place in a computer lab. Before they signed up for the study, students were randomly assigned to either the comparison or to the experimental groups. They were then given access to the appropriate study module when they attended the study session.

In each session, great care was taken to control the student experience. Because students from both the comparison and experimental groups potentially attended each session, I assigned student seating so that the control group would sit on one side of the room and the experimental group would sit on the other. Because of the assigned seating arrangements, students were not able to see what other students were studying, which greatly reduced the chance of Hawthorne effect.

When students arrived at the study session, I briefly explained how the study session would proceed. Students then viewed a 10-minute lecture video that provided an overview of the content. The lecture was provided by Dr. Greg Podgorski, a professor in the department of Biology at Utah State University.

After watching the lecture, students filled out the demographics survey and completed the pretest. This took students between 5 and 10 minutes to complete. Students then watched a short video that described the functionality of the learning module they would be using.

After watching the lecture video, students accessed and worked through the learning module they were randomly assigned to. It took students between 40 and 50 minutes to complete the assigned learning module.

After completing the module, students were directed to fill out the student reaction survey and complete the posttest. Again, this test took between 5 and 10 minutes for students to complete. After completing the posttest, students were directed to leave the study session.

The surveys, quizzes, videos, and modules used for this study session were accessed online using a course in Blackboard Vista, the learning management system used at Utah State University. I carefully controlled student access to the link for each of these steps in the study session so that students moved through the process consistently. When students accessed Blackboard, only the materials to be used at that step in the session were accessible. For example, after completing the pretest, students accessed the course in Blackboard Vista and were only given access to the introduction video. In this way, I controlled the pacing and controlled the amount of time spent for each step in the sequence.

Due to a scheduling conflict in the lab where this research tool place, one group of two students moved across the hall to a separate computer lab. In this case, students still worked through the module using the same procedures as before and using the same type of computer. Care was taken to control the setting and pace of the session, and I followed the same procedures as used in the other sessions, described above.

In-class lecture after study sessions. As mentioned earlier, this study session was conducted in conjunction with USU 1350, a biology course taught at USU. This section briefly describes the lecture provided by the course instructor after the study session. This section then briefly compares it to the microevolution topics covered in the web-based modules.

The week following the study sessions, I attended the June 24 class lecture in which Dr. Warnick lectured on the topic of microevolution. This lecture took place the Monday after the study sessions and the week before the delayed posttest. Students from both groups attended this lecture as part of their normal class schedule. In his lecture, Dr. Warnick presented content that was very similar to the content provided in the learning modules. His discussion focused on content related to the forces of evolution taught in the course, specifically focusing on natural selection. His presentation provided 17 examples during the lecture. He also presented briefly on other forces of evolution, including sexual selection and artificial selection. Table 7 shows the number of examples given during Dr. Warnick's lecture and also shows that natural selection was the force most emphasized during the lecture.

Table 7

Microevolution Examples Used in Instructor Lecture

Force of evolution	Number of examples given
Natural selection	10
Genetic drift	2
Artificial selection	2
Mutation	1
Sexual selection	1
Gene flow	1
Total examples given	17

Dr. Warnick's lecture was primarily information presented to students with examples. In this sense, the lecture was traditional, where learning included fewer active learning strategies. There was some limited interaction between the instructor and the students. Dr. Warnick would ask short-answer questions and students would give short responses. This increased the interactivity of the lecture, but only superficially. Based on my analysis, I rate Dr. Warnick's lecture as level 1 according to Merrill's scale (Merrill, 2007) because it provides students with information about the forces of evolution as well as several examples of the forces.

Delayed posttest. Two weeks after completing the study session and the week after the lecture on microevolution, students were given a multiple choice mid-term, part of which covered the content taught in the microevolution modules. This test took place on Thursday, July 1, and was comprised of 50 multiple choice questions. Students responded to multiple choice questions using a scantron sheet, which was later converted into scores for each question. This test included three questions: one at the remember level, one at the understand level, and one testing the ability to analyze microevolution in a population. The data were compiled by Dr. Warnick, who sent the relevant scores. Table 8 summarizes the sequence of events of the study.

Ethical concerns. Prior to conducting the study, I obtained the approval of the IRB. Participants were provided with a copy of the Letter of Information at the time they were introduced to the study and as an attachment in email. Appendix N contains a copy of the IRB Letter of Information.

Table 8

Sequence of Events for Research Study

Sequence of events	Traditional group	First Principles group
Recorded lecture	X	X
Demographics survey	X	X
Pretest	X	X
Traditional module	X	
First Principles module		X
Reaction survey	X	X
Posttest	X	X
Dr. Warnick lecture	X	X
Delayed posttest	X	X

CHAPTER V

RESULTS

Overview of Chapter

This chapter presents the results of the study. I first provide an overview of student scores at each level within the module. I then address each research question and present statistical results based on the findings. Finally, I analyze student reaction to the data, including qualitative analysis of student responses.

Overview of Student Scores

Table 9 presents a summary of student mean scores at each level within the module, including the mean pre and posttest score as well as the mean gain. Both groups had improvements at the remember level, the traditional group improving slightly more that the First Principles group. The First Principles group improved at the understand level, while the traditional group actually decreased in average score. Finally, while both groups improved at problem solving, the First Principles group improved more than the traditional group.

The following sections analyze effect sizes related to these gains and calculate the statistical significance of gains between and within groups. When discussing significance in this chapter, a result for which the *p* value is .05 or less, is considered significant, a result of a *p* value greater than .05 and less than .1 is considered significant at the .1 level, and a result for which the *p* value is .1 or greater is considered not significant.

Table 9

Summary of Mean Pretest and Posttest Scores

	Remember[a]		Understand[a]		Problem solving[b]	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
Traditional						
Pretest	2.79	1.512	3.26	1.284	1.74	1.045
Posttest	3.74	1.790	3.00	1.666	2.00	.816
Gain	.95		-0.26		0.26	
First Principles						
Pretest	3.29	1.270	3.19	1.123	1.67	1.016
Posttest	3.86	1.314	3.48	1.123	2.29	.845
Gain	0.57		0.29		0.62	

[a] = 5 points possible
[b] = 3 points possible

Calculations Used in Analysis

To compare the main effect for the three levels of remember, understand, and problem solving, I used the following procedures for each effect. I first calculated the effect size of the learning gain to develop insight into the magnitude of differences between groups. Effect sizes are an important measure of the magnitude of differences. To further assess the significance of the main effect, I then calculated the significance of learning gain between the groups using a *t* test or, when normality assumptions were not met, a Mann-Whitney U. Learning gain was calculated using posttest minus pretest as a learning gain score. Because students' final success on the posttest measure is also of interest, I then calculated the significance of the group difference between posttest scores, controlling for pretest scores using ANCOVA. Finally, to determine the learning gain for each individual group, I calculated the significance of any pretest to posttest gain for each group separately using a paired *t* test or a Wilcoxon signed rank when nonparametric assumptions were not met.

Remember and Understand Learning

Research Question 1: Compared to students receiving traditional web-based supplementary instruction, do students receiving supplemental instruction incorporating Merrill's First Principles of Instruction perform better at the "remember" and "understand" levels of Bloom's Taxonomy?

Remember level. Results indicated that the effect size for learning gain between groups at the remember level was small ($d = 0.2$) in favor of the traditional group. A *t* test showed that the main effect of learning gain difference between conditions was not significant ($p = .578$). An ANCOVA comparing posttest scores indicated no significant difference between posttest scores when controlling for pretest scores. To assess learning gain within each group, effect sizes were calculated, the First Principles group with a low medium effect size ($d = 0.4$), and the traditional group with a high medium effect size ($d = 0.6$). The difference between pretest and posttest for First Principles group was significant at alpha = .1, and for the traditional group was significant at alpha = .05. Figure 22 shows the relative average improvement for students in each group.

Comparing learning gain scores. The average learning gain at the remember level was higher for the traditional group than for the First Principles group. The average

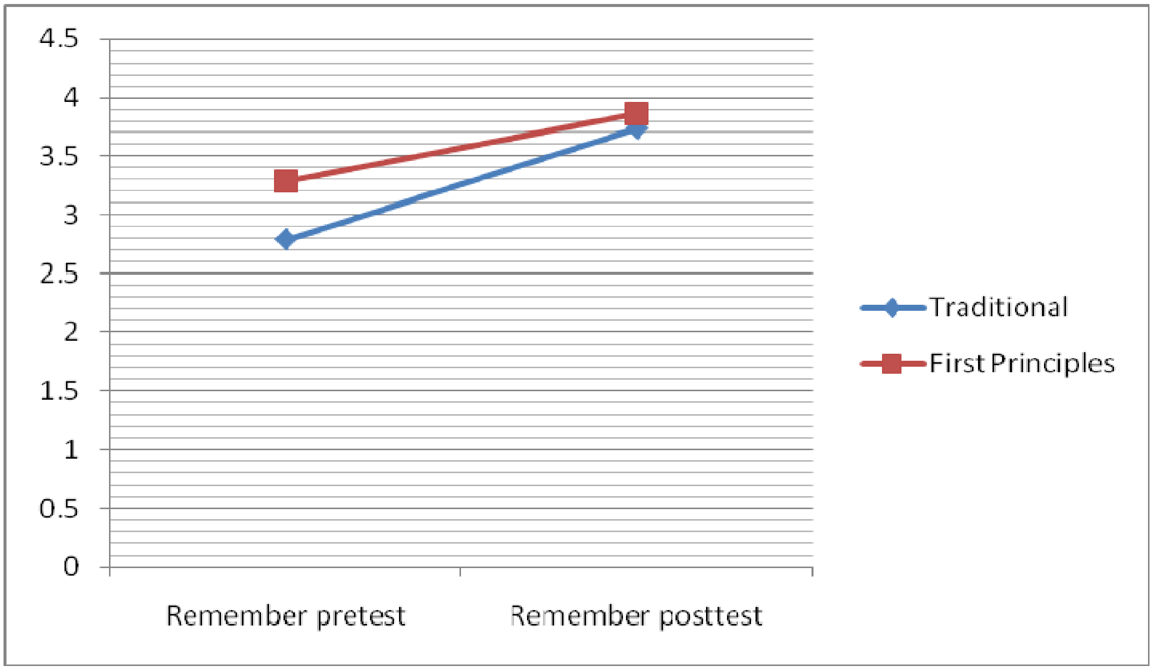

Figure 22. Remember scores.

learning gain for the traditional group was 0.38 points higher than the First Principles group, and the 95% confidence interval for the mean score difference was between -.98 and 1.73 points. A two-tailed *t* test showed that the learning gain difference between conditions was not significant, $t(38) = 1.234$, $p = .578$, *ES*=.2.

Comparing posttest scores. To assess student success on the posttest measure at the remember level, group differences between posttest scores controlling for pretest scores were also calculated using ANCOVA. After adjusting for pretest scores, there was no significant difference between the First Principles and the traditional groups, $F(1, 37) = .071$, $p = .792$.

Remember level pretest to posttest comparison. To calculate the effect of the module on score improvement at the remember level within the First Principles group, the difference between pretest and posttest scores was calculated. The mean difference between pretest and posttest scores was 0.57 and the 95% confidence interval for the score mean difference was between -1.38 and .235 points. A paired *t* test showed that the difference between pretest and posttest was significant at alpha=.1, $t(40) = -1.432$, p = 0.08, *ES* = 0.4. The average student in the First Principles group improved by .4 SDs.

To calculate the effect of the module on score improvement at the remember level within the traditional group, the difference between pretest and posttest scores was also calculated. The mean difference between pretest and posttest scores was 0.95 and the 95% confidence interval for the score mean difference was between -2.04 and 0.14 points. A paired *t* test showed that the difference between pretest and posttest was significant, $t(36) = 1.762$, $p = 0.043$, *ES* = 0.6. The average student in the traditional group improved their score at the remember level by .6 SDs.

The results at the remember level indicate that both the traditional and First Principles groups learned from the web-based modules.

Understand level. Results indicated that the effect size for learning gain between groups at the understand level was small to moderate ($d = 0.3$) in favor of the First Principles group. A *t* test showed that the main effect of learning gain difference between conditions was not significant ($p = 0.182$). ANCOVA testing differences between student posttest scores controlling for pretest scores showed no significant difference. To assess learning gain within each group, effect sizes were calculated, the First Principles group with a small effect size ($d = 0.2$), and the traditional group with a small negative effect size ($d = -0.2$). Learning gain within each group was also tested. Difference between pretest and posttest for both groups was not significant. Figure 23 shows the relative improvement in performance from pretest to posttest for each group.

Comparing learning gain scores. The mean difference at the understand level between the conditions was 0.55 points in favor of the First Principles group and the 95% confidence interval for the score mean difference was between 1.76 and .66 points. The effect size was small to moderate(d = .3). A one-tailed t test showed that the learning gain difference between conditions was not significant $t(38) = .916$, $p = .182$, $ES = .3$.

Comparing posttest scores. To assess student success on the posttest measure at the understand level, the difference between posttest scores was also calculated using ANCOVA. After adjusting for pretest scores, there was no significant effect of the between-subjects factor group on posttest scores, $F(1, 37) = .977$, $p = .329$.

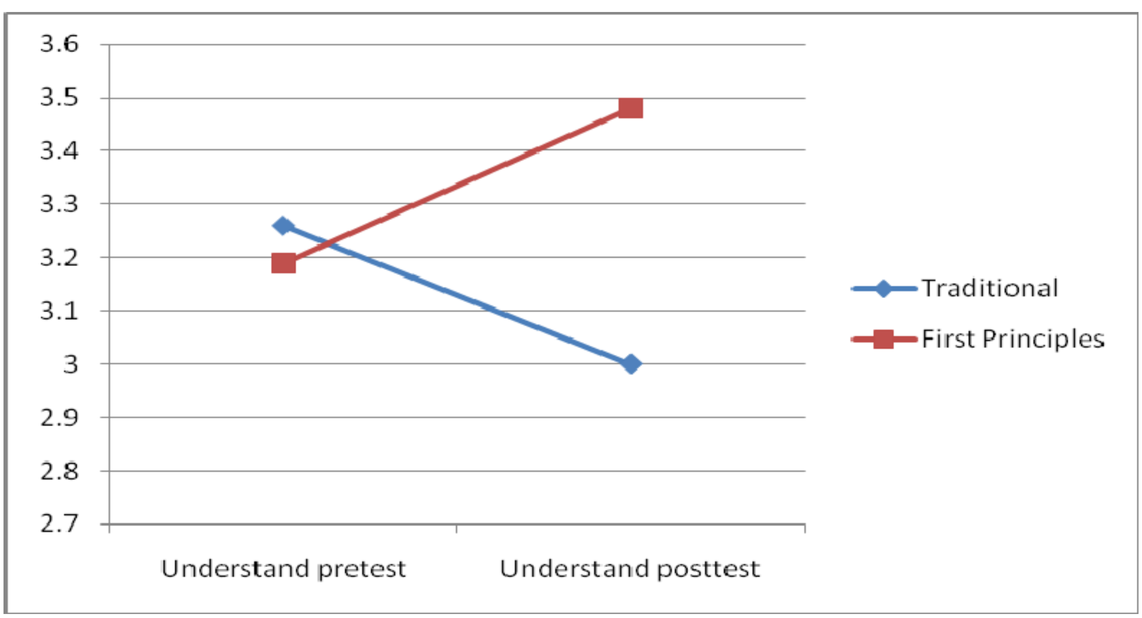

Figure 23. Understand scores.

Understand level pretest to posttest comparison. The difference between pretest and posttest scores at the understand level was calculated for the First Principles group. The mean difference between pretest and posttest scores was 0.29 and the 95% confidence interval for the score mean difference was between -1.065 and .493 points. A paired *t* test showed that the difference between pretest and posttest was not significant $t(40) = .741$, $df = 40$, $p = .231$, $ES = .2$.

Difference between pretest and posttest scores at the understand level was calculated for the traditional group. The mean difference between pretest and posttest scores was -0.26, a decrease in mean score. The 95% confidence interval for the score mean difference was between -0.715 and 1.242 points. A paired *t* test showed that the difference between pretest and posttest was not significant $t(36) = .545$, $p = 0.25$, $ES = -.2$.

Problem Solving Learning

Research Question 2: Compared to students receiving traditional web-based supplementary instruction, do students receiving supplemental instruction incorporating Merrill's First Principles of Instruction improve their ability to solve content-related problems?

Problem solving. Results indicated that the effect size for learning gain between groups at problem solving was small to moderate ($d = 0.3$) in favor of the First Principles group. A *t* test showed that the main effect of learning gain difference between conditions was not significant ($p = 0.125$). An ANCOVA comparing student posttest scores controlling for pretest scores found no significant difference between groups. To assess learning gain within each group, effect sizes were calculated. The First Principles group had a fairly large effect size (*d* = 0.7), and the traditional group had a small to moderate effect size (*d* = 0.3). The difference between pretest and posttest was significant for the First Principles group and was not significant for the traditional group. For additional problem solving measures, no significant difference was found between groups. However, students in the First Principles group more confidently predicted future success at solving problems, and this finding was significant at alpha = .1. Figure 24 shows the average pretest to posttest scores at problem solving for each group.

Comparing learning gain scores. A comparison of learning gain scores indicated that the effect size was small to moderate (*d* = .3) in favor of the First Principles group. A Shapiro-Wilk test was performed and normality was not found; therefore, a

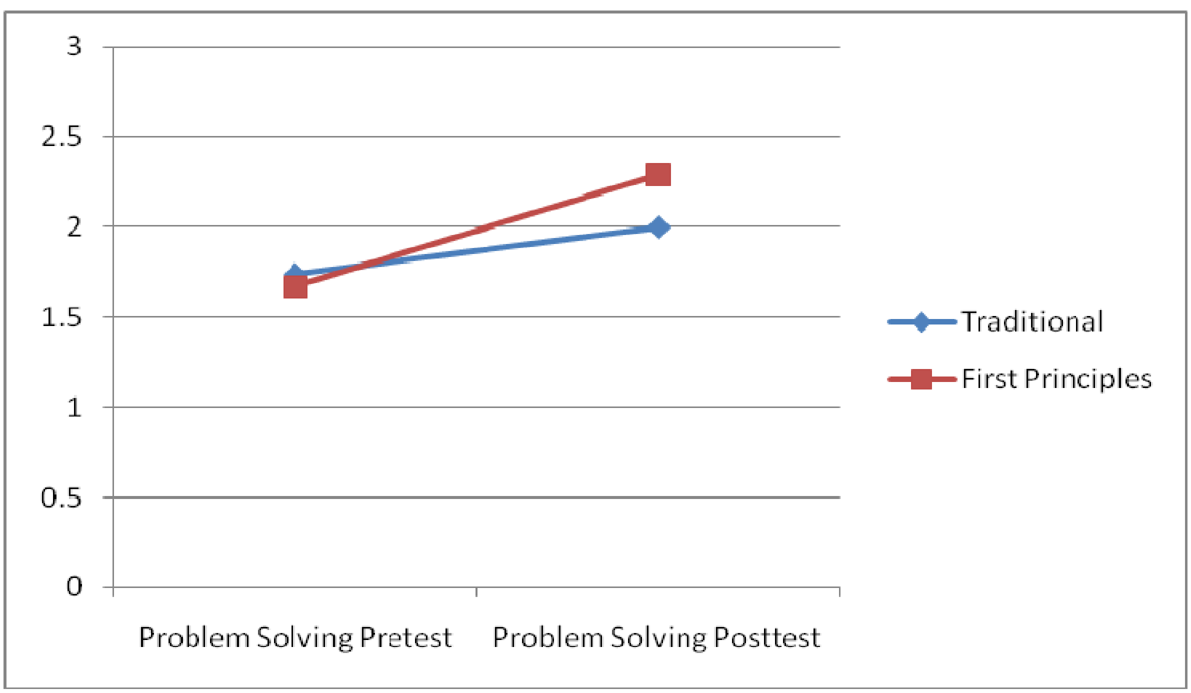

Figure 24. Problem solving scores.

Mann-Whitney *U* test was performed to test for significance of the difference. The results were not significant, $U = 157$, $N1 = 19$, $N2 = 20$, $p = .125$, one-tailed.

Comparing posttest scores. To assess student success on the posttest measure of problem solving, statistical significance testing of the difference between posttest scores was also conducted using analysis of covariance (ANCOVA). After adjusting for pretest scores, there was no significant effect of the between-subjects factor group on posttest score $F(1, 37) = 1.064$, $p = .309$.

Problem solving pretest to posttest comparison. Difference between pretest and posttest scores for problem solving was calculated for the First Principles group. Because normality assumptions were not met, a Mann-Whitney *U* test was performed. The effect size between pretest and posttest scores was large ($d = 0.7$). Results showed that the difference between pretest and posttest was significant ($U = 142.5$, $N1 = 21$, $N2 = 21$, $p = .02$). On average, students in the First Principles group improved by .7 SDs from pretest to posttest.

The difference between pretest and posttest scores at problem solving was also calculated for the traditional group. Because normality assumptions were not met, a Mann-Whitney *U* test was performed. The effect size between posttest scores was small to moderate ($d = 0.3$). Results of the test showed that the difference between pretest and posttest was not significant ($U = 158$, $N1 = 19$, $N2 = 19$, $p = 0.674$).

Additional problem solving measures. In addition to the above measures, I also assessed student problem solving on four additional measures: problem solving reasoning, student prediction of future success, student enjoyment of problem solving, and student rating of problem difficulty.

Student reasoning. To assess student improvement at student reasoning, I analyzed student scores using frequency table analysis and tests of association. As described in greater detail in the previous chapter, student responses were analyzed and ranked on a scale of one to three. I organized each student score into three categories: (a) worsened, (b) stayed the same, or (c) improved. Because the analysis showed that two cells had expected count less than 5, an exact significance test was selected used instead of Pearson's chi-square. There was no significant relationship between group and student reasoning rating $\chi 2$ (2, N = 40) = 1.714, exact p = 0.212.

Prediction of future success. After using their assigned modules and taking the posttest problem solving items, students were asked whether they can succeed at solving problems similar to those on the posttest in the future. A more detailed description of these measures can be found in Chapter IV, and the questions for each of these measures can be found in Appendix L. To assess student prediction of future success, I analyzed student pretest and posttest responses to the question "How often can you succeed at answering these kinds of questions?" by organizing them into three categories: (a) worsened, (b) stayed the same, or (c) improved. Because the analysis showed that two cells had expected count less than 5, an exact significance test was selected. Student prediction of future success was significant at alpha = .1, $\chi 2$ (2, N = 40) = 3.585, p = 0.09, one-tailed. Students in the First Principles group were more likely to be confident in their ability to solve problems like those tested in the posttest measure in the future.

Enjoyment rating. Student rating of enjoyment solving problems was another motivational measure used in this study. Student responses were organized into three categories: (a) worsened (b) stayed the same, or (c) improved. Because the analysis showed that 4 cells had expected count less than 5, an exact significance test was selected. There was no significant relationship between group and student reasoning rating $\chi2$ (2, $N = 40$) = 1.530, $p = 0.252$.

Difficulty rating. This study also measured problem solving motivation by measuring student rating of the difficulty of the problems. Responses were organized into three categories: (a) worsened (b) stayed the same, or (c) improved. Because the analysis showed that two cells had expected count less than 5, an exact significance test was selected. There was no significant relationship between group and student difficulty rating $\chi2$ (2, $N = 40$) = 1.348. $p = 0.303$.

Delayed Posttest Items

Students also took a delayed posttest 2 weeks after the study session. They answered a question at each level: remember, understand, and problem solving, which was scored as correct or incorrect. This section describes the results of the delayed posttest. Table 10 summarizes the percentage of students with correct scores in each group.

Table 10

Delayed Posttest Descriptive Results

Group	Remember	Understand	Problem solving	Overall
First Principles group	43%	76%	66%	62%
Traditional group	61%	66%	83%	70%

Remember Level

A logistic regression analysis was performed with delayed posttest remember (i.e., correct or incorrect) score as the dependent variable and posttest remember score and group as the predictor variables. Thirty-nine cases were analyzed and the full model did not significantly predict success at delayed posttest at the remember level (omnibus chi-square = 1.93, *df* = 2, p = .381). The model only accounted for between 4.8% and 6.4% of the variance in delayed posttest answers, with 51.3% of answers correctly predicted. Table 11 gives coefficients and the Wald statistic and the associated degrees of freedom and probability values for each of the predictor variables. Column 6 indicates that none of the predictor variables reliably predict delayed posttest score.

Understand Level

A logistic regression analysis was also performed with delayed posttest understand score as the dependent variable and group and posttest understand score as predictor variables. Thirty-nine cases were analyzed and the full model was significant at

Table 11

Remember Delayed Posttest Statistical Analysis

	Variables in the equation					
Step 1[a]	*B*	S.E.	Wald	*df*	Sig.	Exp(B)
Group	-.765	.662	1.336	1	.248	.466
Postremember	.169	.215	.618	1	.432	1.185
Constant	.584	1.314	.198	1	.657	1.793

[a]Variable(s) entered on step 1: group, postremember.

alpha = .1 at predicting success on delayed posttest scores at the understand level (omnibus chi-square = 5.19, *df* = 2, *p* = .08). The model accounted for between 12.5% and 17.9% of the variance in delayed posttest answers. Forty-five and one half percent of the incorrect answers were successfully predicted, and 92.9% of the correct answers successfully predicted, with 79.5% of overall scores successfully predicted. Table 12 gives coefficients and the Wald statistic and the associated degrees of freedom and probability values for each of the predictor variables. This suggests that only the posttest score reliably predicts delayed posttest score (see Column 6).

Problem Solving

A logistic regression analysis of problem solving score was performed with delayed posttest problem solving score as the dependent variable and group and posttest problem solving score as predictor variables. Thirty-nine cases were analyzed and the full model was not significant at predicting success at delayed posttest at the problem solving level (omnibus chi-square = 2.43, *df* = 2, *p* = .296). The model only accounted for

Table 12

Understand Delayed Posttest Statistical Analysis

	Variables in the equation					
Step 1[a]	*B*	S.E.	Wald	*df*	Sig.	Exp(B)
Postund	.537	.258	4.333	1	.037	1.710
Group	.311	.768	.164	1	.685	1.365
Constant	-1.200	1.398	.738	1	.390	.301

[a]Variable(s) entered on step 1: postund, group.

between 6% and 8.9% of the variance in delayed posttest answers. None of the incorrect answers were successfully predicted, and 96.6% of the correct answers successfully predicted. Table 13 gives coefficients and the Wald statistic and the associated degrees of freedom and probability values for each of the predictor variables. Column 6 shows that none of the predictor variables reliably predicts delayed posttest score.

It should be recognized that the results for delayed posttest are more exploratory than confirmatory, as the power is very limited.

Summary of Tests for the Main Effect

Both groups improved remember level scores from pretest to posttest. The First Principles group effect from pretest to posttest was significant at alpha = .1, and the traditional group effect was significant at alpha = .05. There was no significant difference between groups at the understand level. At the problem solving level, students in the First Principles group had a higher effect size and this improvement from pretest to posttest for

Table 13

Problem Solving Delayed Posttest Statistical Analysis

	Variables in the equation					
Step 1[a]	*B*	S.E.	Wald	*df*	Sig.	Exp(B)
Group	-1.043	.808	1.667	1	.197	.352
Postprobs	.455	.463	.965	1	.326	1.576
Constant	1.759	1.535	1.313	1	.252	5.808

[a]Variable(s) entered on step 1: group, postprobs.

the First Principles group was significant; however, it was not significant for the traditional group.

Student Reaction to Modules

Quantitative Analysis of Student Reactions

After completing study with their assigned modules, students were asked "How would you rate the usefulness of this study session in helping you learn about microevolution?" Students responded positively, and all students in both groups responded with a rating of "Very useful" or "Useful." Student responses were analyzed using chi square to determine if there were significant differences in student response from group to group. Because the analysis showed that two cells had expected count less than 5, an exact significance test was selected for Pearson's chi-square. There was no significant relationship between group and student reaction rating $\chi 2$ (2, $N = 40$) = 0.043, $p = 0.569$.

Qualitative Review of Student Reactions

Although the two groups rated the usefulness of their modules similarly, some differences appeared in their comments regarding what they liked about the session and what they would suggest to improve the modules. In this section, I analyze student responses beginning with the comments from students in the experimental group. I then analyze the comparison group and finish the section with a comparison of the responses from two groups.

First Principles group student comments. As noted above, students assigned to the First Principles module reacted positively to the module and all participants rated it as somewhat useful or very useful. Students were then asked to write what they liked about the module and what they would suggest to improve it. This section highlights student comments regarding the First Principles module.

What First Principles students liked. I analyzed the students' comments using thematic analysis and identified five themes. These themes included: (a) repetition of key information; (b) examples used in the module; (c) question and answer sessions that helped retention; (d) multimedia in the module; and (e) organization of the module. These themes are described in greater detail in Appendix O. Table 14 shows the percentage of student comments for each theme.

What First Principles students suggested for improving. Students were also asked "What would you suggest to improve this study session?" This section summarizes student suggestions for improvement according to themes identified by the researcher. Themes included: (a) reducing repetition in the module; (b) speeding up the pace, reducing length, and enabling student control of the module; (c) more multimedia; and

Table 14

What Students in First Principles Group Liked About the Module

Theme	Number of comments
Repetition	43%
Examples	24%
Question and answer	24%
Multimedia	24%
Organization	10%

(d) application of content to personal life. Table 15 tallies the student comments on these themes.

Traditional group student comments. As noted above, students who were randomly assigned to the traditional module reacted positively to the module and all participants rated it as somewhat useful or very useful. Students were asked what they liked about the module and what they would suggest to improve it. This section summarizes student responses according to thematic analysis.

What traditional students liked. The researcher analyzed the comments of the students in the traditional group using thematic analysis and identified five themes. These themes include the following: (a) repetition and reinforcement in the module; (b) use of multimedia; (c) interaction with the content; (d) application and feedback in the module; and (e) use of examples. Table 16 tallies the student comments on these themes. These themes are described in greater detail in Appendix O.

What traditional students suggested for improving. The researcher also analyzed the suggestions of the students in the traditional group using thematic analysis and identified five themes. These themes include the following: (a) increased multimedia, (b)

Table 15

What Students in First Principles Group Suggested Improving

Theme	Number of comments
Reduce repetition	38%
Pace, length, and control of the module	19%
Multimedia	10%
Personal application	10%

Table 16

What Students in Traditional Group Liked About the Module

Theme	Number of comments
Multimedia	32%
Interaction	26%
Quiz and feedback	21%
Repetition	16%
Examples	11%

technical improvements, (c) more repetition, (d) more examples, and (e) more interaction. Each of these themes is described in greater detail in Appendix O. Table 17 tallies the student comments on these themes.

Comparing What Students Liked

Students in each group gave comments about what they liked. Several of the themes between groups were very similar. Some of the students in both groups liked the use of repetition, the examples, and the use of multimedia in the modules. However, only students in the First Principles group commented that they liked the organization of their module, and only students in the traditional group commented that they liked the interaction of their module. Table 18 compares the comments by students in each group. There were some similar themes between groups and some unique themes.

Comparing Suggestions for Improvement

Students in each group also made suggestions to improve the modules. Two themes between the groups were very similar. Students in both groups suggested

Table 17

What Students in Traditional Group Suggested Improving

Theme	Number of comments
Multimedia	16%
Technical improvements	19%
Reduce repetition	11%
Examples	11%
Interaction	5%

Table 18

Comparing the Groups' Positive Comments

Group	First principles themes	Traditional themes
Similarities		
Repetition	43%	16%
Examples	24%	11%
Quiz and feedback	24%	21%
Multimedia	24%	32%
Differences		
Organization	10%	-
Interaction	-	26%

reducing repetition in the module and increasing the use of multimedia. Only students in the First Principles group suggested changing the pace and learner control in the module. Only students in the traditional group suggested technical improvements, using more examples, and increasing interaction. Table 19 compares the comments by students in each group.

Table 19

Comparing the Groups Suggestions for Improvement

Group	First principles themes	Traditional themes
Similarities		
Reduce Repetition	38%	11%
Multimedia	10%	16%
Differences		
Control and length of module	19%	
Personal application	10%	
Technical Improvements		16%
Examples		11%
Interaction		5%

Student Comments and Strategies in the Module

When reviewing the student reaction comments, it becomes clear that students' comments are reflective of the kind of strategy used in the module. For example, several students in the First Principles group liked the use of examples in the module, but this kind of comment was not as frequent in the traditional group. This is reflective of the heavy use of real-world examples in the First Principles module, a strategy that was minimized in the traditional module. Table 20 demonstrates the relationship between the strategies used in each module and the student comments.

Table 20

Relationship Between Strategies and Student Comments

Module	Strategy used	Student comment themes
First Principles	Cycle of instruction using three whole problems	Repetition of key information
	Whole problems used to deliver instruction and partial problems used to focus on component strategies	Use of examples in the module
	Application and feedback strategies	Question and answer sessions
	Video presentations using multimedia principles	Multimedia in the module
	Organizing structure used to demonstrate structure of the content	Organization of the module
Traditional	Multiple representations of the content (text, audio, video, image)	Repetition and reinforcement
	Video presentations using multimedia principles	Use of multimedia
	Drag and drop activities	Interaction with the content
	Drag and drop activities, information-only application and feedback	Application and feedback
	Limited examples describing the use of these modules	Use of examples

CHAPTER VI

DISCUSSION

Summary of Chapters 1-4

Review of Problem Statement, Literature, and Module Design

There is a problem of lack of understanding of science concepts in the public, and much of it can likely be traced to the way adults learned science. Unfortunately, many students still struggle with a lack of understanding of science concepts (Halpern & Hakel, 2002; Michael, 2006). In a time in which U.S. students struggle to compete with their international counterparts in understanding science concepts (NCES, 2006a), it is imperative that educators analyze why this problem exists and what can be done to overcome it.

Many people blame the predominant lecture approach for students' lack of science understanding. The traditional lecture approach is particularly criticized because teachers using this format present science as information to be remembered instead of actively used (Halpern & Hakel, 2002; Michael, 2006; Volpe, 1984). Unfortunately, the lecture format is used in many biology courses, and students continue to have poor performance, resulting in high student failure rates (Freeman et al., 2007; Greg Podgorski, personal communication, November 13, 2009).

Current research indicates that more active instructional approaches can improve student learning (Brewer, 2004; Collins & O'Brien, 2003; DiCarlo, 2006; Dori & Belcher, 2005; Ebert-May et al., 1997; Kiboss et al., 2004; Michael, 2006; Reuter &

Perrin, 1999; Riffell & Sibley, 2005; Sanger et al., 2001). Active learning in undergraduate biology courses means having students gather information, think, and solve problems (Collins & O'Brien, 2003). These strategies can include student problem solving (Collins & O'Brien, 2003), web-based assignments (Riffell & Sibley, 2005), student discussion and collaboration (Brewer, 2004; DiCarlo, 2006; Dori & Belcher, 2005; Ebert-May et al., 1997; Michael, 2006), and multimedia presentations (Kiboss et al., 2004; Reuter & Perrin, 1999; Sanger et al., 2001).

Active learning may be difficult to implement because its methods and strategies are diverse, ranging from in-class collaborative problem-solving to out of class multimedia presentations. Interestingly, few studies I reviewed implemented more than one or two of documented active learning strategies. Perhaps this is because it can be difficult to incorporate several of these strategies into a cohesive teaching strategy that works together to increase student learning. For active learning to be most successful, it must incorporate and integrate many of the methods reviewed in Chapter II (Michael, 2006).

First Principles of Instruction provide a framework for implementing active learning strategies. Based on an analysis of several instructional theories, models, and best practices, Merrill (2002) proposed that effective teaching implements five fundamental, "First Principles" of instruction. There are five principles: (a) basing instruction on real world problems or tasks, (b) activating students' prior learning, (c) demonstrating new knowledge in the form of real-world problems, (d) having students apply their new knowledge to a new problem, and (e) having students integrate their knowledge by discussing, reflecting on and presenting on their learning. This study used First Principles as a framework for organizing multiple active learning strategies in a web-based module. Two modules were developed in a FLASH environment, one module using First Principles of Instruction as an instructional strategy and the other using a more traditional, topic-centered approach.

Review of Method

Participants were students in Life Sciences 1350, an introductory biology course. Students were randomly assigned to use either the First Principles module or the traditional module. The First Principles module implemented several active learning strategies and used a progression of whole problems and several demonstration and application activities to teach microevolution. The traditional module implemented a more traditional approach, providing information and explanations about microevolution with limited examples.

Participants first took a pretest designed to assess (a) their existing knowledge of microevolution at the remember and understand levels of Bloom's taxonomy and (b) their ability to solve microevolution problems. They then studied using their assigned modules for about 45 minutes. Finally, they took a posttest to assess their learning at the remember and understand levels, and at the ability to solve microevolution problems. Two weeks later, students also took a delayed posttest, which included one question at each level of assessment.

Interpretation of Results

Research Question 1: Compared to students receiving traditional web-based supplementary instruction, do students receiving supplemental instruction incorporating Merrill's First Principles of Instruction perform better at the "remember" and "understand" levels of Bloom's Taxonomy?

Remember Level

Results indicated that the traditional group improved slightly more at the remember level than the First Principles group. The effect size for learning gain between groups at the remember level was small (d = 0.2) in favor of the traditional group. However, a t test showed that the main effect of learning gain difference between conditions was not significant.

Both modules increased student learning at the remember level. To assess learning increase for each group individually, effect sizes were calculated. The effect size for learning gain within the First Principles group was low medium (d = 0.4), and within the traditional was high medium (d = 0.6). The learning gain within the First Principles group was significant at alpha = .1, and within the traditional group was significant at alpha = .05.

The finding that the traditional group improved at the remember level is not surprising. The traditional module primarily delivered information, definitions, examples, and memory quizzes, all working at the basic remember level. It should be acknowledged that this approach is an effective way to improve memory and recall in students, and perhaps this is one reason that an informational approach to instruction is still prevalent in much instruction today (Barclay et al., 2004; Cropper, 2007; Merrill, 2006b).

While the First Principles group improved less at the remember level, they still improved a substantial and statistically significant amount, which is notable for a module that took students 45 minutes to go through. Perhaps additional data gathering with a variety of instruments could further clarify the differences in learning gain for each module.

The finding that both approaches improve learning at the remember level is important because student ability to recall information is a fundamental part of becoming scientifically literate (AAAS, 2009). However the ability to recall information about microevolution, a core biology concept, does not, in and of itself, constitute scientific literacy. Indeed, the ability to recall and remember large amounts of information is more closely associated with the traditional lecture approach to instruction. In contrast, to be scientifically literate is to be able to converse with science concepts and processes (Hurd, 1998), and people must understand what they are conversing about. While recalling a definition of a concept is arguably an important part of understanding, it is not a full measure of understanding.

Based on the findings of this study, it can be inferred that having students use a web-based module similar to either of those used in this study will help improve student performance on remember-level questions. This is consistent with previous research, which indicated that having students answer biology content-related questions in a web-based module improved performance on course test scores (Kiboss et al., 2004; Riffell &

Sibley, 2004). This study adds to this knowledge base by indicating what types of student performance are improved depending on the instructional strategies used within the web-based modules. The results for the remember level seem to indicate that both traditional and First Principles modules can increase learning at the remember level.

It is important to ensure that the kind of learning outcome sought can be achieved with the instructional strategy selected. For example, when student ability to remember key facts is desired, both modules appear to effectively improve student learning, particularly the traditional module. The belief that the instructional strategy used affects the learning outcome is a foundation of instructional design. It is not necessarily the technology or medium used in the instruction, but the strategies used within that communication that affect the students' learning. This has important implications for the design of web-based modules in undergraduate courses because it clarifies which strategies should be used depending on specific learning outcomes.

Understand Level

Tests were performed to determine whether there was significant improvement for either group at the understand level. The effect size for learning gain between groups at the understand level was small to moderate ($d = 0.3$) in favor of the First Principles group. A t test showed that the main effect of learning gain difference between conditions was not significant.

To assess learning gain at the understand level within each group from pretest to posttest, effect sizes were calculated. The First Principles group had a small effect size ($d = 0.2$), and the traditional group had a small negative effect ($d = -0.2$). Learning gain within each group was also tested and difference between pretest and posttest for both groups was not significant.

As indicated by the effect sizes, the First Principles group improved in understanding from pre to posttest. However, it is not clear if this difference is due to First Principles or chance since the difference was not significant. Because this study is exploratory in nature, this effect sizes can be seen as an indication that a more confirmatory study, including a larger sample size and therefore greater power, is warranted. However, this purely speculation, since the results of this study indicate no significant difference. Clearly more research is needed to explore this relationship.

A finding that the use of First Principles improved student understanding of microevolution content more than the traditional would be important because it sheds light on previous research (e.g., Kiboss et al., 2004; Riffell & Sibley, 2004; Sanger et al., 2001), clarifying what levels of learning are affected by which kinds of strategies are used within the modules. For example, in one study, computer animations depicting processes of osmosis increased student understanding of those processes (Sanger et al., 2001). Knowing what kinds of learning are improved is important, because some active learning studies found that course scores and grades were improved with the use of web-based modules (e.g., Kiboss et al., 2004; Riffell & Sibley, 2004) but did not clarify what kind of learning was tested. Certainly, more research on the effect of specific strategies used in web-based modules is needed to help clarify how learning at the understand level is affected.

The kinds of animations used could also affect whether understand level learning takes place. For example, animations used in the First Principles modules were problem-centered and demonstrated how microevolution took place in several specific populations. In contrast, the animations used in the traditional module described the content without a providing a real-world context. However, this was not an isolated variable in the study, and additional research is needed to confirm the effectiveness of multimedia with a variety of subjects and settings.

It is important to note that the questions at the remember and understand level do not measure a student's ability to use the content in a meaningful way, one of the fundamental goals of undergraduate biology courses (AAAS, 2009). This ability is better measured by the problem solving instrument because of its focus on forming hypotheses, a key part of the scientific process.

Research Question 2: Compared to students receiving traditional web-based supplementary instruction, do students receiving supplemental instruction incorporating Merrill's First Principles of Instruction improve their ability to solve content-related problems?

Problem Solving

Results indicated that the effect size for learning gain between groups at the problem solving was moderate ($d = 0.3$) in favor of the First Principles group. Problem solving learning gain for the First Principles group was significant, with a low-large effect size ($d = 0.7$). For the additional problem solving measures, no significant difference was found between groups. For additional problem solving measures, students in the First Principles group had improved self-ratings at predicting future success at solving problems, and this finding was significant at alpha = .1.

These findings suggest that teaching microevolution using active learning strategies in a First Principles framework is effective at increasing students' abilities to solve microevolution problems. This is important because the ability to solve problems using the scientific method is a core goal of undergraduate biology instruction (AAAS, 2009). In addition, evolution is a core biology concept (AAAS, 2009), and this study suggests that using active learning strategies in a First Principles framework is an effective method for teaching this concept. The First Principles module taught how scientists analyze microevolution in a population to form a hypothesis, one important step in the scientific process, and students in the First Principles group performed this step more accurately.

Because this study is exploratory in nature, this effect between groups at problem solving can be seen as an indication that a larger, more confirmatory study, including a larger sample size and therefore greater power, is warranted.

This finding aligns with some current undergraduate biology active learning research. Reuter and Perrin (1999) found that using a problem-centered dynamic model to demonstrate biology phenomenon increases students' ability to analyze problems related to the content taught. This study further suggests that problem-centered instruction may enable students to solve future problems. Certainly, additional research can provide further knowledge of the effect of problem-centered active learning strategies on problem solving ability.

Based on the findings of this study, it can be inferred that having students use a web-based module similar to those used in this study will help improve student performance on problem-solving questions, and that performance is more pronounced with the use of the First Principles module. This is consistent with previous research, which indicated that having students answer biology content-related questions in a web-based module improved the students' performance on course test scores (Riffell & Sibley, 2005) and demonstrates that the problem-centered approach improves student performance at problem solving questions. This study also indicates what types of student performance are improved depending on the instructional strategies used within the web-based module.

It is interesting that there was an increase in student performance at the problem solving level. This makes sense because the exposure to multiple problems and scenarios within the module could provide students with context for the content they are learning.

From a practical perspective, preparing students to solve real-world problems using scientific processes is important. Informed members of society should have the capacity to participate more intelligently in society, particularly as they interact with their environment and "solve every-day problems and use evidence and logic to reach sound conclusions" (AAAS, 2009, p. 5). If using active learning in a First Principles framework can engender this capacity in students, then it should be implemented more broadly into undergraduate curriculum and integrated into multiple methods of instruction, including lectures and collaborative assignments. Again, additional research is needed to confirm the effectiveness of these principles.

It is important to note that this research only directly informs active learning research related to the use of web-based modules and computer animations. There are many other kinds of active learning strategies that could be made more effective using a First Principles framework. For example, using student response systems (clickers) as part of a course is shown to decrease failure rates for the course (Freeman et al., 2007). However, no mention is made of whether this also increases student ability to solve problems or whether there is increased science literacy. In addition, collaboration and discussion are shown to be important active learning strategies that improve student understanding (Ebert-May et al., 1997). However, no active learning research has yet indicated whether student ability to solve problems is increased. I suggest that making these and other active learning strategies centered on real-world problems within a First Principles framework may potentially further improve student ability to solve problems. Improving the way that these methods are used could provide a marked improvement in student learning overall. Of course, more research will provide greater understanding of how these principles can be incorporated into an overall strategy, and whether doing so does increase student learning.

Delayed Posttest Items

Student retention of learning gain was tested with a delayed posttest which was implemented two weeks after the study session as part of the course midterm. This posttest included one question at each level measured: remember, understand, and problem solving. A logistical regression analysis was performed to determine whether group or performance on the posttest successfully predicts a correct response on the delayed posttest. The majority of these tests showed no significant results; however, as reported above, student success on the posttest at the understand level successfully predicted student success on the delayed posttest measure at the understand level.

The finding of no significant difference between groups on delayed posttest items at the remember and problem solving level seems to indicate no difference in student retention between the two groups. However, the format of the delayed posttest was different from the pre and posttests, and was potentially influenced by lectures and reading in the course. Future studies should include instruments for the delayed posttest that include more questions at each level of learning, more control over the test environment, and should be similar to the pretest and posttest structure for a more thorough approach.

Again, it should be emphasized that the results of the logistic regression analysis for the delayed posttest are more exploratory than confirmatory because of the small sample size for this study and the fact that the delayed posttest contained only one item at each level. Future research should include more participants and a more robust delayed posttest measures to ensure greater power.

Student Reaction to the Modules

Student rating of the usefulness of the module was almost identical in both groups. All students in each group rated the module as useful or very useful. These ratings are not statistically significantly different, indicating a high level of satisfaction for each group with their respective treatment.

Students also commented on what they liked about the assigned web-based module. These student comments were analyzed using thematic analysis. Analysis revealed that although students in each group liked the module, the reasons for liking the module were different depending on the group. Students in the First Principles group commented that they liked: (a) repetition of key information, (b) examples used in the module, (c) question and answer sessions that helped retention, (d) multimedia in the module, and (e) organization of the module. Students in the traditional module also liked the repetition used in the module, the examples in the module, and multimedia used in the module. However, they also liked the interaction provided by the traditional module.

It is interesting that the positive student comments reflected the strategies used in each the module. This means that students have some level of awareness of the strategies used in the module they were assigned to. This gives some credence to student comments about the strategies used in a course, and could provide further evidence that student comments are a useful source of information about strategies used in a particular course. For example, in a separate unpublished study, I used student comments along with other data sources to determine the kinds of strategies used by award-winning instructors (Gardner, 2010). And the trend that student comments were reflective of the strategies in this study gives me added confidence in the credibility of those student comments. Surprisingly, all students in both groups still rated their modules as useful or very useful, with no statistical significance between ratings. Although the students liked different things about each module, it did not affect the perceived usefulness. Therefore, usefulness or effectiveness of the module must be measured by the other means described above.

Implications

Implications for Active Learning Research

This study provides some limited support that active learning strategies do increase student learning at multiple levels of knowledge. Importantly, it provides further insight into the kinds of learning that active learning strategies can help improve. These results indicate that active learning strategies can improve learning at remembering and problem solving.

One implication of this research is that the way an active learning strategy is implemented is very important. For example, because both modules were web-based modules that included multimedia and question-answer activities, they could immediately be categorized as active learning strategies. However, the methods used within the modules, including the how the multimedia was presented and whether real-world problems were presented, appears to be a crucial factor in student success within these modules. Simply including question and answer might improve student performance on course quizzes (Riffell & Sibley, 2005), but the kinds of questions asked might influence what level of learning is increased. Similarly, using multimedia is shown to improve student understanding (Kiboss et al., 2004; Reuter & Perrin, 1999) and decrease student misconceptions (Sanger et al., 2001). While both modules in this study used multimedia to teach microevolution, they implemented those multimedia using different methods.

Perhaps most key to the use of web-based modules is the use of a problem-centered instructional strategy. This approach appears to result in a measurable improvement in student ability to solve problems effectively, a core goal of undergraduate biology courses (AAAS, 2009). However, it must be acknowledged that this improvement was not significantly different from improvement in the comparison group, was only apparent on the posttest, and students in the traditional group performed slightly better on the delayed posttest.

The results of this study seem to confirm the results of other research that indicates that the medium used in instruction is not as critical as instructional strategy in increasing student learning. For example, Means, Toyama, Murphy, Bakia, and Jones (2009) reviewed over 1,000 studies comparing different media used in education and concluded that the instructional elements used in the course was a great influence on the success of the course.

As mentioned above, both modules used in the study can be seen as using active learning methods. Both are web-based modules that require students to answer questions about biology content. Both use animations to teach the content. However, the major difference between the modules is the use of problem solving in the First Principles module. In addition, the First Principles module goes beyond merely having students solve problems and explicitly demonstrates to students how to solve those problems. As well, the First Principles module uses an organizational structure that explicitly instructs students on the process of designing instruction. Table 21 compares the active learning strategies used in each of the modules according to the themes identified in Chapter II.

Table 21

Comparing Active Learning Strategies Between Modules

Active learning strategy	First principles module	Traditional module
Problem solving	X	
Web-based assignments	X	X
Animations	X	X
Collaboration and discussion	--	--

It is important to note that it is difficult to compare findings in this study to previous studies because the reports I reviewed were often not clear about what was being tested. Using a standard scale such as Bloom's Revised Taxonomy could provide a frame of reference that active learning researchers could use to compare findings of different studies. I would suggest that this or a similar taxonomy be adopted among other active learning researchers to provide a standard taxonomy through which findings can be compared.

It would also be important to test several modules of these kinds as a part of an overall strategy within a semester-long course. Although this research used students in an introductory biology course, the study was somewhat detached from the strategies used in the course overall. Certainly, additional research, including research on the use of these modules as part of an overall strategy could provide additional support for the use of problem-centered web-based modules to increase student understanding and problem solving.

Implications for First Principles Research

This study provides some evidence that the use of First Principles of Instruction can increase student learning gain, particularly the ability to solve real-world problems; however, this increase was not shown to be significant when compared to the use of more traditional strategies. Students in the First Principles group improved significantly on problem solving measures from pretest to posttest. The findings are similar to those found in the Thomson (2002) study in which students receiving a problem-centered approach using First Principles of Instruction also improved performance significantly. However, the Thomson study is different because the duration of the study was much longer, taking place over several weeks. This variation in the way these principles are implemented shows the flexibility of First Principles of Instruction because they provide a framework that can be applied in an hour of instruction or over several weeks. The result of this study provide more support to the notion that First Principles of Instruction do increase the ability to solve problems, and it also indicates that the ability to remember key information.

More research should be performed in a variety of settings to test these principles. Research with a greater variety of populations, courses, subjects, and with different lengths of intervention would provide further insight into and potential support for the effectiveness and optimization of these principles. To gather more data on the effectiveness of First Principles, a repetition of this study is planned for an upcoming introductory biology course with a much larger student population. It is hoped that the additional power associated with the larger sample size will improve understanding about the effect of these principles on student learning.

It would also be useful to study the use of this web-based module as a part of a larger problem-centered strategy in a full introductory undergraduate biology course. In many of the active learning studies reviewed above, web-based modules were added to traditional lecture courses. However, combining several problem-centered web-based modules like the First Principles module with a problem-centered course similar to that described by Francom and colleagues (2009) could yield even greater learning gains because of the increased exposure to course content and the addition of collaboration and discussion activities. In addition, a course of this kind could truly provide students with improved learning of the core concepts and processes identified by the AAAS (2009).

Results of the current study indicate significant short-term gain among students, but the long-term benefits are not yet apparent. Previous studies using First Principles of Instruction seem to indicate long-term improvements (Thomson, 2002), but further research in an undergraduate biology setting would potentially provide greater support for the use of these principles, particularly a treatment of a longer duration.

Implications for Instructional Design

These findings suggest that designing instruction that uses First Principles increases student ability to solve problems and remember key information; however, this increase was not significant when compared to the use of more traditional strategies. Still, it is important to keep a perspective on what this study really does indicate. Because students in this introductory undergraduate biology course appear to benefit somewhat from the use of these principles, students of similar backgrounds learning at the same level might benefit from a similar strategy. In addition, it is important to acknowledge that because of time and scope restraints, and this study did not incorporate integration activities into the First Principles module. The inclusion of integration learning activities could further influence and improve student learning. Integration strategies tend to focus on the long-term retention of knowledge, and using them in studies of this kind could influence student performance on the delayed posttest in future studies. Based on this study and the research reviewed above, students may benefit from instruction that engages students in whole problems and including demonstration and application of a progression of problems as a part of that instructional strategy.

Limitations and Suggestions for Future Research

Did Not Use All Strategies

One limitation of this study is that I did not employ all of Merrill's First Principles of Instruction in the First Principles module. Some strategies were not used because of time and scope restraints for performing this study. For example, the activation strategy of providing an organizing structure was used, but students were not directed to activate their prior microevolution learning. In addition, no integration strategies were used for this study. Perhaps if more First Principles strategies were used in the module we would see higher levels of learning gain in the First Principles group.

The partial use of strategies also applies to the use of active learning strategies identified in Chapter II. While I employed problem solving, web-based assignments, and multimedia as key parts of this module, a collaboration and discussion strategy were not used. This also limits the potential effectiveness of employing multiple active learning strategies.

Use of Some Strategies in Comparison Module

Another limitation of the study is the use of a high quality module as the comparison module. In this case, the traditional module used multiple active learning strategies and even made limited use of some First Principles strategies. For example, the traditional module used effective demonstration of information as well as demonstration using specific examples of the forces being taught. The use of the demonstration principle potentially increased the effectiveness of the module, thereby negating some of the potential difference between the two modules.

In addition, the traditional module itself incorporated some active learning elements because it is a web-based module that uses multimedia. Future research including an additional control group receiving traditional lecture and no web-based module would provide further insight into learning gain that can be expected from a module of this kind.

Teacher Effect on the Delayed Posttest

One potential limitation of this study is the lecture and study materials provided by the course instructor between the posttest and the delayed posttest. The instructor gave one 75-minute lecture on microevolution, and students also read about microevolution using the course textbook. These factors could have influenced the effect being measured in the delayed posttest because students studying the textbook, attending the lecture, or studying lecture notes could have gained more knowledge, thereby potentially conflicting with the results on the delayed posttest.

Technical Difficulties and Other Inconsistencies

During this study, there were a few minor inconsistencies the study implementation. For example, two study session groups participated in the study in another computer lab because of a scheduling conflict. This change of environment may have had a minor influence on student experience with the study. However, students from both groups participated in these sessions, the computers used for this session were the same type as those in the regular lab, and great care was taken to maintain consistency in the pacing all of the sessions. In addition, some students experienced minor technical problems with the audio on the modules, though these problems were of a short duration and were quickly remedied as soon as they were found.

Length of Intervention

Another limitation of this study is the relatively short time period for the intervention. Students participated in the study for only 90 minutes. In comparison, other studies like the Thomson (2002) study incorporated instruction over a longer period of time. The use of a greater variety of active learning strategies in a First Principles framework over a longer period of time could yield more complete data and could also provide improved understanding of the effect these principles have on student learning.

Time Between Intervention and Testing

Another limitation of the study is the short period of time between the intervention and the posttest and delayed posttest. Students took the posttest immediately after finishing their randomly assigned modules, which tested short-term retention of knowledge.

Another limitation of this study is its exploratory nature. Because the sample for the study was small, there was a reduced ability to find a significant effect.

Threats to Internal Validity

Regression to the mean. One potential threat to internal validity is regression to the mean. However, in this case students were not selected based on their performance as outliers, so regression based on their previous performance is not an issue. There is the possibility that students in one of the groups performed above or below average on the pretest and then regressed to the mean on the posttest. One particular area of concern was the decrease in performance at the understand level by the traditional group. However, this appears unlikely, since both groups performed similarly on pretest items and the regression would potentially apply to both groups on the posttest.

Low power. Another threat to the validity of this study is low statistical power. A post hoc power analysis indicated that the power was .147, considered low power, meaning it has a low probability to reject a false null hypothesis. There were fewer participants than desired in this study, which likely impacted the statistical power. In addition, the effect sizes between groups were also low, contributing to a reduction in power.

Threats to External Validity

It is not reasonable to say that any particular study can be generalized to all settings. This study took place in a summer introductory biology course at Utah State with a specific set of students. It is difficult to say whether these principles will work in other locations with different student demographics, since these variables could influence the outcomes of the study. Certainly more research in a variety of settings with a variety of students would provide greater insight into the effectiveness of these principles. However, it can tentatively be concluded from this study that there is some evidence that using active learning strategies within a First Principles framework to teach microbiology in an introductory undergraduate biology course can improve student learning at the remember and problem solving levels.

Future Research

Plans are under way to replicate this study with a larger introductory undergraduate biology course. In addition, further studies on active learning and First Principles of Instruction could be conducted in a variety of settings to gain further knowledge about the effectiveness of these principles. There is some evidence that First Principles can help students solve microevolution problems when they are taught with a problem-centered approach. Additional research would expand on this to test the effect of each individual principle on learning.

Conclusion

Because students will face many problems in the future, and those problems will potentially be related to the natural world, it is increasingly important that students become scientifically literate (AAAS, 2009), and that educators provide them with the knowledge and skills needed to participate responsibly in society. Because of this, it is vital that instruction enable students to understand core ideas such as microevolution, and be able to use scientific processes to think and interact with the world (AAAS, 2009).

Active learning strategies have been shown to be effective methods for engaging students in biology learning and improving student success in introductory undergraduate biology courses (Armbruster et al., 2009; DiCarlo, 2006; Ebert-May et al., 1997; Freeman et al., 2007; Michael, 2006; Nelson, 2008; Smith et al., 2005). In addition, demonstrating biology phenomena using web-based multimedia increases student understanding of biology concepts (DiCarlo, 2006; Kiboss et al., 2004; Reuter & Perrin, 1999; Sanger et al., 2001). This study confirms that the use of active learning strategies within a web-based module increases student learning in both modules.

The use of each individual First Principles of Instruction has been shown to increase student learning in other settings (Cropper, 2007; Merrill, 2006; Thomson, 2002). Certainly, more research would provide greater insight into the kinds of learning expected when a problem-centered strategy is employed. The finding that students in the First Principles group significantly improved at problem solving is encouraging, and the use of these principles should be studied further in similar and different settings.

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APPENDICES

Appendix A

Microevolution Pretest Questions

Microevolution Pretest Questions

- ______________ has a stronger effect on small populations than on larger populations:
- gene flow
- macroevolution
- mutation
- **genetic drift**

- Mutation is defined as:
- **The random creation of new gene forms (alleles).**
- a directed process that creates new selectively beneficial gene forms
- a change in allele frequency that occurs primarily in small populations
- the cause of genetic bottlenecks that change allele frequency in a population

- _____________ is caused by migration. It is any movement of genes from one population to another.
- mutation
- natural selection
- genetic drift
- **gene flow**

- The founder effect is a special case of:
- mutation
- **genetic drift**
- stabilizing selection
- gene flow

- Genetic drift is:
- a change in allele frequency due to movement of alleles between populations
- the creation of new alleles due to DNA sequence changes
- **the random fluctuation in allele frequency due to chance**
- one form of natural selection

- When food and water are scarce:
- **some individuals may be unable to obtain what they need to survive**
- the individuals will find other food sources, so there is always enough
- the individuals all eat and drink less so that all individuals survive
- there is always another source of food and water in the environment to meet the individuals' needs

- In microevolution, what are the primary changes that occur gradually in a population over time?
- The traits of each individual gradually change
- **The proportions of individual having different traits change**
- Successful behaviors learned by individuals are passed on to offspring
- Mutations occur to meet the needs of the individuals as the environment changes

- In natural selection:
- Most of the individuals in a population cooperate to find food and share what they find.
- Many of the individuals in a population fight with one another and the physically strongest ones win.
- There is always more than enough food to meet all the individuals' needs so they don't need to compete for food.
- **Individuals in a population compete, and if there are limited resources, those better adjusted to the environment (more fit) survive.**

- How do new genetic characteristics <u>first</u> arise in a population of birds?
- The changes in heritable characteristics occur because of individual birds' need to survive.
- **Changes in heritable characteristics occur by chance, and when there is a good match between the new characteristic and the environment, it is passed on to offspring.**
- The changes in the characteristics occur because the environment induces the desired genetic changes in the birds.
- The characteristics change when individual birds adapt to the environment and pass it down to offspring.

- What type of variation in a population is passed to the offspring?
- Any behaviors that are learned during an individual's lifetime.
- Only characteristics that are beneficial during an individual's lifetime.
- **All characteristics that are genetically determined.**
- Any characteristics that are positively influenced by the environment during an individual's lifetime.

Appendix B

Microevolution Posttest Questions

Microevolution Posttest Questions

1. Microevolution is defined as:
    a. the evolution of microbes and other small organisms
    b. rapid evolution
    c. generation-to-generation genetic changes in populations
    d. natural selection
2. In microevolution, what evolves?
    a. genes
    b. cells
    c. individuals
    d. alleles
    e. populations

3. _____________ is a random fluctuation in allele frequency due to chance events:
    a. genetic drift
    b. gene flow
    c. mutation
    d. natural selection

4. _______________ increases the survival and reproduction of individuals in a population:
    a. genetic drift
    b. natural selection
    c. macroevolution
    d. gene flow

5. Which of the following is the only evolutionary force that creates new gene forms (alleles)?
    a. gene flow
    b. directional selection
    c. mutation
    d. genetic drift

6. Which statement best describes the individuals of a single species in an isolated population?
    a. The individuals share all of the same characteristics and are identical to each other.
    b. The individuals are all quite different from each other in every way
    c. The individuals are identical on the inside but have many differences in appearance.
    d. The individuals share many essential characteristics, but also vary in many features.

7. Natural selection only works:
    a. in large populations
    b. in small populations
    c. on heritable traits
    d. for sexually reproducing organisms

8. Why would individuals in a population have a variety of sizes?
    a. They needed to change body size in order to survive, so they developed beneficial new body sizes.
    b. They wanted to become different in size, so beneficial new body sizes gradually appeared in the population.
    c. Random genetic changes created different body sizes.
    d. The environment caused beneficial genetic changes that altered body size.

9. In a population, what are the primary changes that occur gradually over time?
    a. The traits of each individual within a population gradually change.
    b. The proportions of individuals with different traits within a population change.
    c. Successful behaviors learned by certain individuals are passed on to offspring.
    d. Mutations occur based on the needs of the individuals as the environment changes.

10. In a population of fish in a pond, individuals eat a variety of insects and plants. Which statement describes the availability of food for fish in a stream?
    a. Finding food is not a problem since food is always in abundant supply.
    b. Since the fish can eat a variety of foods, there is always enough food for all of them at all times.
    c. Fish 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 fish.

Appendix C

Demographics Survey

Demographics Survey

What is your school rank?
Freshman
Sophomore
Junior
Senior

What is your sex?
Male
Female

What is your current Grade Point Average?
3.6 to 4.0
3.0 to 3.5
2.0 to 2.9
1.0 to 1.9
0.0 to 0.9

What grade do you expect to receive in this course?
A
B
C
D
E

What is your age?
18-19
20-21
22-24
25-30
30 or older

Appendix D

Student Reaction Survey

Student Reaction Survey

How would you rate the usefulness of this study session in helping you learn about evolution?

Very useful
Useful
Slightly useful
Not really useful

What did you like about this study session?

What would you suggest to improve this study session?

Appendix E

Student Sign-Up Sheet

90 Minute Study Session Sing-up | Merrill-Cazier Library, Room 202

- Write your **name** and **email address** on the page below.
- **Circle the time you plan to attend the study session**.
- You will receive an email reminder the day before.
- Thank you for your participation!

Name	Email Address	Tues June 14	Wed June 14	Thurs June 14	Fri June 14
John Doe	Johndoe123@aggiemail.usu.edu	10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm
		10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm
		10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm
		10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm
		10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm
		10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm
		10:00 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	8:15 am 1:45 pm 3:45 pm	10:00 am 12:00 pm 2:00 pm

Appendix F

Full Rating of Traditional Web-Based Module

Table F-1

Full Rating of the Traditional Web-Based Module

Traditional course component	TELL	ASK	SHOW	DO	INFO-ABOUT	PARTS	KINDS	HOW-TO	WHAT-HAPPENS	WHOLE TASK	STRUCTURE	FEEDBACK	GUIDANCE	COACHING
Introduction section														
Evolution definition	X				X									
Macroevolution definition	X				X									
Microevolution definition	X				X									
Overview video concept map	X				X									
Mouse-over overview concept map	X				X									
Definition and example of populations	X		X		X									
Definition and example of mutation	X		X		X									
Definition and example of genetic drift	X		X		X									
Definition and example of gene flow	X		X		X									
Definition and example of natural selection	X		X		X									
Drag and drop activity assembling overview concept map		X			X							X		
Information about Charles Darwin	X				X									
Microevolution as science	X				X									
Question and answer on overview content		X			X							X		
Mutation section														
More mutation information and examples (several screens)	X		X		X									
Mutation video concept map	X				X									

Traditional course component	TELL	ASK	SHOW	DO	INFO-ABOUT	PARTS	KINDS	HOW-TO	WHAT-HAPPENS	WHOLE TASK	STRUCTURE	FEEDBACK	GUIDANCE	COACHING
Mouse-over mutation concept map	X				X									
Examples of mutation concepts			X											
Drag and drop activity assembling mutation concept map		X			X							X		
More mutation information	X				X									
Question and answer on mutation concept map content		X			X							X		
Genetic drift section														
Genetic drift video concept map	X				X									
Mouse-over genetic drift concept map	X				X									
More information about genetic drift	X				X									
Example of genetic drift			X											
More information about genetic drift	X				X									
Drag and drop activity assembling genetic drift concept map		X			X							X		
More information about genetic drift	X				X									
Question and answer on genetic drift content		X			X							X		
Gene flow section														
Gene flow video concept map	X				X									
Mouse-over gene flow concept map	X				X									
Drag and drop activity assembling gene flow concept map		X			X							X		
Example of gene flow			X											
Additional information about and examples of gene flow (several screens)	X		X		X									

Traditional course component	TELL	ASK	SHOW	DO	INFO-ABOUT	PARTS	KINDS	HOW-TO	WHAT-HAPPENS	WHOLE TASK	STRUCTURE	FEEDBACK	GUIDANCE	COACHING
Question and answer on gene flow concept map content		X			X							X		
Natural selection section														
Natural selection video concept map	X				X									
Mouse-over natural selection concept map	X				X									
More information about natural selection	X				X									
Example of natural selection concepts (several slides)			X											
Information about common misconceptions of natural selection	X				X									
Drag and drop activity assembling natural selection concept map		X			X							X		
Additional example of and information about natural selection	X		X		X									
Question and answer on natural selection concept map content		X			X							X		
Totals	29	10	12		39							10		

Appendix G

Full Rating of First Principle Module

Table G-1

Full Rating of First Principle Module

Course Component	TELL	ASK	SHOW	DO	INFO-ABOUT	PARTS	KINDS	HOW-TO	WHAT-HAPPENS	WHOLE TASK	STRUCTURE	FEEDBACK	GUIDANCE	COACHING
Introduction Section														
Video: Microevolution, Macroevolution and examples	X		X		X									
Video: Microevolution, more details and example	X		X		X									
Video: Course Structure and Introduction to Component Strategy	X										X			
Problem 1														
Problem 1 Overview			X							X				
Component 1 Demonstration	X		X		X		X	X		X				
Component 2 Demonstration	X		X		X			X	X	X				
Component 3 Demonstration	X		X		X			X	X	X				
Problem 3 Summary				X	X		X	X	X	X				
Component 1 Detailed Demonstration (four examples)	X		X				X	X						
Component 1 Detailed Application (four applications)	X			X			X	X				X	X	
Problem 2														
Problem 2 Overview			X							X				
Component 1 Application	X			X			X			X	X	X	X	
Component 2 Demonstration	X		X					X		X				

Course Component	TELL	ASK	SHOW	DO	INFO-ABOUT	PARTS	KINDS	HOW-TO	WHAT-HAPPENS	WHOLE TASK	STRUCTURE	FEEDBACK	GUIDANCE	COACHING
Component 3 Demonstration				X					X	X		X	X	
Problem 2 Summary					X		X	X	X	X				
Component 2 Detailed Demonstration (four examples)	X		X					X	X					
Component 2 Detailed Application (four times)	X			X				X	X			X	X	
Component 3 Detailed Demonstration (four examples)	X		X					X	X					
Component 3 Detailed Application (four applications)	X			X				X	X			X	X	
Problem 3														
Problem 3 Overview										X				
Component 1 Application	X		X		X		X			X	X			
Component 2 Application	X		X		X				X	X				
Component 2 Application				X				X				X	X	
Problem 3 Summary					X		X	X	X	X				
Totals	16		13	7	10		8	14	11	14	1	6	6	

Appendix H

Description of How Subjects Are Taught in Each Module

Table H-1

Description of How Subjects Are Taught in Each Module

Microevolution subject	How taught in traditional module (comparison)	How taught in first principles module (experimental)
Macroevolution	Definition provided with simple example. Students quizzed on definition.	Definition provided with simple example.
Microevolution	Definition provided. Video of concept map defines microevolution, relates forces of evolution to microevolution. Students mouse over concept map for definition. Students quizzed on definition	Definition provided with simple example. Definition and example provided in greater detail.
Population	Defines population. Example given.	Defines population. Example given.
Mutation	Definition given. Example given. Drag and drop to test memory of definition. More detail provided on mutation including: categories of mutation given: beneficial, neutral, harmful need for mutation to be heritable to effect evolution. kinds of effects on phenotype (no change, small change, big change) identified and described. example of small change given- a cat's ears curl backwards. Video describes how mutations function in context of concept map. Mouse-over activity to see definition of mutation and related terms. Drag and drop activity to test memory of concept map layout. Mutation as relating to DNA sequence is described. Students quizzed in definition of mutation. Student memory of mutation as source of all new genes quizzed.	Definition and example of mutation given. How mutation acts on population described, including simple example. Students quizzed on identifying mutation as the force of evolution acting on a real-world population example. Students quizzed on identifying mutation as the force of evolution acting on another real-world population example. Detailed example (HIV resistance) of mutation described in context of biologists studying microevolution. Example includes second and third steps of analyzing microevolution in a population. Three steps showing how mutation works on population in example of HIV resistance summarized. Description and example of how mutation affects a population is given. Students quizzed on how mutation is affecting s a specific real-world population example. Description and example of how mutation might affect

Microevolution subject	How taught in traditional module (comparison)	How taught in first principles module (experimental)
	Student understanding of mutation's randomness quizzed. Student memory of categories of mutation quizzed.	a population over time is given. Students quizzed on how mutation might affect a specific real-world population over time.
Genetic Drift	Definition given. Example given. Drag and drop to test memory of definition. Video describing genetic drift in context of concept map is given. Mouse-over activity to see definition. Genetic Drift described in greater detail using generic example. Previous example of genetic drift revisited with more detail. Drag and drop activity to test memory of definition. Genetic Drift contrasted with natural selection. Memory of definition quizzed. Understanding of effect of genetic drift on large vs. small populations quizzed. Memory of different categories of genetic drift quizzed. Genetic bottleneck is described in context of genetic drift concept map Mouse-over activity to see definition. Drag and drop activity to test memory of definition. Memory of genetic bottleneck as significant type of genetic drift quizzed. Founder effect is described in context of genetic drift concept map. Mouse-over activity provides definition. Drag and drop activity to test memory of definition. Memory of founder effect as significant type of genetic drift quizzed. Understanding of what happens in founder effect quizzed.	Definition and example of genetic drift given. How genetic drift acts on population described, including simple example. Genetic bottleneck described. Example of genetic bottleneck given. Founder effect described. Students quizzed on identifying genetic drift as the force of evolution acting on a real-world population example. Description and example of how genetic drift affects a population is given. Students quizzed on how genetic drift is affecting s a specific real-world population example. Description and example of how genetic drift might affect a population over time is given. Students quizzed on how genetic drift might affect a specific real-world population over time. Students quizzed on identifying genetic drift as the force of evolution acting on another real-world population example. Students quizzed on how genetic drift is affecting s another specific real-world population example. Students quizzed on how genetic drift might affect another specific real-world population over time. Three steps showing how genetic drift works on population in example of genetic blindness summarized.
Gene Flow	Definition given. Example given.	How gene flow acts on population described, including simple example.

Microevolution subject	How taught in traditional module (comparison)	How taught in first principles module (experimental)
	Drag and drop to test memory of definition. Gene flow is described in context of genetic drift concept map. Mouse-over activity provides definition. Gene flow definition and example revisited, along with several brief examples. Relation of mobility to gene flow described. Example of gene flow in a population of grass given. Memory of definition of gene flow is quizzed. Understanding of gene flow in animal and plant populations is quizzed. Understanding of effect of gene flow is quizzed.	Students quizzed on identifying gene flow as the force of evolution acting on a real-world population example. Description and example of how gene flow affects a population is given. Students quizzed on how gene flow is affecting s a specific real-world population example. Description and example of how gene flow might affect a population over time is given. Students quizzed on how gene flow might affect a specific real-world population over time.
Natural Selection	Definition given. Example given. Drag and drop to test memory of definition. Natural selection defined and described in context of concept map. Presentation includes categories of mutations: harmful, neutral, beneficial. Mouse-over activity provides definition and related definitions. Basic tenets of natural selection described. Basic tenets of natural selection applied to example of beetles. Misconceptions about natural selection identified. Drag and drop activity to test memory of definition and related definitions. Example of natural selection given. Natural selection acting on phenotype is described Memory of definition of natural selection quizzed. Memory of definition of phenotype quizzed. Memory of natural selection as random event quizzed. Understanding of beneficial mutation quizzed.	Detailed example (peppered moths) of natural selection described in context of biologists studying microevolution. Example includes three steps of analyzing microevolution in a population. Three steps showing how natural selection works on population in example of peppered moths summarized. How natural selection acts on population described, including simple example. Students quizzed on identifying natural selection as the force of evolution acting on a real-world population example. Description and example of how natural selection affects a population is given. Students quizzed on how natural selection is affecting s a specific real-world population example. Description and example of how natural selection might affect a population over time is given. Students quizzed on how natural selection might affect a specific real-world population over time.

Appendix I

Subjects Taught and Tested

Subjects Taught and Tested

Macroevolution

Microevolution

Population

Mutation

Genetic Drift

Gene Flow

Natural Selection

Appendix J

Pretest Microevolution Problem Solving Questions

Pretest Microevolution Problem Solving Questions

Consider this microevolution scenario and then answer the following questions.

In the 1890s, northern elephant seals were hunted nearly to extinction. Hunting reduced their population size to as few as 20 individuals at the end of the 19th century. Their population has since rebounded to over 30,000, but the seals now appear to have a lot more similarities in their traits than before they were hunted. In fact, a similar population of southern elephant seals that was not so intensely hunted has much more genetic variation than the northern elephant seals.

Which force of evolution is most likely acting on this population?

- Mutation
- **Genetic Drift**
- Gene Flow
- Natural Selection

Please explain your thinking for your answer to question 1. Why did you select the force you did?

Based on what you know about this population of seals, how is this force of evolution acting on this population?

- As the seal population has begun to grow to a larger population, only individuals with beneficial mutations have survived.

- **The reduction in the number of seals has reduced the genetic variation in the population.**
- The environment has changed, which has caused an increase in the number of harmful mutations in the population.
- The population has increased levels of gene flow.

Based on what you know about this population, how would this population likely change over the next 3 generations as the population continues to grow?

- **It will continue to have little genetic diversity**
- It will regain the same genetic diversity as the population before hunting
- It will contain many more large seals due to natural selection
- It will be less fit than the population immediately after it was hunted

Appendix K

Posttest Problem Solving Section

Posttest Problem Solving Section

Consider this microevolution scenario and then answer the following questions.

Guppies are small fish found in streams in Venezuela, and some male guppies have a genetic trait that makes them brightly colored. Biologists studying guppies noticed something interesting. When a guppy population lives in a stream with no predators, the proportion of males that are bright and flashy increases in the population. However, if a few aggressive predators enter the same stream, the population of bright-colored males decreases within 3-4 generations.

Which force of evolution is most likely acting on this population?

- Mutation
- Genetic Drift
- Gene Flow
- **Natural Selection**

Please explain your thinking for your answer to question _. Why did you select the force you did?

Based on what you know about this population of guppies, how is this force of evolution affecting this population?

- The predators are causing gene flow, in which each guppy has plainer coloration.
- The predators are causing a genetic bottleneck in which genetic variation is reduced.

- **The predators are selecting against bright colored guppies.**
- The predators are inducing mutations which produce plainer coloration.

If the predators continued to live in the same stream as this population of guppies, how would this population change over time?

- The brightly colored guppies will learn to become faster and more agile so as to avoid the predators.
- **The proportion of brightly colored fish will continue to decrease.**
- It will have regained the same genetic diversity as the population
- It will contain larger guppies due to natural selection

Appendix L

Additional Problem Solving Questions

Additional Problem Solving Questions

Consider questions _ through _ above and answer the following questions.

How often can you succeed at answering these kinds of questions without help?

- Never
- Not often
- Often
- Every time

Do you enjoy yourself when answering questions of this kind?

- Yes
- No

How difficult were these questions for you to answer?

- Very difficult
- Somewhat difficult
- Slightly difficult
- Not difficult at all

Appendix M

Delayed Posttest Questions

Delayed Posttest Questions

1. ____________ is caused by migration and is the movement of genes from one population to another.

a. mutation

b. natural selection

c. genetic drift

d. gene flow

2. Why do individuals in a population have a variety of characteristics?

a. They need to change characteristics in order to survive, so different individuals evolved different traits.

b. They needed to evolve beneficial new characteristics and the necessary mutations for these characteristics were induced when needed.

c. Random genetic changes created different characteristics.

d. Because visible characteristics depend only on environmental factors and these factors differ widely between individuals in natural populations.

3. Biologists studying a population of finches on the Galapagos Islands have performed recent DNA analysis which leads to the conclusion that all of the finches evolved from the warbler finch. Different finch species live on different islands. For example, the medium-sized ground finch lives on one island and the cactus finch lives on another island. One important difference in these different finch species is the size and

shape of their beaks, which vary greatly and are an adaptation to different food sources on different islands.

Question: Which force of evolution most likely acted on the different groups of finches to create variations of finches on the different islands?

a. Natural selection

b. Gene flow

c. Genetic drift

d. genetic bottleneck

Appendix N

Letter of Information

UtahState University
Department of Instructional
Technology and Learning Sciences
2830 Old Main Hill
Logan UT 84322-2830
Telephone: (435) 797-2694

Full AAHRPP Accreditation

USU IRB Approved: May 26, 2010; Page 2 of 2
Approval Terminates: 05/25/2011
Protocol #261
Approved per IRB Administrator

LETTER OF INFORMATION
Testing Web-based Learning

Professor Belland and Joel Gardner in the Department of Instructional Technology and Learning Sciences at Utah State University are conducting a research study to find out more about teaching microevolution. You have been asked to take part because you are a student in USU 1350. There will be approximately 10 participants at this site. There will be approximately 60 total participants in this research.

If you agree to be in this research study, the following will happen to you:

1. Before attending a study session, you will watch a 20 minute video teaching microevolution content. This video is accessed in the course Blackboard Vista page.
2. You will attend a 90 minute study session at the Merrill-Cazier Library. In this session, you will:
    1. take a short quiz testing your understanding of microevolution
    2. learn from a web-based module teaching microevolution content
    3. take another short quiz testing your understanding of microevolution.

Participation in this research study may involve some added risks or discomforts. These may include discomfort from taking quizzes about course content and/or discomfort from sitting for 90 minutes.

There may or may not be any direct benefit to you from these procedures. The investigator, however, may learn more about effective methods for teaching and learning science concepts, which could be of great benefit to current and future students at USU.

Joel Gardner has explained this research study to you and answered your questions. If you have other questions or research-related problems, you may reach Professor Belland at (435) 797- 2535. There will be no cost to participate in this study.

By participating in this study, you will automatically be entered into a drawing to receive one of six $10 gift cards for your participation in this study. Your professor will provide a small amount of extra credit (about 1%).

Participation in research is entirely voluntary. You may refuse to participate or withdraw at any time without consequence or loss of benefits. You may be withdrawn from this study without your consent by the investigator if you choose not to participate in the study sessions described above.

Research records for this study will be kept confidential, consistent with federal and state regulations. Only the investigator and Joel Gardner will have access to the data which will be kept in a locked file cabinet in a locked room. As soon as data is fully gathered, researchers will download it to a password protected computer and all data will be deleted from the survey account. Any information identifying a specific student will be altered so that student identity is protected. Student A numbers will be used to identify you in this study but this information will be kept in a password protected account. Then the A numbers will be deleted and replaced with code numbers to protect your privacy to ensure no identifiable information remains.

UtahState University
Department of Instructional
Technology and Learning Sciences
2830 Old Main Hill
Logan UT 84322-2830
Telephone: (435) 797-2694

Full AAHRPP Accreditation — Association for the Accreditation of Human Research Protection Programs, Inc.

USU IRB Approved: May 26, 2010; Page 2 of 2
Approval Terminates: 05/25/2011
Protocol #261
Approved per IRB Administrator

LETTER OF INFORMATION
Testing Web-based Learning

The Institutional Review Board for the protection of human participants at USU has approved this research study. If you have any pertinent questions or concerns about your rights or a research-related injury, you may contact the IRB Administrator at (435) 797-0567 or email irb@usu.edu. If you have a concern or complaint about the research and you would like to contact someone other than the research team, you may contact the IRB Administrator to obtain information or to offer input.

Brian Belland, Ph.D.
Principal Investigator
797- 2535
brian.belland@usu.edu

Joel Gardner
Student Researcher
797-8559
joel.gardner@usu.edu

Appendix O

Full Description of Student Reaction Comments

First Principles Module Student Comments

What Students Liked

Repetition

"I liked the repetition in the study. It helped me to understand the concepts easier, because if I didn't understand it the first time, it usually went back and clarified that concept."

-Student comment

Several students wrote that they liked the repetition of concepts in the module. Students wrote that they liked that "the main points were repeated and highlighted" and that it reviewed everything over and over again." Another wrote that the repetitive nature of the module, "is beneficial for me because it instills it in my brain."

Examples

Students also liked the examples used in the module. Student liked that the module "Explained microevolution with examples that made it very easy to understand each type" and "put it into scenarios." Another wrote that the module "had you apply (what you learned) to something." The use of examples or whole tasks was a key component in this module, so these comments make sense.

Question and Answer

"I liked that it asked questions during the module so you weren't just listening and watching a presentation. It actually made you think about what you were learning and put it into scenarios..."

- Student Comment

Another theme that emerged from the analysis was that students liked the use of "questions during the lesson." One student wrote that they appreciated "how it went over an idea and then had you apply it to something... to not have it apply to anything makes it very easy to forget." Another wrote that "It was a lot better to be able to apply it to something. It was also good how it was interactive, so I answered questions as I went long and not all at the end."

Multimedia

Students also liked the use of multimedia in the module. One student wrote that "The pictures and diagrams helped explain the concepts." Another student liked the module and wrote that "I have to be able to see things to understand and just hearing and seeing words doesn't work as well for me." Students wrote that the module had "good pictures that helped understand it more" and that "the type of narration made it easier as well."

Organization

Students also appreciated the organization of the module. One student liked that "there were visual markers reminding me what was being discussed." Another wrote "I like the step by step process." Perhaps this is why other students wrote that the module "was easy to follow" and that "it was easier to follow along when studying like this."

What Students Suggested for Improving

Reduce Repetition

Although many students indicted that they liked the repetition of the First Principles module, there were several student comments that they did not like the repetition.

Students wrote that “There was a little too much redundancy” and that “some parts were extremely repetitive.” One student wrote that the repetition “helped me learn better” but also wrote that “it was also boring to hear about the same examples over and over again.” Another student also indicted that the repetition helped the learning but was boring, writing that the module “was very repetitive, which was good, but after a while almost more bothersome than helpful. It definitely engraved it into my head though.”

Pace, Length, and Control of the Module

Students also indicted that they might improve the pace of the module, including it’s length and the level of student control. One student commented that the module “was a little too long. It was dragging at some parts.” One improvement that was suggested was for students to have “the option to skip ahead or skip over repetition when it is clear that I have learned the thing being repeated.” Another student suggested providing the ability to “switch between segments of the module.”

Multimedia

Though some students liked the multimedia used in this module, some students also gave suggestions to improve how it was used. One suggested that the module include “more moving pictures and graphics” and added “but don’t get cheesy.” Another suggested adding “more things to look to while talking.”

Personal Application

One suggestion that students gave was to include ways to apply the subject to them personally. One student suggested “just give me ways to apply it to something real around you.” Another wrote “if it were applied in some way to the student to the student's everyday life aspects, it might be an additional way that could be shown during the presentation."

Traditional Module Student Comments

What Students Liked

Repetition

Some of the students appreciated the repetition and review in the traditional module. One student liked that the module "tells the concept very many times, so one may learn the concept quite easily." Another liked "The constant review of each force of evolution."

Multimedia

Students also liked the multimedia used in the module. One student "loved the beetle diagrams" and wrote that "They were very helpful in understanding everything." Students wrote that they liked the "visual aids," that the module was "very visual," and that the "visual aids... explain the difference between the forces of evolution."

Interaction

Students also liked the "interaction" of the module. "I liked the ability to scroll over things to find out more information" wrote one student. Others liked that "It's interactive" and "It was helpful when I can know a meaning of the word just by clicking the word." Another student wrote that "Interactivity always increases learning."

Quiz and Feedback

Several students also commented that they enjoyed being able to apply their knowledge and get feedback as they moved through the module. Students wrote “I liked putting answers to the right spot in the module” and “I liked how there was activities along with what we learned that helped me remember what was taught.” Another student wrote “I liked that it had little activities for you to do and quizzes to take throughout the module because it... help(ed) me remember it and learn it better.”

Some students commented that this application helped them in the learning process. One wrote “I was able to (assess) how much I learned about each thing right after I studied it, while also getting feedback.” Another student liked that “If you made a mistake you were able to learn from it because it immediately told you it was wrong.” One student commented “(I) was able to make sure I got one concept down before moving onto the next thing.”

Examples

Students also commented on the use of examples in the module. One student liked “One consistent example (beetles).” Another wrote “I loved the beetle diagrams.”

What Students Suggested for Improvement

Multimedia

Students made several suggestions for improving the use of multimedia in the traditional module. One student wrote “I wanted more videos to explain words in the module, otherwise I will be getting bored when I m used to studying with the module.” Other students wrote, “One or two of the videos was too long” and “if there are more pictures, I think it will be improved.”

Technical Improvements

There were some technical issues that could be improved in the module, as well. Several students suggested using “bigger text” and called a few parts of the module “very hard to read.” another suggested to, “have formatting improved to show all pop-up text in the opening sections of the module.”

Reduce Repetition

Students also suggested that the repetition in the module should be decreased. One wrote, “though it was great (it was) a little repetitive at the end.” Another student wrote, “It was... very repetitive... Variation would help! Rewording or something to make it more challenging.”

Examples and Interaction

Students also suggested using more examples and increasing interaction. One student wrote, “I think more examples would be helpful.” Another wrote, “Use a story like the elephant seal thing in the context of the module in order to explain which force affected that specific example. Use other stories to illustrate the other forces as well.” In addition, a suggestion was given to increase interaction. One student suggested, “Even more interaction, click and drag sorta thing might improve attention.”

Appendix P

Letter of Permission for Using Evolution 101 Site Content

from Understanding Evolution <uewebmaster@berkeley.edu>

reply-to	Understanding Evolution <uewebmaster@berkeley.edu>	hide details Aug 10 (5 days ago)
to	joel gardner <jgardner@cc.usu.edu>	
date	Tue, Aug 10, 2010 at 2:12 PM	
subject	Re: request to use your materials	

Hello,

This sounds like a great use of our materials, and you have our permission. Please credit what you use to the UC Museum of Paleontology's Understanding Evolution (http://evolution.berkeley.edu). Also, we'd love to see whatever results the study produces, so it would be great if you could send us an update.

Thank you,
Josh Frankel
UCMP
- Hide quoted text -

----- Original Message -----
From: joel gardner
To: uewebmaster@uclink.berkeley.edu
Sent: Friday, July 16, 2010 4:56 PM
Subject: request to use your materials

Hello,

I am a PhD student at Utah State University studying the effective use of web-based instruction. I am very impressed with your Understanding Evolution website. I was hoping to use some of your materials as a small portion of the modules I am developing for my study. Specifically, I am interested in using some of the images and text in the section on microevolution.

I would like to get your permission to use some of the text and images from your site. Would that be okay? Is there anything else I should do to get your permission to use these materials?

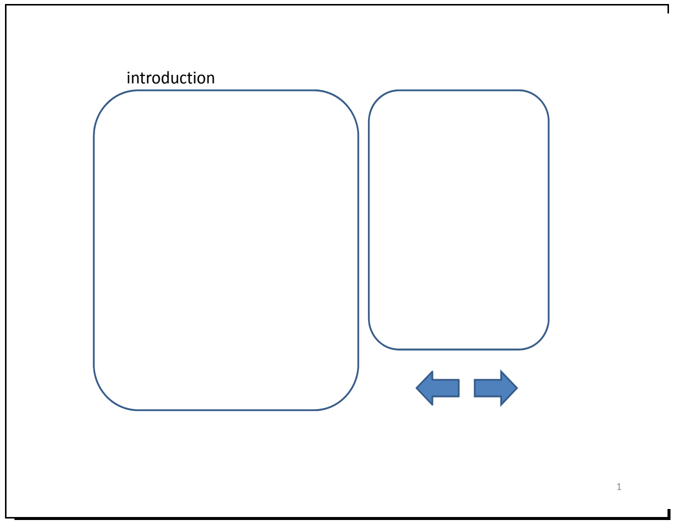
Thanks very much,

Joel Gardner
PhD Student, Department of Instructional Technology and Learning Sciences, Utah State University

Appendix Q

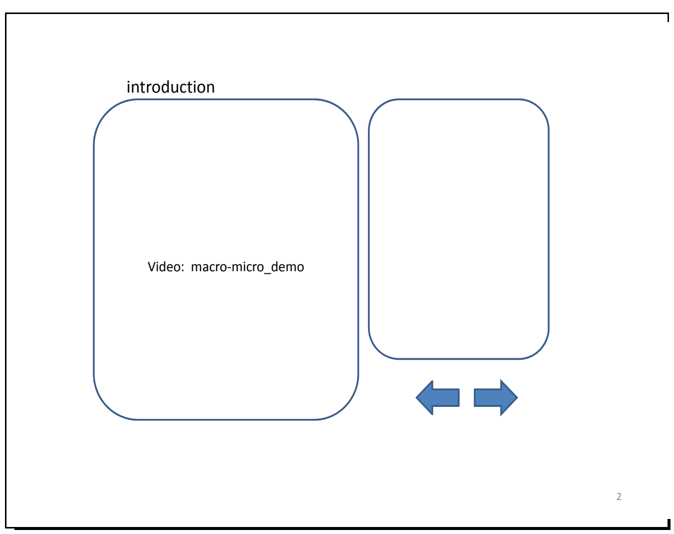
Full First Principles Storyboard

Slide 1



Text: Welcome to this module on microevolution. In this module, you will **read**, watch short **videos**, and do **activities** that will help you learn and understand microevolution. The goal of this module is to help you learn how to analyze how microevolution works in different populations. To navigate from page to page, click the hand icons in the bottom of the screen. You may also receive instructions or answer questions in the panel on the right. Click the Next button to begin.

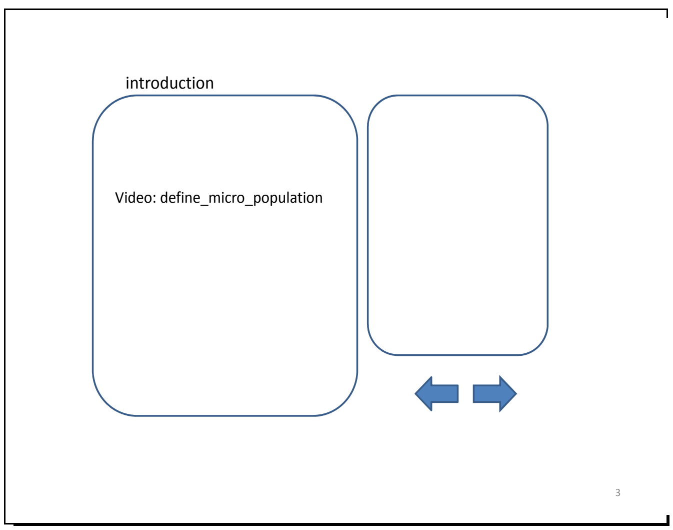
Slide 2



Audio: In studying evolution, there are two major areas of study: macroevolution and microevolution. **Macroevolution** considers longer-range phenomenon, particularly how species arise and expire. For example. In contrast, **Microevolution** considers the evolutionary forces that alter the genetic composition of populations over a relatively small number of generations. For example, microevolution might study how a population of beetles has evolved over several generations. and is the driving force behind macroevolution. This module will focus on **Microevolution**.

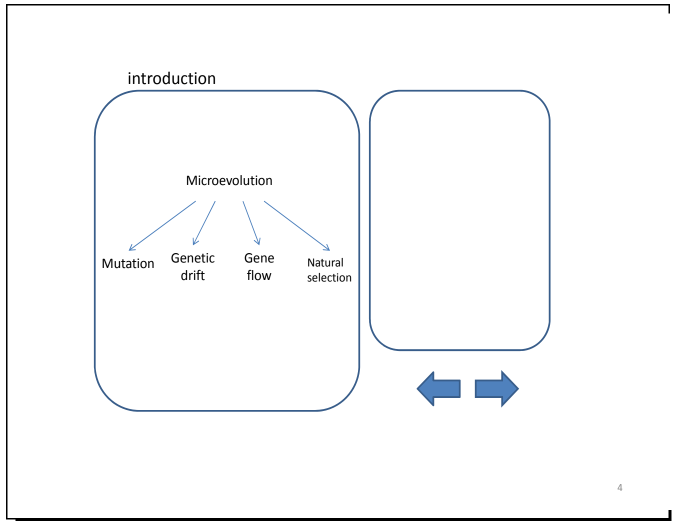
(Switch the order of micro and macroevolution (micro first) and get an curving arrow that connects micro- to macroevoution to give the idea the microevolution powers macroevolution)

Slide 3



Audio: **Microevolution** considers the evolutionary forces that alter the genetic composition of populations over a relatively small number of generations. Microevolution in action is the change in the genetic composition in a population over time. For example, a population of beetles having specific traits might evolve or change over time to have a different set of traits. In microevolution, biologists study populations as the unit of evolution. This is because populations evolve, not individuals within a population. A population is a group of individuals of the same species living in the same place at the same time, like a population of beetles living on an island.

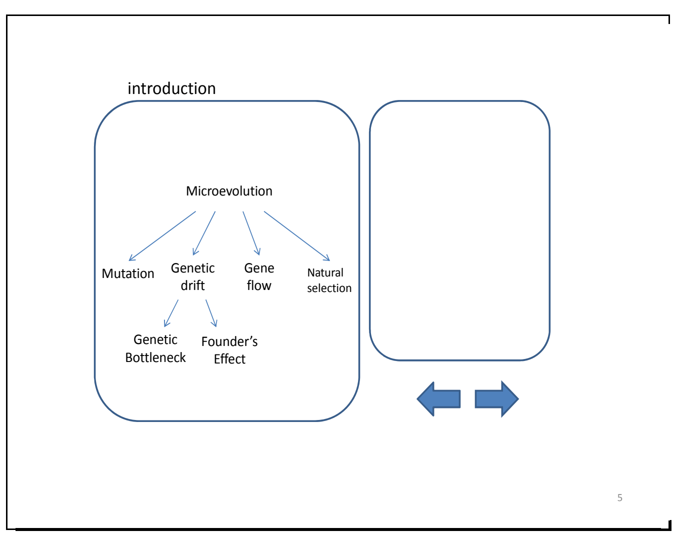
Slide 4



Text: There are four main forces of evolution that bring about the genetic change in populations over time. These forces act on a population in different ways, and understanding which of these forces is affecting a population is a key part of understanding how microevolution works. To learn about these forces, click the Next button.

<This introduces the four forces. The next page allows them to learn about these forces, briefly>

Slide 5



Text: Mouse over the definitions below to read definitions of each of these forces of evolution. When you are ready to learn how biologists approach understanding cases of microevolution, click the next page button below.

Action: Each item provides the definition of the force of evolution.

<<These are the new definitions that we will include in this activity. Also, we have included genetic bottleneck and founder's effect in this map- different than before.>>

Microevolution
Considers the change in genetic composition of a population over successive generations and the evolutionary forces that alter the genetic composition of that population. In microevolution, biologists study populations as the unit of evolution.

Mutation
A permanent, heritable change in the genetic makeup of an individual in a population. These changes are often neutral, meaning they don't change the characteristics of an individual. They are sometimes harmful and decrease an individual's ability to survive. They are rarely beneficial and increase an individual's ability to survive and reproduce.

Genetic Drift
The process of change in the genetic composition of a population due to chance or random events rather than by natural selection, resulting in changes in allele frequencies over time.

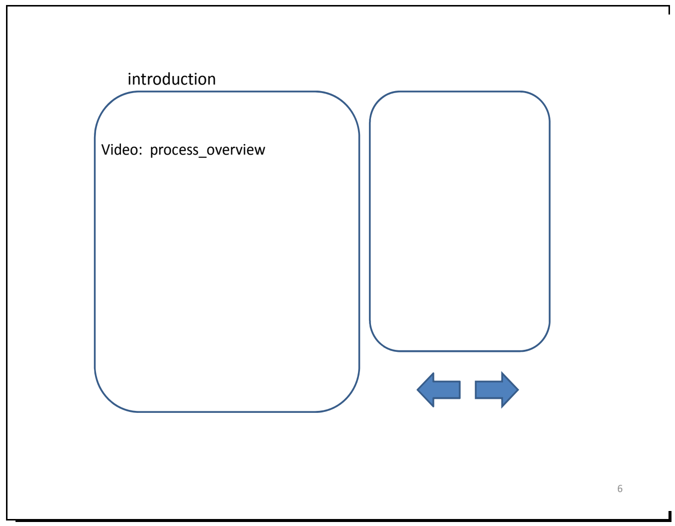
Genetic Bottleneck
Random reduction of the size of the population, which reduces the variation of gene types. This alters the genetic composition of the population by reducing the kinds of traits that are passed on to offspring.

Founder's Effect
Occurs when a portion of a population migrate to a new area. The smaller size of the population reduces the variation of gene types. This alters the genetic composition of the population by reducing the kinds of traits that are passed on to offspring.

Gene Flow
The movement of genes from different populations of species. This flow of genes from one population to another tends to reduce variation between populations.

Natural Selection
A process in nature in which organisms possessing certain genotypic characteristics that make them better adjusted to an environment tend to survive and reproduce.

Slide 6



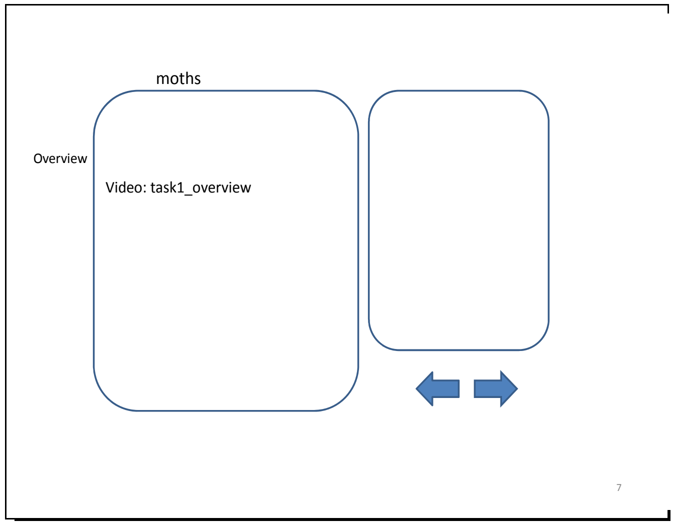
Audio:

When biologists attempt to analyze the evolution taking place in a population, they follow four steps points about the population they are studying. First, they Hypothesize which force(s) of evolution are acting on a specific population. Next, they Predict specifically how this force is affecting the population. They then Predict how the population will change over time based on what is known. Finally, they Design experiments or look for evidence in support of the hypothesis. In this module, we will focus on the first three steps. We will go through several examples of scientists analyzing microevolution occurring in different populations. These three steps are a key part of the scientific method because they help biologists form a hypothesis of what is happening based on what they know.

As you go through this module, you will work through 3 examples of microevolution, which are highlighted in the tabs on the top of this module. As you go through each example, you will know which step you are on because it will be highlighted on the left. In the first example, you will learn how biologists analyze microevolution in a population of moths. In the second example, you will work through an example of a population of people have developed resistance to HIV. Finally, you will work through an example of microevolution in a population of individuals on an isolated island. Throughout the module you will practice each of these three steps on several other examples.

Visual: the four items will appear as they are explained. These four items will be referred to as each task is completed by the individuals.

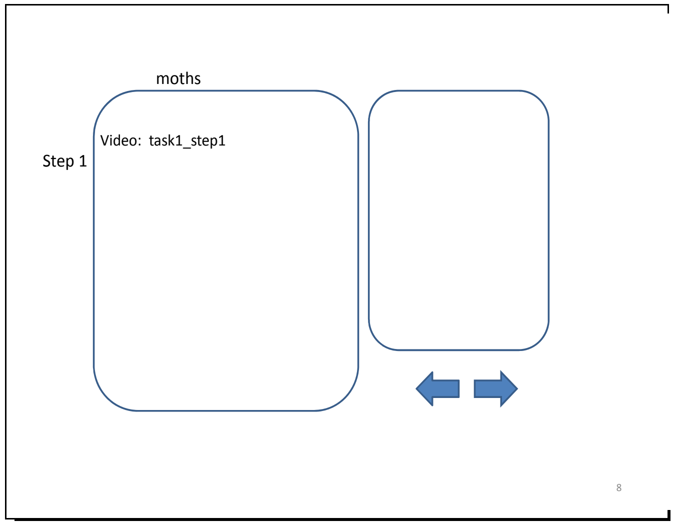
Slide 7



Audio: Let's look at our first example of how biologists analyze microevolution in a population. Over two hundred years ago, biologists noticed something interesting about peppered moths, which live in forests in England and are eaten by birds. Prior to 1800, most peppered moths had a light pattern with a few dark splotches. During this time, dark-colored pepper moths were rare. However, during the 1800s, there was a change in the environment. Soot and other industrial wastes darkened tree trunks where peppered moths often landed. Biologists noticed that the light-colored moths became more and more rare, and the dark-colored moths became more abundant. Eventually, light-colored moths were a rare thing, and nearly all peppered moths were dark colored. Biologists suspect that microevolution was at play.

Peppered moth images:
http://www.hmcsciencebus.org/resources/images. Use these effectively to demonstrate the increase and decrease of each population.

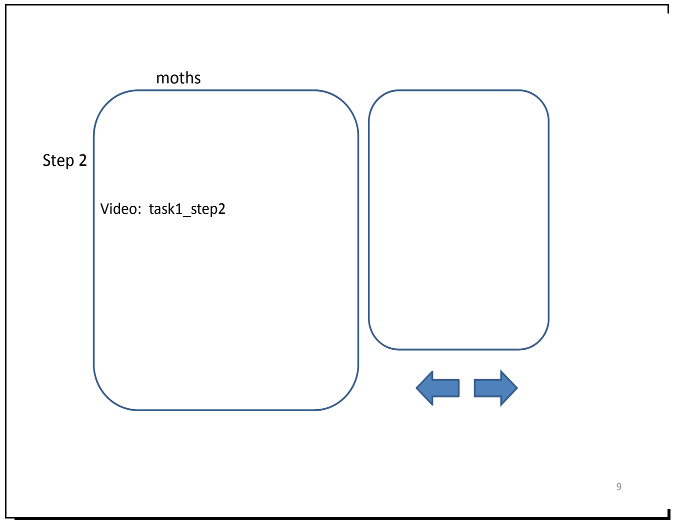
Slide 8



Audio: The first step in analyzing a microevolution scenario is to identify which force(s) of evolution are acting on a specific population. In this scenario, the biologists determined that *natural selection* was the force of evolution at play. Natural selection is a process in nature in which organisms possessing certain genetic traits that make them better adjusted to an environment tend to survive and reproduce. In this case, before soot and industrial waste changed the environment, the lighter peppered moths had the greatest survival and reproductive success because they were less likely to be seen and eaten than the darker peppered moths. However, when the environment changed and the trees became darker, the darker peppered moths were more likely to survive and have reproductive success. Natural selection favored the color of moth that was most fit to the environment.

<Visual: This demonstration should show the evidence or givens for component 1. This will be displayed and highlighted in text and image at the top. This demonstration should also show the four components at the bottom. It should reveal to the students the force at play and should also tell students why this force is the one. It should give the reasoning behind the selection.>

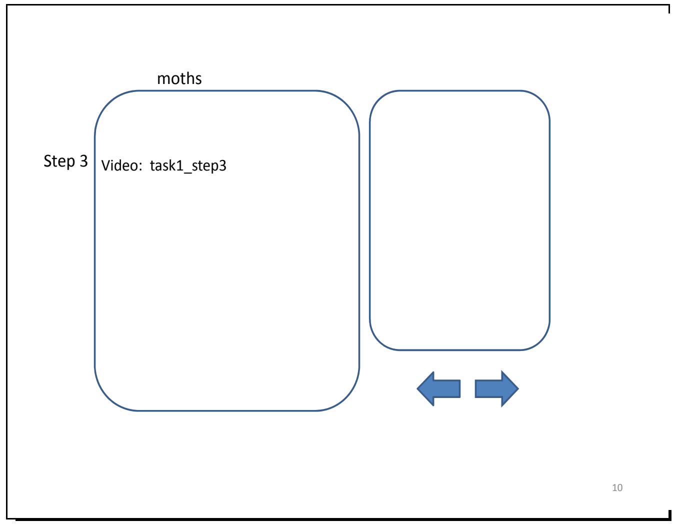
Slide 9



Audio: After hypothesizing what force of evolution is acting on the population, biologists attempt to predict specifically how this force is affecting the population. To determine how natural selection might be altering the population of peppered moths, one biologist did a simple experiment. He released the same number of dark and light peppered moths into a forest that had trees darkened by pollution. After several weeks, he returned to the area and gathered as many peppered moths as survived. He found that darker peppered moths were twice as likely to survive than the white peppered moths, confirming the notion that the new environment selected darker peppered moths because fit to survive and reproduced than white ones. This experiment was replicated in a forest with no soot, and the white moths were more likely to survive, further confirming natural selection of the fittest moth type.

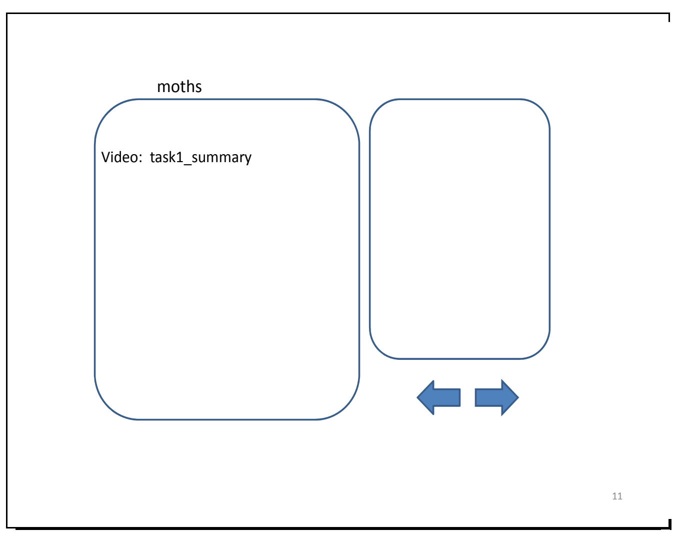
Visual: This screen will provide an audio-visual demonstration of how the second step was solved. It will show the moths increasing in number, etc.

Slide 10



Audio: After determining how natural selection is effecting the population of peppered moths, scientists work to predict how the population will change over time based on what they know. In this case, biologists realized that many pollution control regulations being implemented in the area would decrease the amount of soot in the forests. They predicted that as the trees became lighter, this new environment would favor white peppered moths more and that the white color genetic trait would give them increased survival and reproductive success.

Slide 11



Audio: So, to summarize, biologists analyzing the population of peppered moths

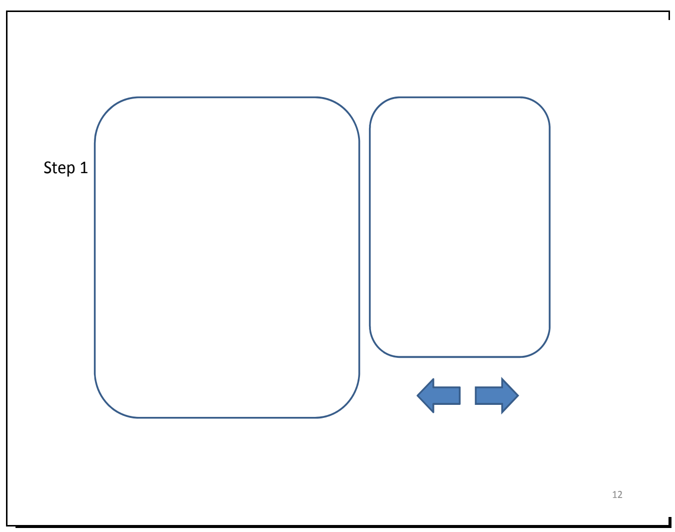
first hypothesized which force of evolution was acting on the population.
They proposed natural selection as the force of evolution acting on the population of peppered moths because the change in environment seemed to favored reproduction of the dark moths.

They then predicted how this force was working. One biologist did an experiment that showed that the environment did favor darker peppered moths.

Finally, they made a prediction that because of the future reduction of soot in the forests, the population of peppered moths would likely have an increased percentage of white moths because white moths would be more likely to survive and reproduce.

Visual: Show the steps and highlight them when they are being discussed.

Slide 12



Header: Step 1: Which force?

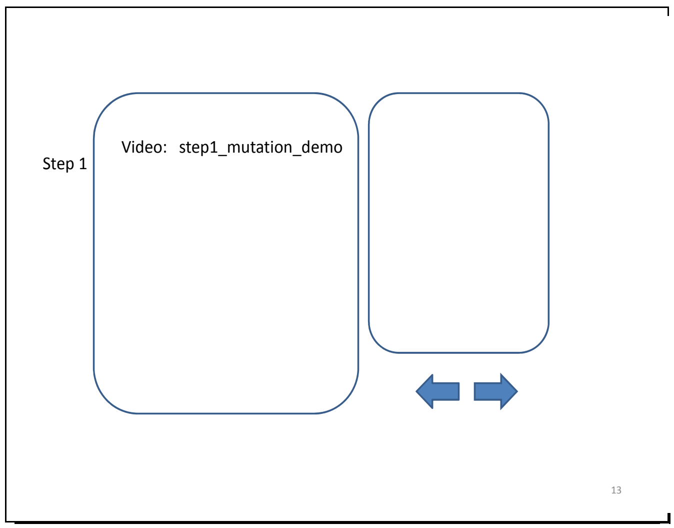
Text: Being able to identify which force of evolution is acting on a population is the first step in analyzing how microevolution is acting on a population. In the previous example, scientists identified natural selection as the force of evolution acting on a population of moths. There are four main forces of evolution:

- Mutation
- genetic drift

- gene flow
- natural selection

Each of these forces acts on a population in different ways. Click the next button to learn more about what these evolutionary forces are and how they act on populations.

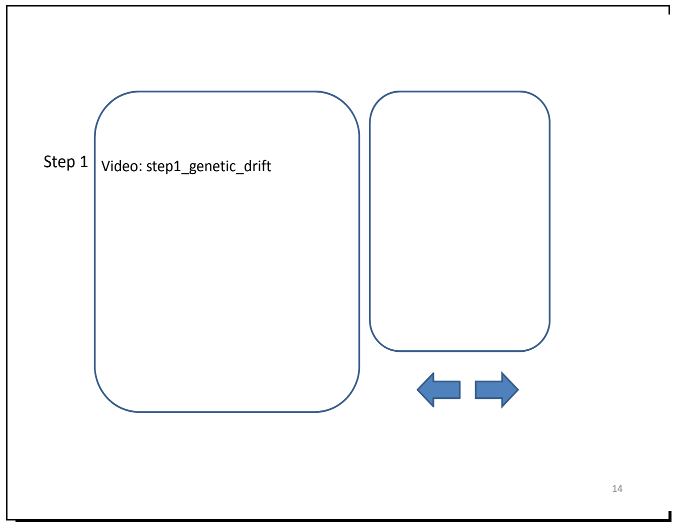
Slide 13



Audio:
General:
Mutation is one force of evolution. **Mutation** is the random creation of new gene forms (alleles). It is the source of new alleles in all species. These changes are often neutral, meaning they don't change the characteristics of an individual. They are sometimes harmful and decrease an individual's ability to survive. They are rarely beneficial and increase an individual's ability to survive and reproduce.

Specific:
For example, in a population of bugs, a mutation could cause parents with genes for bright green coloration to have offspring with brown coloration because the sperm or egg of one of the parents had a chance mutation. This would make the allele for brown beetles more frequent in the population. Since this and other mutations are rare, the population wouldn't change much from this mutation acting on its own. Although this is a simple example, it highlights how mutations work in a population.

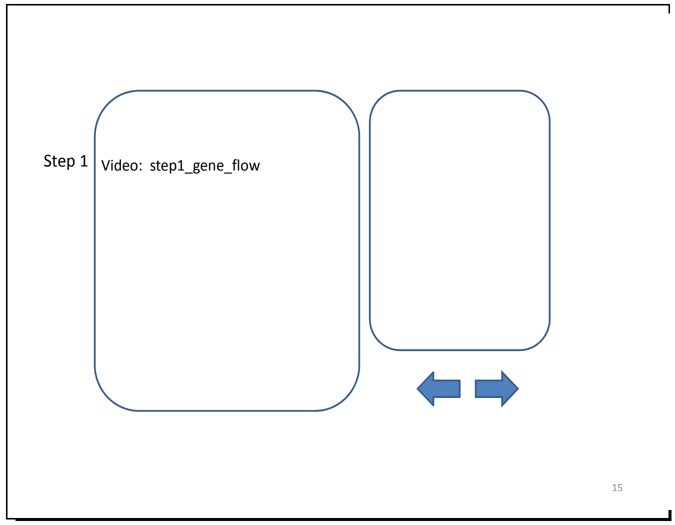
Slide 14



Audio: Genetic drift is another force of evolution. Genetic Drift is the process of change in the genetic composition of a population due to chance or random events rather than by natural selection. Two particularly important forms of genetic drift are a genetic bottleneck and the founder effect. In a genetic bottleneck, a population is reduced in size. Along with the reduction in individuals comes a reduction in the genes. Some alleles in the original population may be lost by chance and the frequency of surviving alleles also altered by chance. In the founder effect, a small group breaks off and migrates to a new area. Just as in a bottleneck, chance alone may mean that this group has different sets and frequencies of alleles than found in the larger population that the founders migrated from.

Consider the following example of genetic drift. Imagine that in one generation, a population of brown and green beetles is nearly killed off by humans stepping on them. There weren't many green beetles to begin with and just by chance most of these were killed when someone accidentally stepped on them. Once again, by chance, fewer of these green beetles successfully reproduce over the next few generations. Due to chance events, the population after a few generations is very different than the population that existed before the careless person came by. These random changes in gene frequency from generation to generation are known as genetic drift.

Slide 15

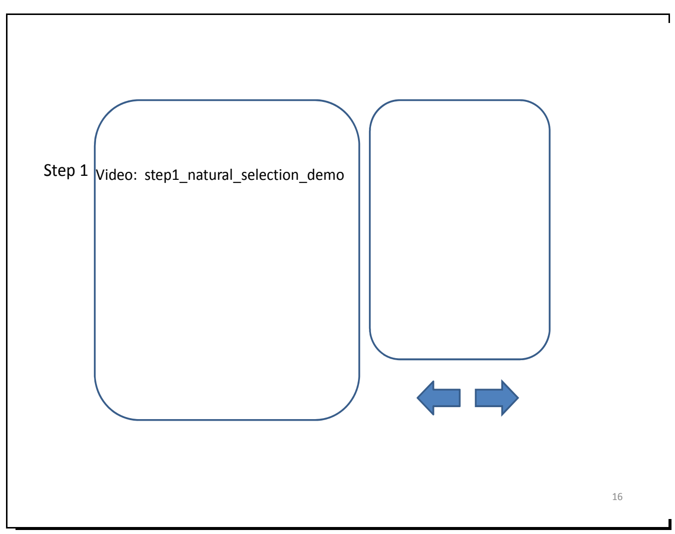


Audio: Lets look at another evolutionary force.

Gene flow is the movement of genes (alleles) between populations and is due to migration between populations. Gene flow tends to keep different populations alike.

Consider the following example of gene flow. Some individuals from a population of mostly brown beetles migrate to the area where the population of green beetles lives. These migrants increases the frequency of the brown allele and trait in the population of beetles. This migration has the affect of keeping the two populations of beetles alike because it distributes genes or alleles between populations.

Slide 16



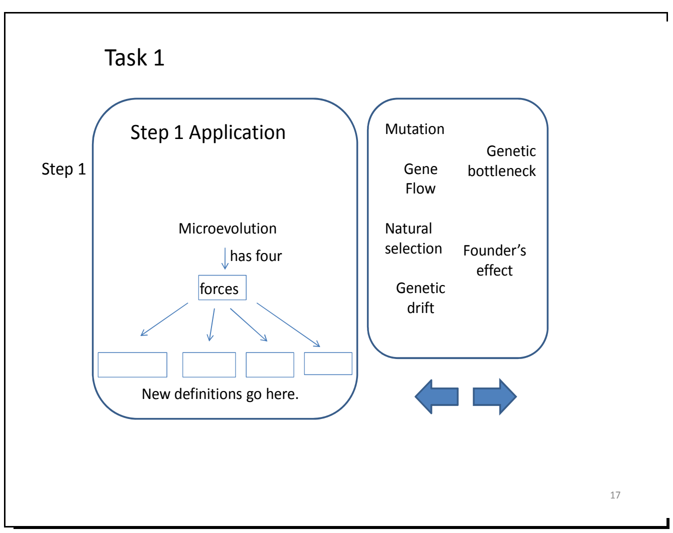
Audio:
General:
The final force of evolution is **Natural selection**. Natural selection is a process in nature in which organisms possessing certain genetic characteristics that make them better adjusted to an environment tend to survive and reproduce. It arises from differential reproductive success, which means certain characteristics in population members are more likely to allow that individual to survive and reproduce in a specific environment than others.

Specific:
For example, imagine that green beetles are easier for birds to spot (and hence, eat). Brown beetles are a more likely to survive to produce offspring. They pass their genes for brown coloration on to their offspring. So in the next generation, brown beetles are more common than in the previous generation.

Remember, natural selection is the force of evolution that was acting on the population of moths. In forest with dark trees, dark moths were more likely to survive and reproduce than white. Therefore, there was natural selection of dark peppered moths to survive and reproduce.

Keep in mind that these are simple examples of the forces of evolution, but they do highlight now these forces work on a population. Later examples in this module will be more interesting and complex.

Slide 17



Activity: remember- ask.

In this activity, drag and drop the terms with the correct definitions. (should be the same functionality as we have had before, just with new definitions.

Definitions:

Mutation
A permanent, heritable change in the genetic makeup of an individual. These changes are often neutral, meaning they don't change the characteristics of an individual. They are sometimes harmful and decrease an individual's ability to survive. They are rarely beneficial and increase an individual's ability to survive and reproduce.

Genetic Drift
The process of change in the genetic composition of a population due to chance or random events rather than by natural selection, resulting in changes in allele frequencies over time.

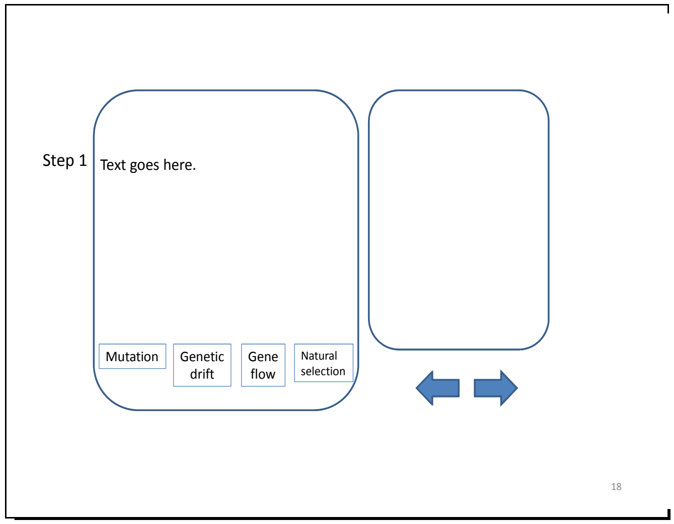
Genetic Bottleneck
Random reduction of the size of the population, which reduces the variation of gene types. This alters the genetic composition of the population by reducing the kinds of traits that are passed on to offspring.

Founder's Effect
Occurs when a portion of a population migrate to a new area. The smaller size of the population reduces the variation of gene types. This alters the genetic composition of the population by reducing the kinds of traits that are passed on to offspring.

Gene Flow
The movement of genes from different populations of species. This flow of genes from one population to another tends to reduce variation between populations.

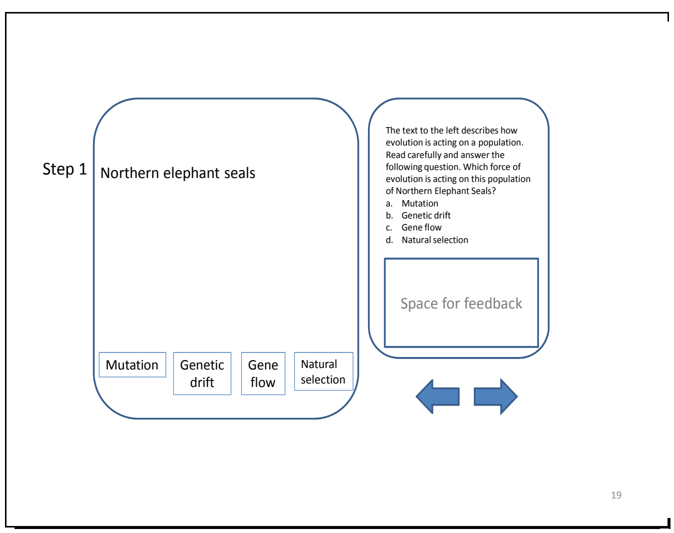
Natural Selection
A process in nature in which organisms possessing certain genotypic characteristics that make them better adjusted to an environment tend to survive and reproduce.

Slide 18



Text: Now that you have learned what these forces of microevolution are, you will have an opportunity to test your knowledge. You will read about several populations being affected by a specific force of evolution. Read the description and consider which force of evolution might be acting on the population. If you need a hint, mouse the over boxes on the bottom of the screen to review the definition of each force. When you are ready, click the answer on the right-hand side of the screen.

Slide 19



Step #1 practice #1

Text: In the 1800s, Northern Elephant Seals were hunted nearly to extinction. At one point, only about 20 seals were believed to be alive. This population became protected and the population of seals has grown. However, these seals now all have very similar genetic makeup compared to the time before they were hunted to near-extinction.

Image: Northern Elephant Seal. http://en.wikipedia.org/wiki/File:See_elefanten_edit.jpg

Question: Which force of evolution is at play? Click on the force of evolution that appears to be acting on this population.

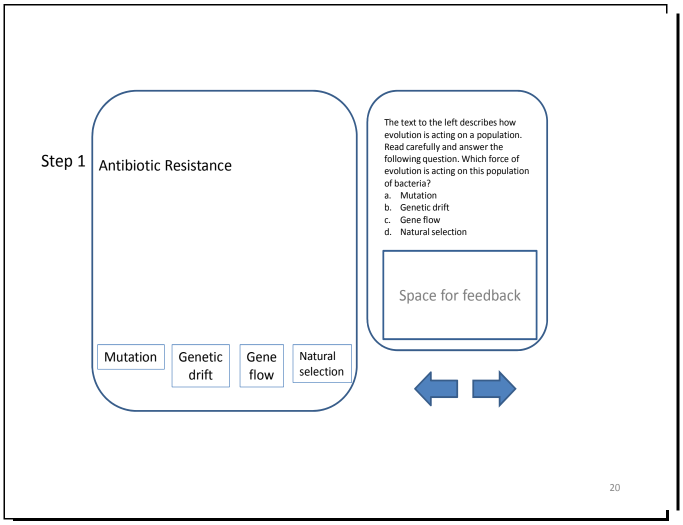
Correct Answer: Genetic Drift.

Correct Answer Feedback: That's right. Genetic Drift is in the form of a genetic bottleneck that acted on these seals, causing evolution in this population by reducing the variety of alleles and traits.

Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

Mutation: Not correct. Remember, mutation is the creation of new gene forms (alleles). Try again.
Gene Flow: Not correct. Remember, gene flow is the movement of alleles between populations due to migration between populations. Please try again.
Natural Selection: Not correct. Remember, in natural selection beneficial genetic traits make an individual more likely to survive and reproduce than other traits. Please try again.

Slide 20



Step #1 practice #2

Text: Since the discovery of penicillin in 1928, antibiotics have been used to fight bacterial diseases. Bacterial populations are huge and contain considerable genetic variation. When exposed to antibiotics, most bacteria die quickly, but some have a genetic makeup that resists the antibiotic and allows them to survive. These survivors then reproduce, and subsequent generations of bacteria have more members that resist antibiotics.

Image: a pill. http://en.wikipedia.org/wiki/File:FlattenedRoundPills.jpg

Question: Which force of evolution is at play? Click on the force of evolution that appears to be acting on this population.

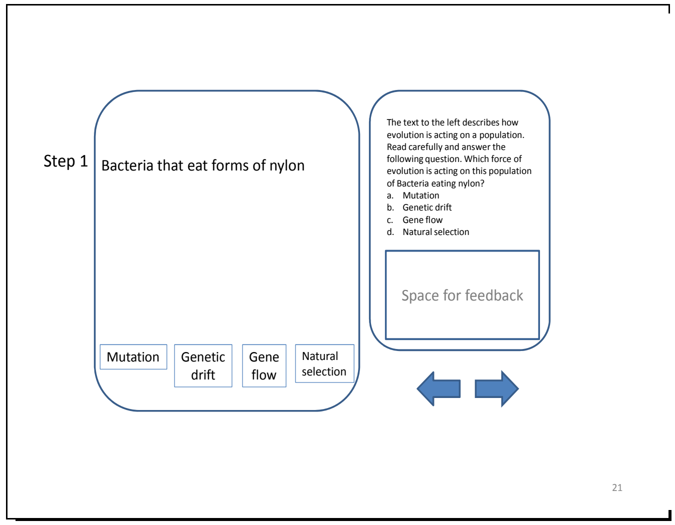
Correct answer: Natural Selection.

Correct answer feedback: Correct. Natural selection is the process by which heritable traits that increase an organism's chances of survival and reproduction are favored over less beneficial traits. In this case, individual bacteria with a genetic makeup that resists antibiotics survive and reproduce and other individuals do not, and the population evolves to having more individuals resistant to penicillin.

Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

Mutation: Not correct. Remember, mutation is the creation of new gene forms (alleles). In this case, the gene forms are already present in the population. Try again.
Gene Flow: Not correct. Remember, gene flow is the movement of alleles between populations due to migration between populations. Please try again.
Genetic Drift: Not correct. Remember, genetic drift is random fluctuation in allele frequency due to random events other than natural selection. Please try again.

Slide 21



Step #1 practice #3
Text: In the 1940s, nylon was invented. It proved to be a product that was very useful and durable, especially because it was not something that bacteria could consume. However, some time after it was invented, scientists discovered that some populations of bacteria had begun to be able to consume nylon. Scientists realized that the ability to digest nylon was a new ability in these bacteria.

Image: bacteria http://en.wikipedia.org/wiki/File:EMpylori.jpg

Question: Which force of evolution is at play? Click on the force of evolution that appears to be acting on this population.

Correct answer: Mutation.

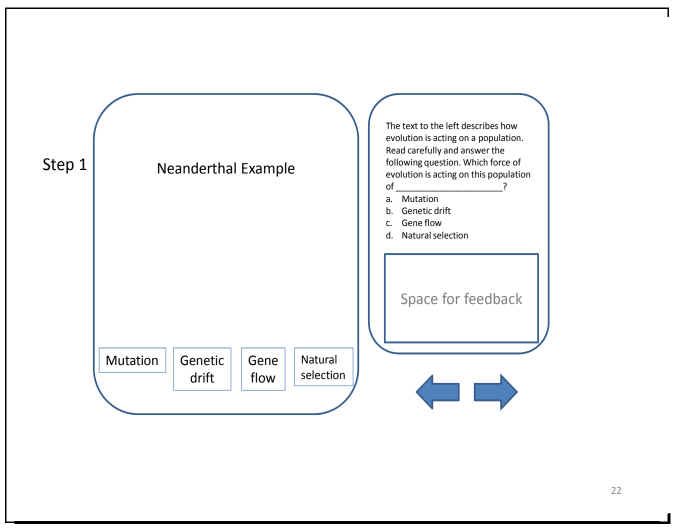
Correct answer feedback: That is correct! Mutation is the random creation of new gene forms (alleles). In this case, an individual in the bacteria population appeared with a random change in genetic makeup that enabled it to eat some forms of nylon. This ability gave the bacteria increased ability to survive in some environments and it passed its genetic makeup on to later generations. Natural selection came into play to increase the frequency of the mutation, but without the new mutation, no bacteria could have consumed nylon.

Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

Genetic Drift: Not correct. Remember, genetic drift is random fluctuation in allele frequency due to chance. Try again.

Gene Flow: Not correct. Remember, gene flow is the movement of alleles between populations and is due to migration between populations. It opposes the genetic differentiation of populations (it keeps different populations alike). Please try again.
Natural Selection: Not quite but close. Remember, natural selection is the process by which heritable traits that increase an organism's chances of survival and reproduction are favored than less beneficial traits. Since the ability to consume nylon was "a new ability in these bacteria," something must have created this new trait and gene, with natural selection acting to increase the frequency of nylon-digesting bacteria. Please try again.

Slide 22



Step #1 practice #4
Text: Neanderthal
Neanderthal genome was sequenced (2/3 of it). In addition, we know the sequences from Africans, Europeans and Asians. When there were comparisons made, in European genomes, there are some neanderthal sequences in Europeans and Asians. They are not found in African populations. There was some limited breeding in ancestors to Asians and Europeans. Probably occurred when the group was coming out of Africa. We as Europeans had some limited interbreeding with them.

Image: http://en.wikipedia.org/wiki/File:Neanderthaler_Fund.png

Question: Which force of evolution is at play? Click on the force of evolution that appears to be acting on this population.

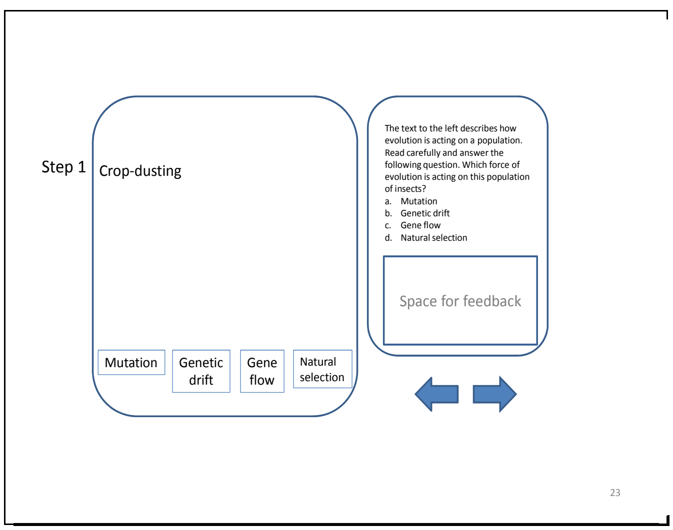
Correct answer: Gene Flow. There was limited interbreeding in these populations.

Correct answer feedback: That is correct! Gene flow is gene flow is the movement of alleles between populations and is due to migration between populations. So, in this case a group of humans migrated to an area where a group of Neanderthals lived and had offspring, resulting in similarities within each of the populations.

Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

Genetic Drift: Not correct. Remember, genetic drift is random fluctuation in allele frequency due to chance. Try again.
Mutation: Not correct. Remember, mutation is the random creation of new gene forms (alleles). Please try again.
Natural Selection: Not correct. Remember, natural selection is the process by which heritable traits that increase an organism's chances of survival and reproduction are favored than less beneficial traits. Please try again.

Slide 23



Step #1 practice #5

Text: One way that farmers improve the quality of their harvest is by dusting their crops with pesticides designed to kill insect pests. For years, this technique greatly reduced the number of insects eating crops. However, farmers noticed that each year a greater number of insects survived crop-dusting. Biologists realized that insects have considerable genetic variation and that some have a genetic makeup that allows them to resist pesticides and survive. These survivors then reproduce, and subsequent generations of insects are more and more likely to have a genetic makeup that resists pesticides.

Image: airplane. http://en.wikipedia.org/wiki/File:Crop_Duster.jpg

Question: Which force of evolution is at play? Click on the force of evolution that appears to be acting on this population.

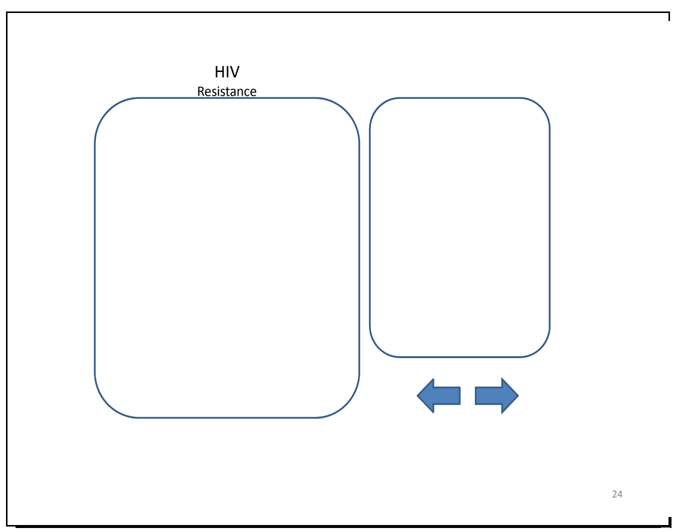
Correct answer: Natural Selection.

Correct answer feedback: Correct! Natural selection is the process by which heritable traits that increase an organism's chances of survival and reproduction are favored over less beneficial traits. So, in this case, insects with a genetic makeup that makes them resistant to crop-dusting are more likely to survive and reproduce.

Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

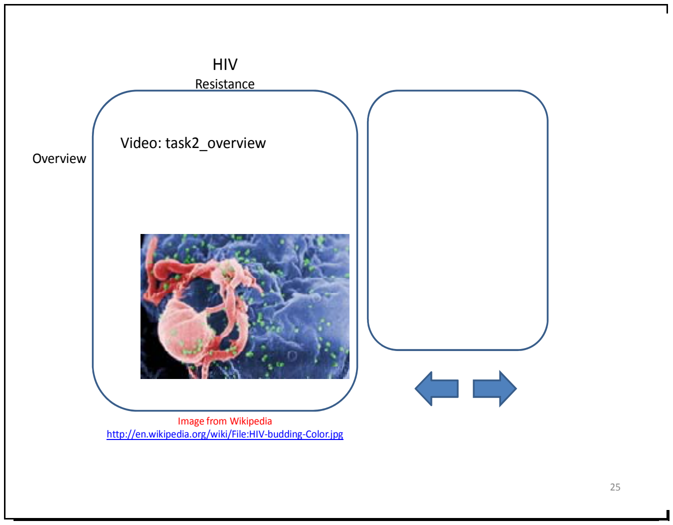
Genetic Drift: Not correct. Remember, genetic drift is random fluctuation in allele frequency due to chance. Try again.
Gene Flow: Not correct. Remember, gene flow is the movement of alleles between populations and is due to migration between populations. Please try again.
Natural Selection: Not correct. Remember, natural selection is the process by which heritable traits that increase an organism's chances of survival and reproduction are favored than less beneficial traits. Please try again.

Slide 24



Text: Great work. Now that you have learned about the forces of evolution and how each of them functions, lets take a look at another example of biologists analyzing microevolution in a population. Remember, **microevolution in action** is change in the genetic composition in a population over time. In microevolution, we study **populations** as the unit of evolution, and in the next example, we will see how biologists study a human population. Click the next button to continue.

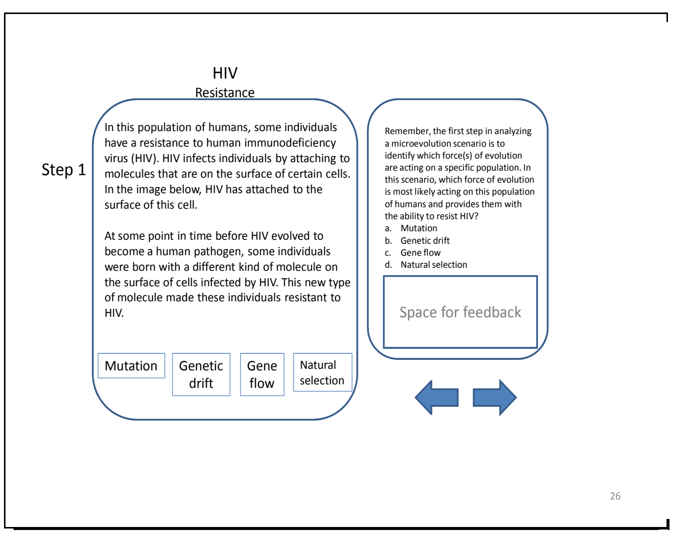
Slide 25



Audio: Let's look at another example of how biologists analyze microevolution in a population. In this population of humans, some individuals have a resistance to human immunodeficiency virus (HIV). HIV infects individuals by attaching to molecules that are on the surface of certain cells. In the image below, HIV has attached to the surface of this cell.

At some point in time before HIV evolved to become a human pathogen, some individuals were born with a different kind of molecule on the surface of cells infected by HIV. This new type of molecule made these individuals resistant to HIV.

Slide 26



Text: In this population of humans, some individuals have a resistance to human immunodeficiency virus (HIV). HIV infects individuals by attaching to molecules that are on the surface of certain cells. In the image below, HIV has attached to the surface of this cell.

At some point in time before HIV evolved to become a human pathogen, some individuals were born with a different kind of molecule on the surface of cells infected by HIV. This new type of molecule made these individuals resistant to HIV.

Question Text: Remember, the first step in analyzing a microevolution scenario is to identify which force(s) of evolution are acting on a specific population. In this scenario, which force of evolution is most likely acting on this human population to provides] some members with resistance to HIV?

Correct answer: Mutation.

Correct answer feedback: That is correct! Mutation is the creation of new gene forms (alleles). It is the source of new alleles in all species. So, in this case a new gene form (or *allele*) was randomly created by mutation of an existing allele that provided resistance to HIV. It was then passed down to offspring. Click the next button to continue with this example.

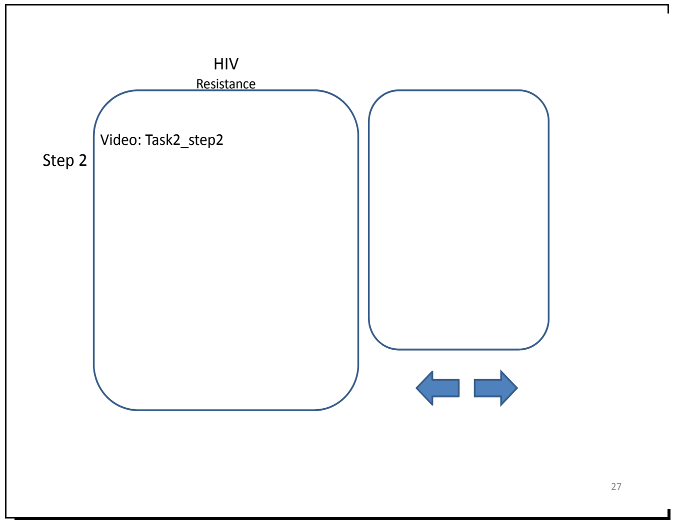
Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

Genetic Drift: Not correct. Remember, genetic drift is random fluctuation in the frequency of existing allele frequency due to chance. Try again.

Gene Flow: Not correct. Remember, gene flow is the movement of alleles between populations. Please try again.

Natural Selection: Not correct. Although natural selection might play a part in how this population changes over time, it does not create new gene forms (alleles). Please try again.

Slide 27

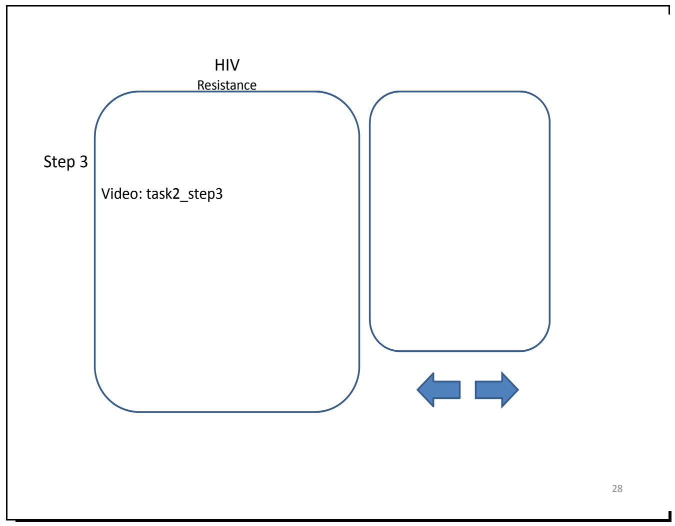


Audio:

General:
After identifying which force of evolution is at play in a population, it is important to determine how this force of evolution is affecting the population. In this case, a new gene form was randomly created through mutation. Based on their knowledge of microevolution, biologists realized that a mutation creates a new characteristic that has the possibility of being acted upon by natural selection. However, the force of mutation itself does not make the mutation spread through the population in subsequent generations.

Specific:
So, in this case the mutation created a new gene form that changed the surface of some cells, making the individuals resistant to HIV. However, this only introduced that resistance in an individual in the population. It was up to natural selection to act on the force and have it continue throughout the population.

Slide 28

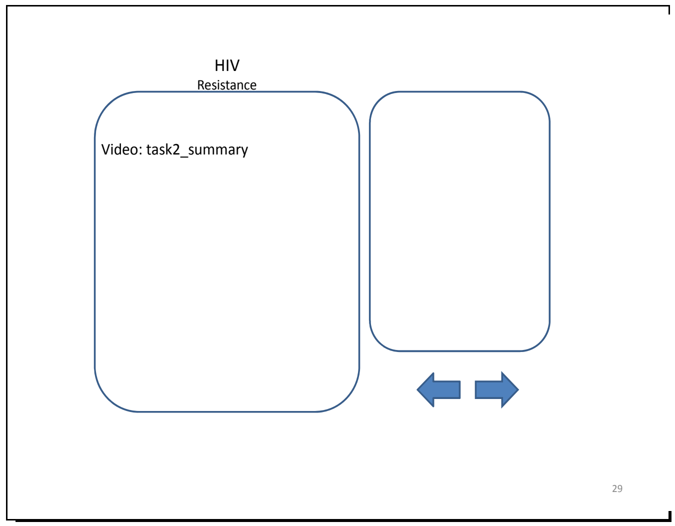


Audio: After identifying mutation as the force of evolution acting on this population of humans, biologists work to predict specifically how the population will change over time.

General:
Mutation can be harmful, neutral or beneficial. If it is a harmful mutation it decreases fitness (the ability to survive and reproduce), and natural selection will select against it and its frequency will decrease, perhaps even being weeded out of the population. If it is a neutral mutation, it has no effect on fitness and natural selection does not act on it. Finally, if this or any mutation is beneficial, it improves fitness (or its ability to survive and reproduce) and natural selection can act upon it to increase its frequency in later generations.

Specific:
In this case, individuals with the new gene form have an increased resistance to HIV. Because there are so many factors influencing the future of a population, it is often difficult to predict how microevolution will effect that population. In this case, if the population is exposed to HIV, people with the mutation will have greater survival and reproductive success in the population over time.

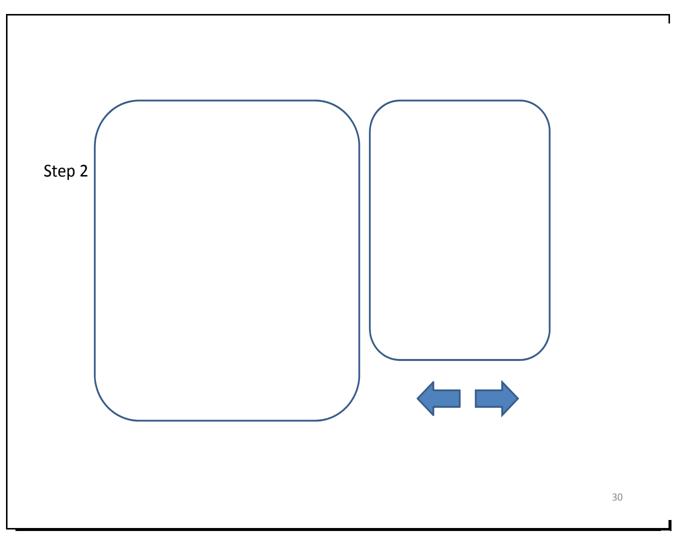
Slide 29



Audio: So, to summarize, because all new gene forms come about by mutation, biologists realized that mutation must have created resistance to HIV. Biologists then worked to determine in more detail how the population was being affected and determined that the mutation created the opportunity for natural selection to change the genetic makeup of the population. Finally, based on what they knew, they predicted that if the population were exposed to HIV, there would likely be an increase in the number of individuals with the mutant gene form because it would increase their chance for survival and reproduction.

Visual: Show the steps and highlight them when they are being discussed.

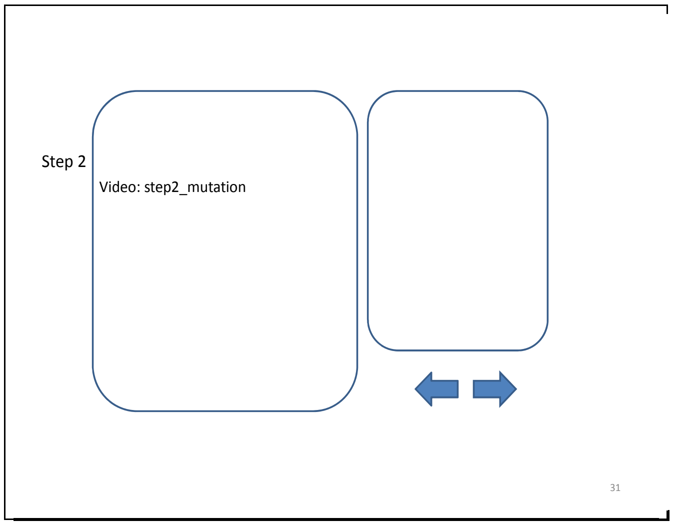
Slide 30



Header: Step 2: How is it working?

Text: As mentioned earlier, the second step for analyzing microevolution in a population is to predict how the force of evolution is affecting the population. To learn more about how to do this, click the next button.

Slide 31



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Images: show the beetle images and the boxes below.

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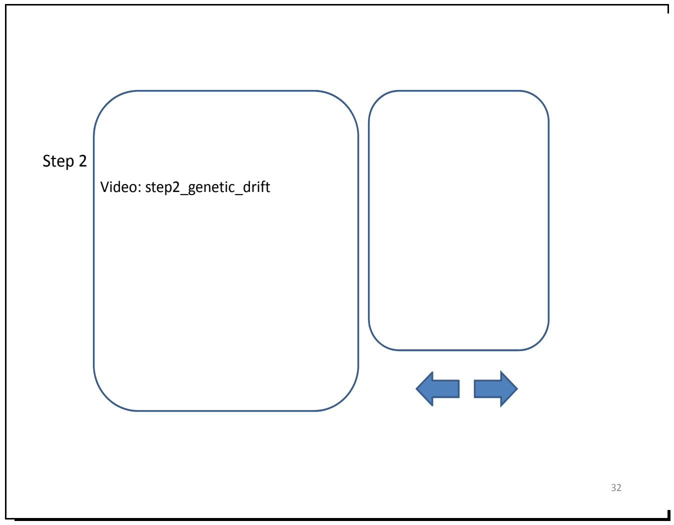
Video: Show all the simple bug examples and show how they affect the population. Go through them quickly.

Slide 32



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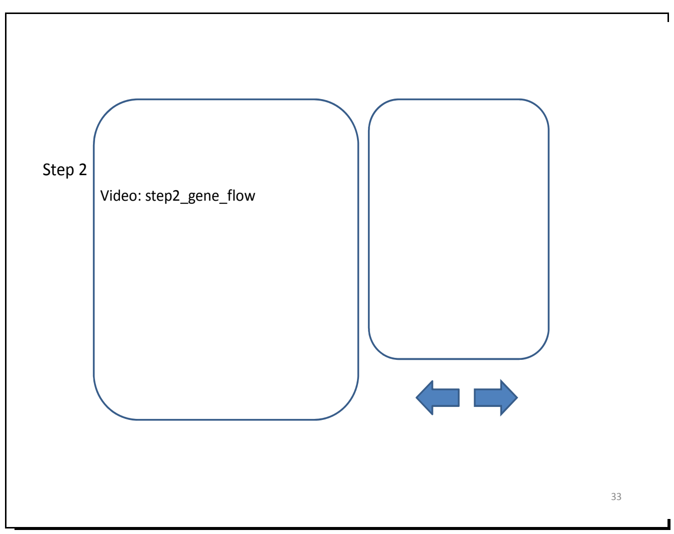

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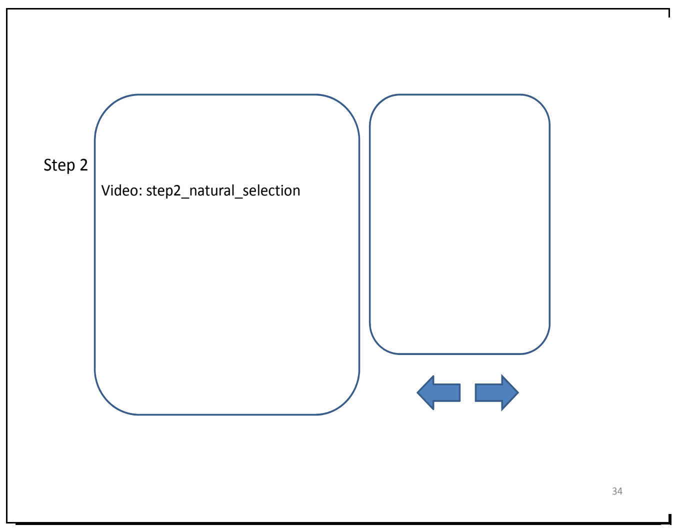

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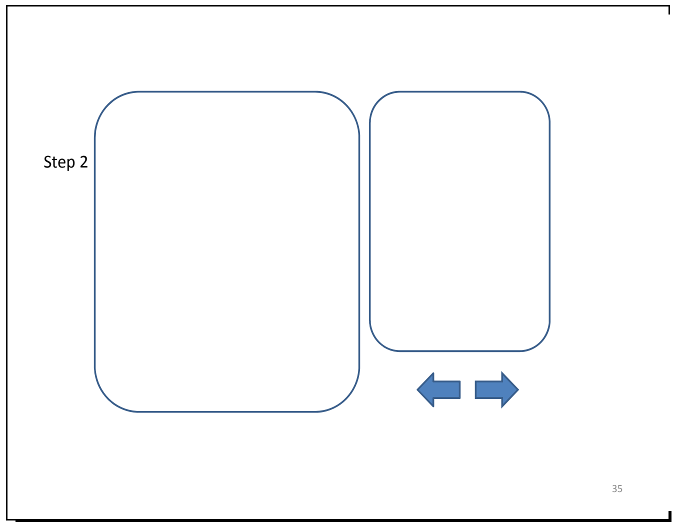
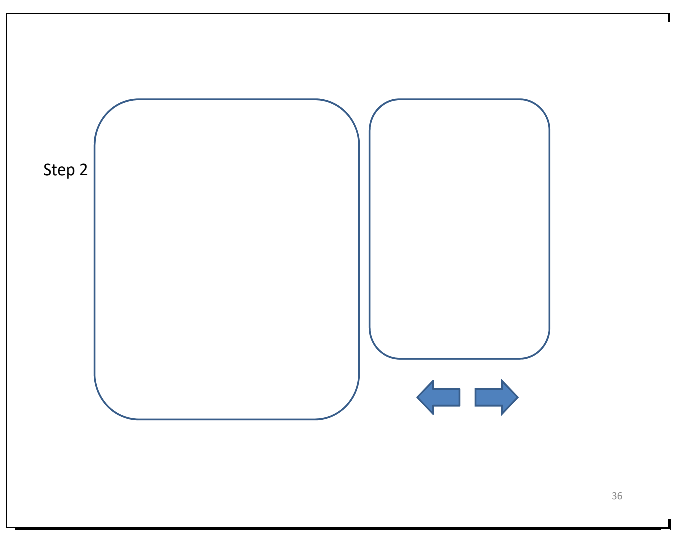


Text: Now it is your turn to determine how different forces of evolution are affecting different populations. You will be given several examples of different populations and will have the opportunity to test your understanding of how evolutionary forces affect them. Click next button to continue.

Slide 36



Text: Genetic Drift
In the 1800s, Northern Elephant Seals were hunted nearly to extinction. At one point,

only about 20 seals were believed to be alive. Luckily, this population became protected from hunters.

Image: http://en.wikipedia.org/wiki/File:See_elefanten_edit.jpg

Question text:
Based on what you know, how would you predict genetic drift is affecting this population?

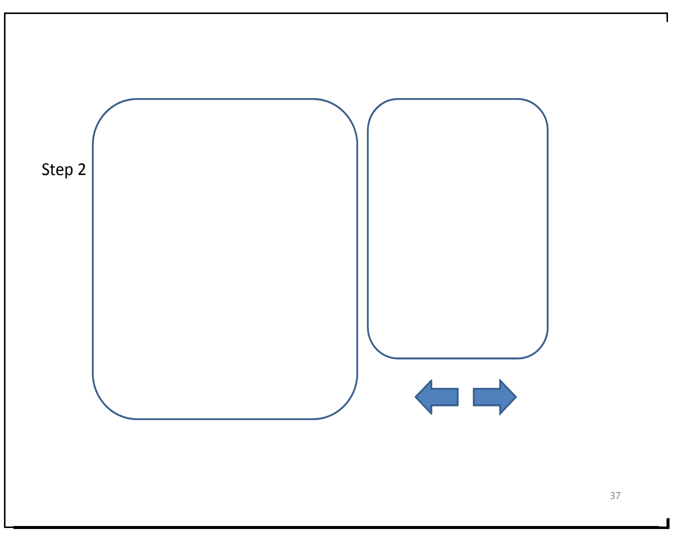
Answer options:
- The seal population will begin to mutate at a faster rate to make up for lost seals.
- The seal population has the same genetic composition as before, just fewer seals.
- Because the population is reduced in size due to hunting, there is a smaller variety of genes.

Correct answer: C

Correct answer feedback: Correct! This is an example of genetic bottleneck. A reduction in the number of seals reduces genetic variation in the population.

Incorrect answer feedback:
- Incorrect. Remember, mutation occurs randomly.
- Incorrect. Note that there is a reduction in seals, so there must be some change in population's genetic composition.

Slide 37



Text: Natural Selection

Since the discovery of penicillin in 1928, antibiotics have been used to fight bacterial diseases. Bacterial populations are huge and contain considerable genetic variation. When exposed to antibiotics, most bacteria die quickly, but some have a genetic makeup that resists the antibiotics.

Image: a pills. http://en.wikipedia.org/wiki/File:FlattenedRoundPills.jpg

Question Text: Based on what you know, how is natural selection affecting this population?

Answer options:
- The bacteria are adapting to natural selection and figuring out how to survive.
- Natural selection is favoring the gene forms that allow resistance to antibiotics.
- Natural selection is causing new mutations to occur in the population, thereby creating new genes that resist antibiotics.

Correct answer: B

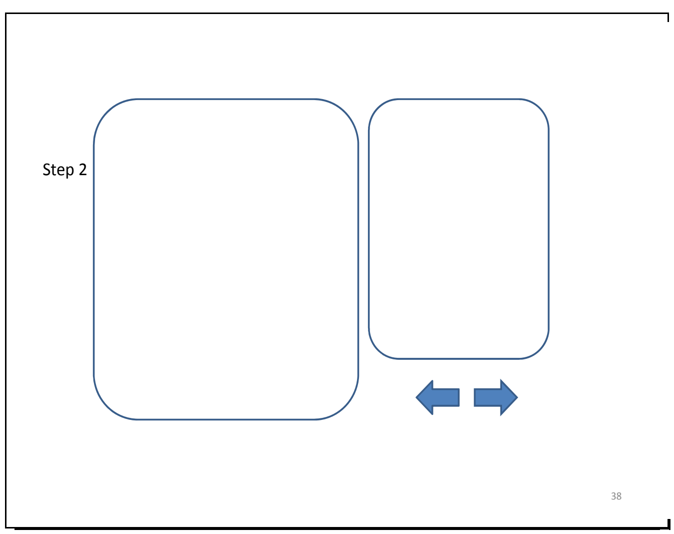
Correct answer feedback: Correct! Natural selection allows bacteria possessing favorable characteristics to survive and reproduce.

Incorrect answer feedback:

- Incorrect. Bacteria cannot adapt or figure out how to survive. Their genetic traits either enable or hinder survival and reproduction. Try again.

c. Incorrect. Natural selection does not cause mutations. It does, however, favor beneficial mutations because it enables them to survive and reproduce.

Slide 38



Text: Mutation

In the 1940s, nylon was invented. It proved to be a product that was very useful and durable, especially because it was not something that bacteria could consume. However, some time after it was invented, scientists discovered that some populations of bacteria had begun to be able to consume nylon. Scientists realized that the ability to digest nylon was a new ability in these bacteria.

Image: bacteria. http://en.wikipedia.org/wiki/File:EMpylori.jpg

Question Text: Based on what you know about this population, how is this force of evolution affecting the population?
Answer options:

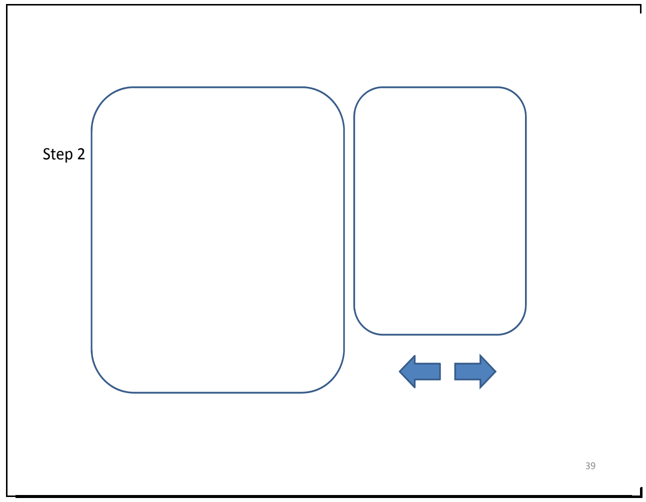
- The mutation randomly introduced a new gene form into the population. However, no change would likely take place with natural selection acting on the population.
- Bacteria exposed to nylon mutated so that they could start eating nylon forms.
- The mutation caused the new gene form to spread to others in the population.

Correct answer: A

Correct answer feedback: Correct. Remember, mutation only introduces a new gene type into a population. The mutation can then be acted on my natural selection to increase or decrease its frequency in the population.

Incorrect answer feedback:
b. Incorrect. The bacteria did not mutate with a purpose. Rather, mutations occur randomly.
c. Incorrect. Mutation does not cause the spread of a ne gene form but introduces the gene form into the population.

Slide 39



Text: Gene flow

Neanderthal example. Need to get more information, here...

Image: neanderthal. http://en.wikipedia.org/wiki/File:Neanderthaler_Fund.png

Answer options:

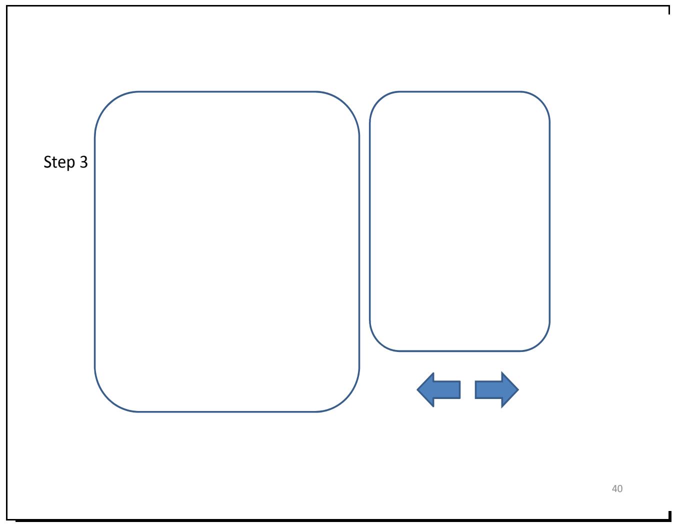
- Asd
- Asd
- Asd

Correct answer:

Correct answer feedback:

Incorrect answer feedback:

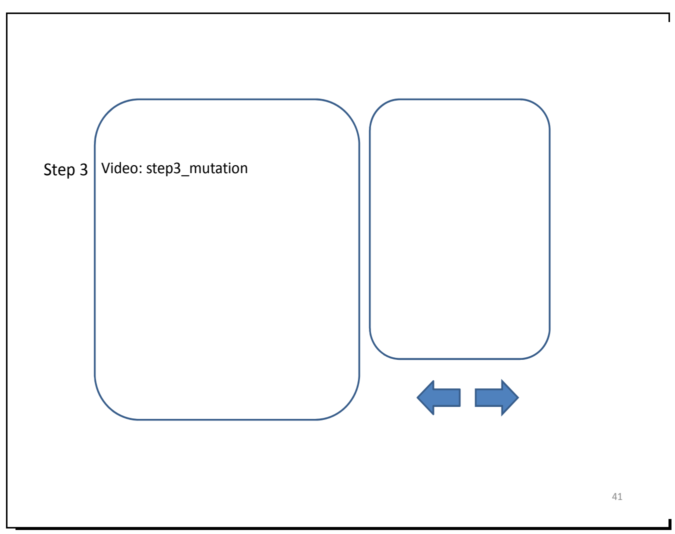
Slide 40



Header: Make a prediction.

Text: After predicting how the force of evolution is affecting the population, biologists attempt to predict how the population will change over time based on what they know. Click next to learn more how to do this step.

Slide 41



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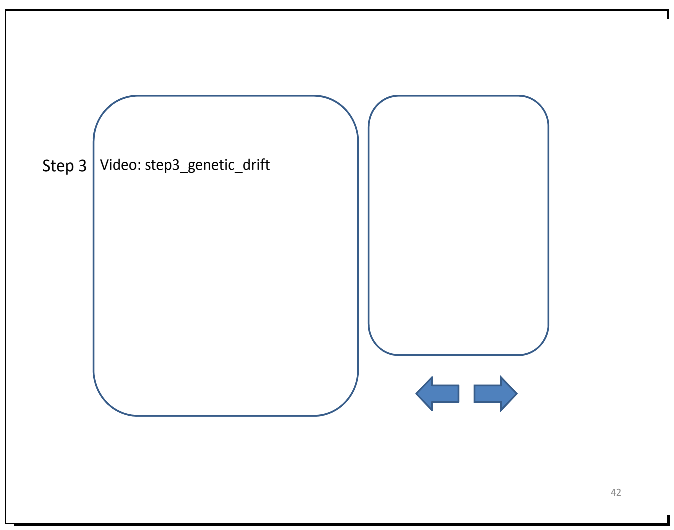
Video: Show all the simple bug examples and predict what will happen with them based in a couple of givens. Go through them quickly.

Slide 42



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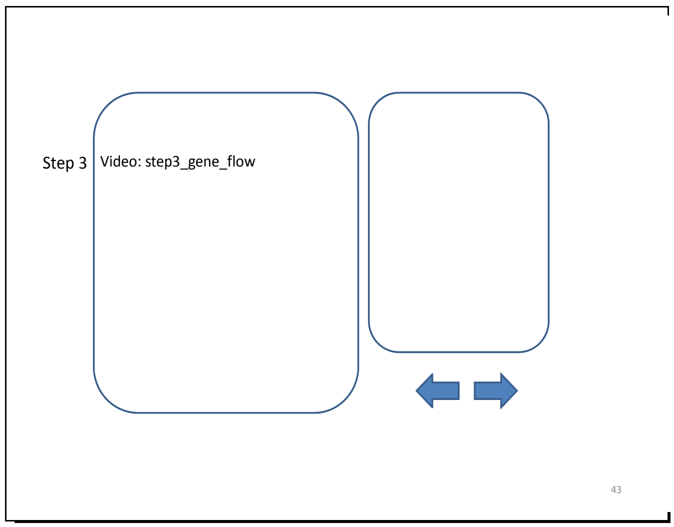

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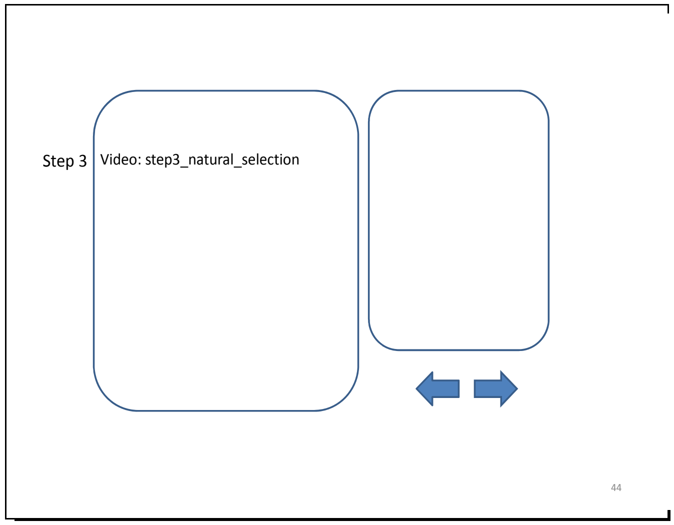

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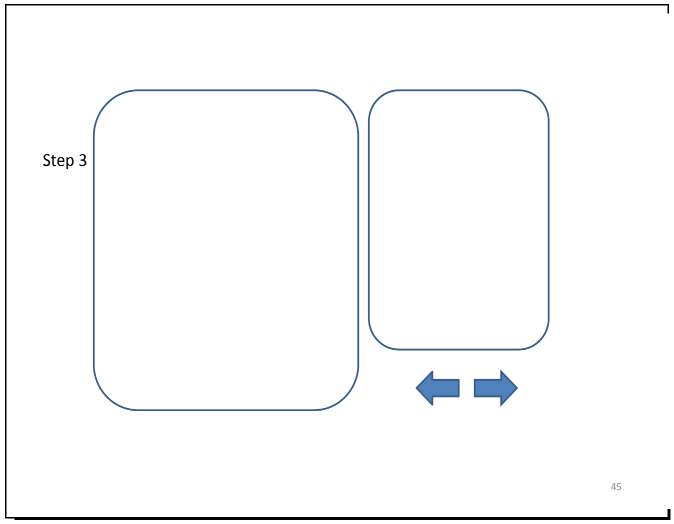
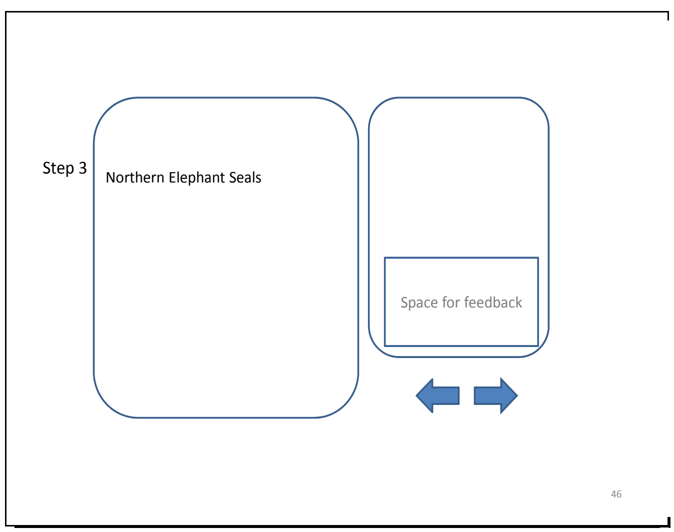
Slide 45



Text: Now that you have seen a few examples of how biologists can predict how a population might change over time, it is your turn to practice on a few examples of microevolution in action. Click the next button to continue.

Slide 46



Step #3 practice #1

Text: Genetic Drift

One example of genetic bottleneck (a form of genetic drift) is the Northern Elephant Seals, which were hunted nearly to extinction. At one point, only about 20 seals were alive. The endangered population was protected and it has grown. How might this population change over time?

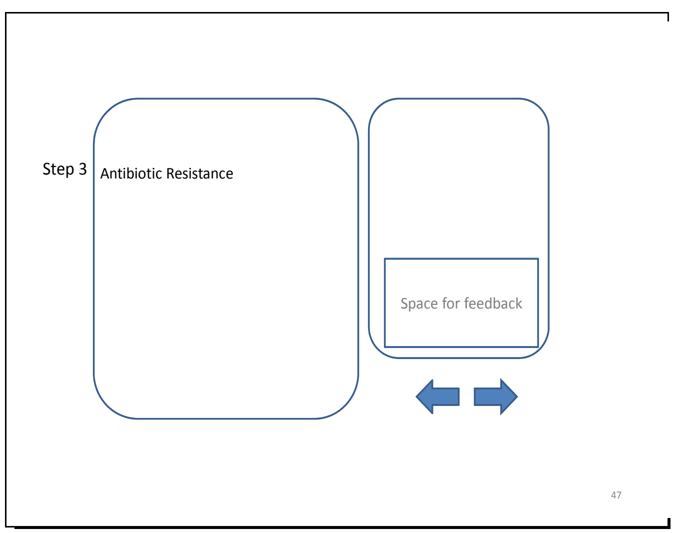
Image: Northern Elephant Seal. http://en.wikipedia.org/wiki/File:See_elefanten_edit.jpg

Answer options:
a. The seal population will be more fit than it was before hunting.
b. The expanding seal population will have a genetic makeup very similar to the population before hunting.
c. Several new mutations will occur to help the seals survive.
d. The seal population will have reduced variation in genes and traits relative to the population before hunting.

Correct answer: D

Answer feedback:
a. incorrect. Remember, genetic bottleneck means the genetic variety of the population is reduced.
b. incorrect. Remember, mutations happen by chance and might not occur in this population.
c. Incorrect. Mutations don't arise when they're needed; mutations occur randomly.
d. Correct. A genetic bottleneck reduces genetic variation.

Slide 47



Step #3 practice #2

Text: Natural Selection
When exposed to antibiotics, most bacteria die quickly, but some have genetic makeup that resists the antibiotic and allows them to survive and reproduce. Based on what you know, how will this population change over time?

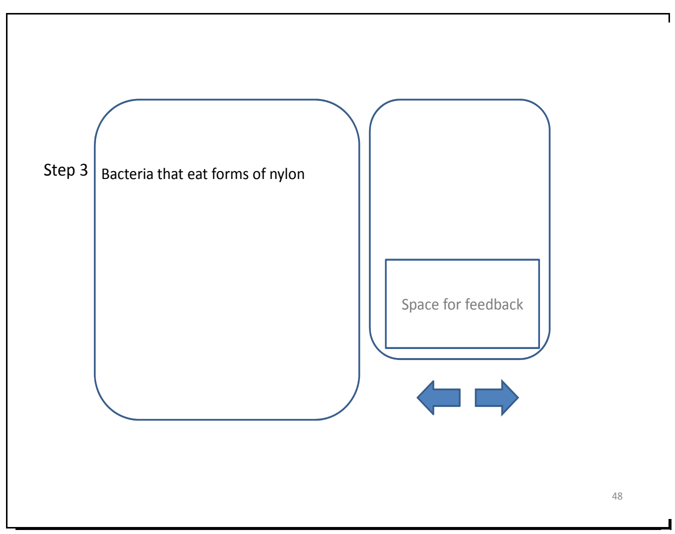
Image: pills. http://en.wikipedia.org/wiki/File:FlattenedRoundPills.jpg

Answer options:
- Over time, the bacteria population will figure out how to evade antibiotics.
- The population will come up with even better mutations that will help them survive.
- The surviving bacteria will reproduce, and later generations of bacteria will be more likely to have genetic makeup that resists antibiotics.

Correct answer: C

Answer feedback:
- Not correct.
- Not correct. Remember, natural selection occurs randomly and cannot be initiated by the population.
- Correct! If some bacteria have a genetic makeup that resists antibiotics, then they will be more likely to survive and reproduce.

Slide 48



Step #3 practice #3

Text: Mutation

Some time after nylon was invented, scientists discovered that some bacteria appeared with the ability to consume different types of nylon. The ability to ingest nylon was a new ability in these bacteria. If nylon is available to this population as a primary food source, how would you predict this population will change over time?

Image: bacteria http://en.wikipedia.org/wiki/File:EMpylori.jpg

- The bacteria will continue to stay the same as it is now, based on its genetic makeup.

b. The bacteria will realize that the ability to eat nylon is great and will mutate to eat other materials.

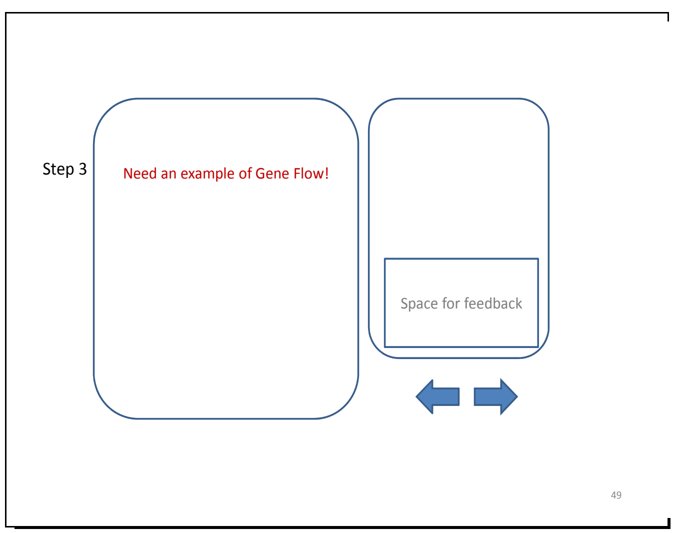
c. The ability to consume nylon will be passed down to later generations and become more and more common because it increases the ability of the bacteria to survive and reproduce.

Correct answer: C

Answer feedback:

- Not likely. Bacteria will continue to evolve based on the forces of evolution.
- Not correct. Bacteria cannot intentionally mutate, since mutation is a random event.
- Correct! Since the ability to consume nylon is a beneficial mutation, natural selection will likely select that trait and it will be passed on to offspring.

Slide 49



Step #3 practice #4

Text: Gene Flow.

Earlier we described a population of humans that migrated and interacted with a group of Neanderthals. There is some evidence that these two groups had offspring.

Image: Neanderthal. http://en.wikipedia.org/wiki/File:Neanderthaler_Fund.png

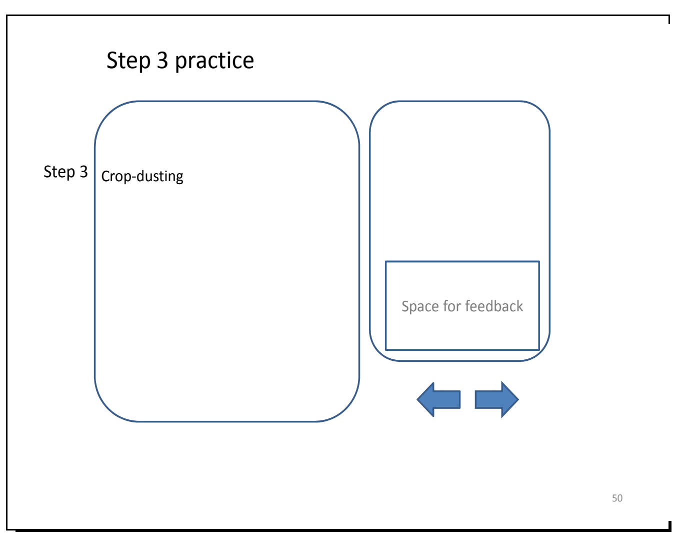
Question: Based on what you know about this population, what would have happened to the two populations over time?

Answer options:
- Adsf
- Sadf
- The two populations will start to have more genetic similarities.
- Asfd

Correct answer:

Answer feedback:
- Adsf
- Afd
- Correct! Gene flow tends to reduce genetic variations between populations, so in this case the two groups will likely become more similar over time.
- Sadf

Slide 50



Step #3 practice #5

Text: Natural Selection

Farmers have noticed that each year a greater number of insects survive crop-dusting. Biologists realized that the insects that eat crops have considerable variation in their genetic material and that some have a genetic makeup that allows them to survive the pesticide. Based on what you know, how will this population change over time?

Image: airplane http://en.wikipedia.org/wiki/File:Crop_Duster.jpg
Answer options:

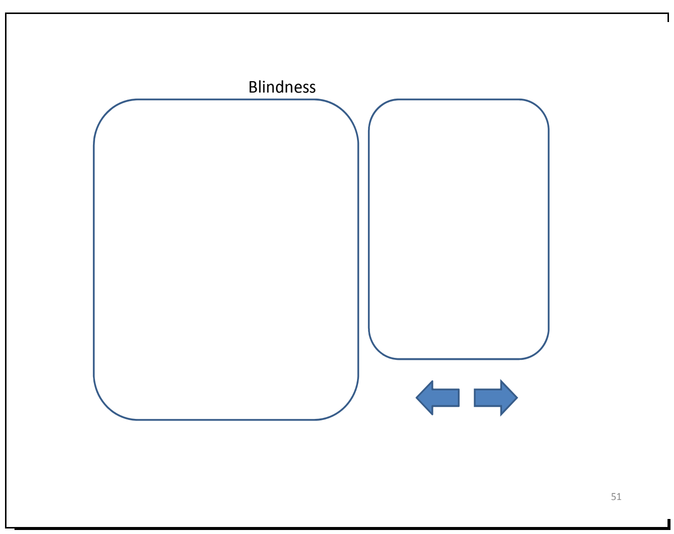
- Later generations of these insects are more and more likely to have a genetic makeup that resists pesticides.
- As they are exposed to new pesticides, some individual insects will mutate to adapt to new antibiotics.
- The genetic makeup of the population will not change much over time.

Correct answer: A

Answer feedback:

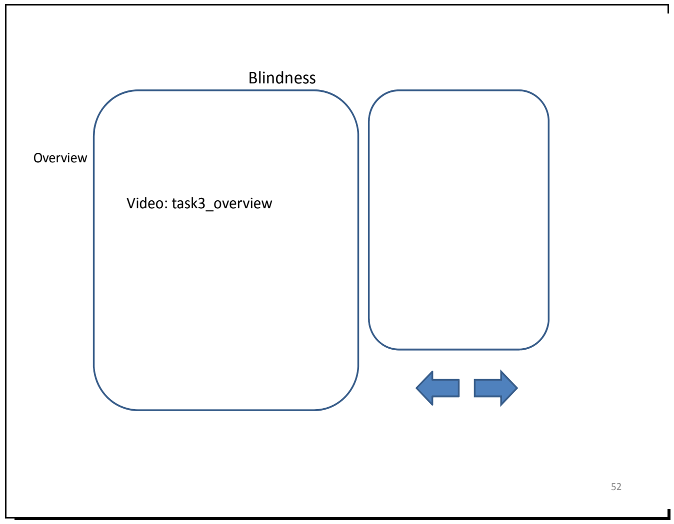
- Correct! Insects with genetic makeup to resist crop-dusting will survive and reproduce more than those that do not have the genes to resist crop-dusting.
- Incorrect. Individuals cannot mutate to adapt. Mutations occur randomly and are due to chance.
- Incorrect. Natural selection will select the resistant insects because they will be much more likely to survive and reproduce.

Slide 51



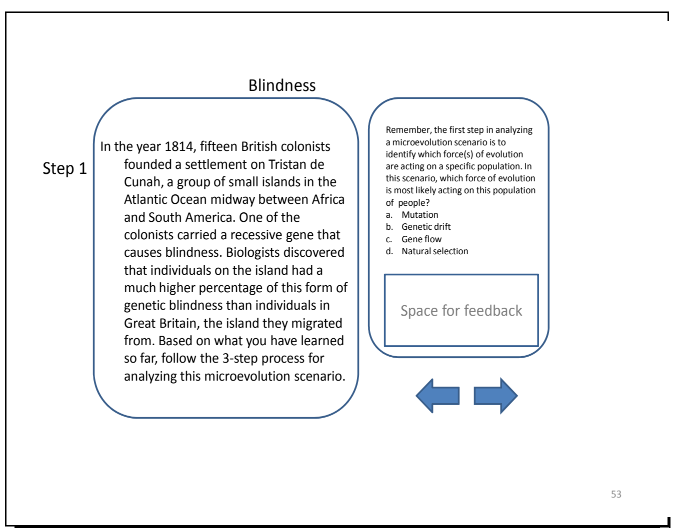
Text: Great work. Now it's time to put it all together and analyze microevolution in a population using all three steps. In this scenario, we will study another human population with a certain form of genetic blindness. Click the next button to analyze this population.

Slide 52



Audio: In the year 1814, fifteen colonists migrated from Great Britain and founded a British settlement on Tristan de Cunha, a group of small islands in the Atlantic Ocean midway between Africa and South America. Although they did not realize it at the time, one of the colonists carried a recessive gene that causes blindness. Several years later, biologists discovered that individuals on the island had a much higher percentage of this form of genetic blindness than individuals in Great Britain, the island they migrated from. Based on what you have learned so far, follow the 3-step process for analyzing this microevolution scenario.

Slide 53



Question text: Remember, the first step in analyzing a microevolution scenario is to identify which force of evolution is acting on a specific population. In this scenario, which force of evolution is most likely acting to cause this population to have a higher proportion of blind people than the population in Great Britain?

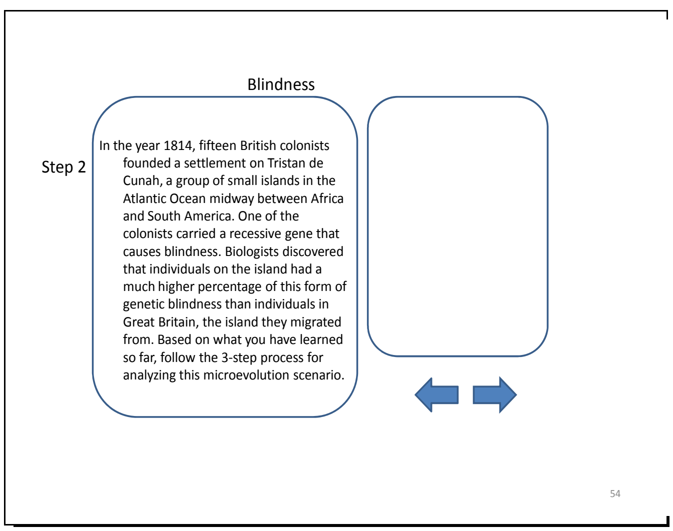
Correct answer: Genetic Drift

Correct answer feedback: That is correct! This population experienced founder's effect, a form of genetic drift in which the genetic makeup of the population is much more limited than the original population.

Incorrect answer feedback. If these incorrect items are selected, then provide this feedback based on what was selected:

Mutation: Not correct. Remember, mutation is the source of new alleles in all species, and in this case the population was affected by an existing genetic structure.
Gene Flow: Not correct. Remember, gene flow is the movement of alleles between populations. Please try again.
Natural Selection: Not correct. Although natural selection might play a part in how this population changes over time, it does not create new gene forms (alleles). Please try again.

Slide 54



Question text: After identifying which force of evolution is at play in a population, it is important to determine how this force of evolution is affecting the population. In this case, how is genetic drift acting on this population?

Answer options:

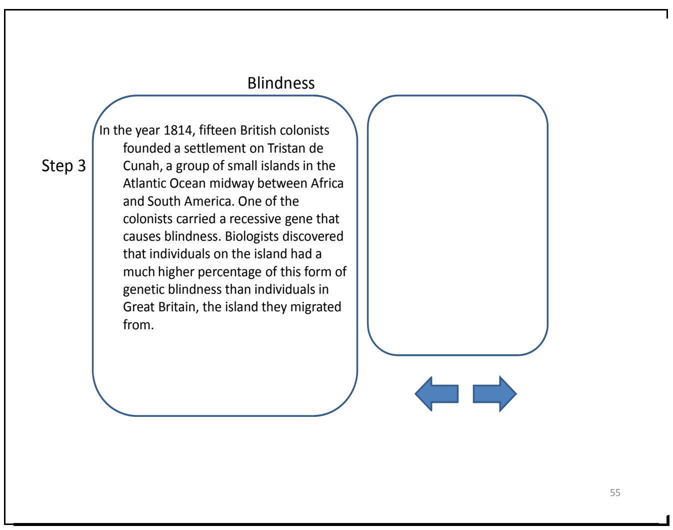
- It introduced a new gene form into the population.
- It reduced the genetic variation of the group, so there was a higher proportion of individuals with the genetic blindness.
- Over time, it will balance out the number of blind people to be comparable to those in Great Britain.

Correct Answer: B

Answer feedback:

- Not correct. Although this genetic trait was probably originally a mutation, it was not new carried into the island population by an individual.
- Correct! The proportion of people with genetic blindness was increased because of the decrease in the number of individuals on the island. This caused the genetic makeup of the islanders to drift away from the population from which they migrated.
- Not correct. Remember, genetic drift results in changes in allele frequency over time.

Slide 55



Question text: Assume that many other groups of individuals began migrating to the island and having offspring with the population on the island. Based on what you have learned about microevolution, how would you predict this population will change over time?

Answer options:

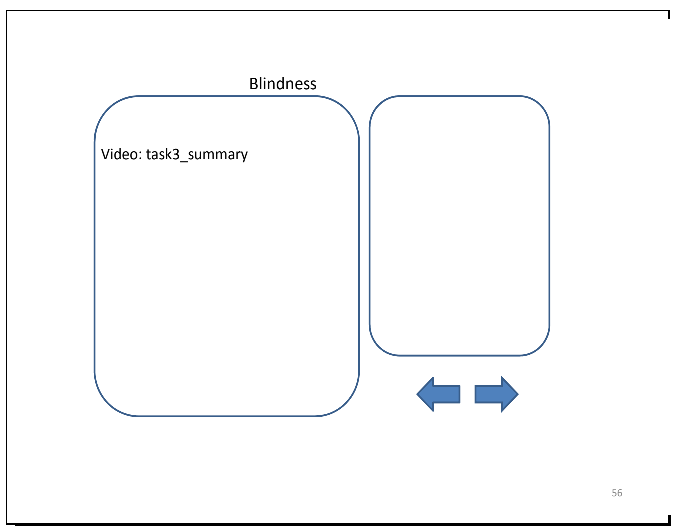
- The population will continue to have about the same genetic variety as before the new

migrants come to the area.
- The population will start to develop new mutations to counteract a change in gene frequency.
- If other populations began migrating to the island, the population on the island would eventually start to have the same genetic variety as the rest of the population.

Correct Answer: C

Answer feedback:
- Not correct. In this case, new individuals migrating might have an affect on the population.
- Not correct. Remember, mutations happen randomly.
- Correct! This is an example of gene flow, which tends to reduce variation between populations.

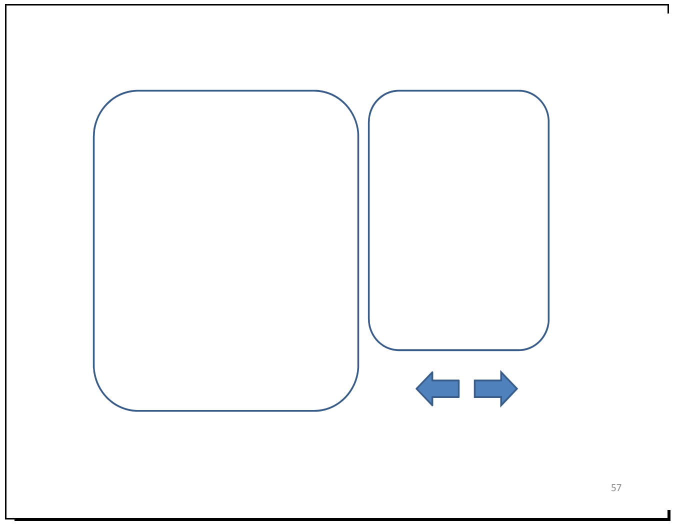
Slide 56



Audio: So, to summarize, we identified genetic drift as the force that caused an increase in the allele causing blindness in this population. We then worked to determine in more detail how the population was being effected and determined that the chance event that one of the few founding members had the allele for blindness made this population different from the larger British population. As well, the reduced size of the population made the genetic blindness more prevalent because a higher proportion of the population inherited it. Finally, if new populations moved to the island and had offspring with the island population, it would begin to have a genetic makeup more similar to the rest of the human population due to gene flow.

Visual: Show the steps and highlight them when they are being discussed.

Slide 57



Text: Congratulations! You have finished this module on microevolution.

<restart module button available here>

Slide 58

Sources:

http://www.umsl.edu/services/govdocs/wofact2003/maps/bv-map.gif

http://theindecisivemoment.files.wordpress.com/2010/01/stacktree.jpg

http://www.hmcsciencebus.org/resources/images

http://www.law.georgetown.edu/rossrights/chapters/images/358px-Uk_map_northern_ireland.png

VITA

JOEL GARDNER

Education

PhD, Instructional Technology & Learning Sciences, *Utah State University*, Logan, UT, 2011

Master of Science, **Instructional Technology,** *Utah State University,* Logan, UT, 2007

Bachelor of Arts, **Communication,** *Westminster College,* Salt Lake City, UT, 2005

Associate of Arts, General Studies, *Snow College*, Ephraim, UT, 2002

Work Experience

Instructional Design Faculty, *Franklin University*, July 2010 – present (full-time)
Design and develop online and face-to-face courses with Franklin faculty.
Serve on faculty development committee to improve faculty effectiveness.

Instructional Designer, *USU Faculty Assistance Center for Teaching*, May 2008 – July 2010
Collaborated with USU faculty to design and develop online and face-to-face courses.
Used theory and technology to create effective learning environments.
Provided greater access to courses for students throughout the state of Utah.

Course Designer, *USU Instructional Technology Department*, Summer 2007 (part-time)
- Developed online graduate grant-writing course using Camtasia, Blackboard Vista, HTML.
- Implemented current instructional theory to increase course effectiveness.
- Increased availability of fully-online course to students throughout the state of Utah.

Training Specialist, *Discover Card Financial Services,* 2005-2006 (full-time)
- Designed and implemented several month-long new-hire trainings.
- Taught over 100 students the knowledge and skills of effective customer service. Several trainees were later recognized as top performers and employees of the month.

Publications

Peer Reviewed Journal Articles

Gardner, J., Bentley, J., & Cropper, M. (2008). Evaluating On line Course Quality: Teaching Evaluation Using First Principles of Instruction. *Midwest Journal of Educational Communication and Technology*, 2(2), pp. 1-7.

Gardner, J., & Jeon, T. K. (2009). Creating task-centered instruction for web-based instruction: Obstacles and solutions. *Journal of Educational Technology Systems*, (38)1, pp. 21-34.

Gardner, J. (2009). A Framework for Understanding Instructional Contexts. *International Journal of Instructional Technology and Distance Learning*. 6(7), pp. 59-67.

Journal Article

Gardner, J. (2010). Applying Merrill's First Principles of Instruction: Practical Methods Based on a Review of the Literature. *Educational Technology Magazine*. 50(2), pp. 20-25.

Book Chapters

Joeckel, G., Jeon, T., Gardner, J. (2010). Instructional Challenges In Higher Education: Online Courses Delivered Through A Learning Management System By Subject Matter Experts. In Song, H. (Ed.) Distance Learning Technology, Current Instruction, and the Future of Education: Applications of Today, Practices of Tomorrow.

Book Reviews

Marx, S., Gardner, J. Hays, M., Johnson, K., Sheridan, D., Thurgood, L., Westenskow, A. (2010). Review of the book, Theory and Educational Research: Toward Critical Social Explanation by Jean Anyon. *International Journal of Qualitative Studies in Education*. 23(2), pp. 237-249.

Evaluation Reports

Joel Gardner, Nathan Sanders, Jeremy Haddock, Jessica Freeman, Eric Hjorten, Tiffany Ivins Spence, Brooke Robertshaw, Nathan Sanders, Alex Stoddard, Kristin Stokes Strong, Nathan Terry, Jiayi Wan, Wei Zhai & Nick Eastmond (2006). Evaluation report for the LSTA (Library Services Technology Act). Logan, UT: Dept. of Instructional Technology, USU.

Articles Currently Drafting

<u>How Award-Winning Instructors use First Principles of Instruction in Higher Education</u>
This article is based on my study of award-winning teachers in a well-known western university. It describes how these professors use First Principles of Instruction in their teaching and how these principles were personalized to the professors' individual styles and backgrounds. This article is scheduled to be submitted for publication in the spring 2011.

<u>Investigating Theoretical Support for First Principles of Instruction: A Meta-Synthesis</u>

This article reviews several current instructional and learning theories to determine whether First Principles of Instruction are emphasized in the theoretical literature. Preliminary results show that all principles have theoretical support to varying degrees. This article will be submitted for publication in spring of 2011.

Using Interactive Concept Maps to Teach Biology

This article describes a study in which students interacted with a web-based instructional concept map to learn concepts of gene expression. Preliminary results show a significant increase in student learning compared to control group. This article will be submitted for publication in fall of 2010.

Honors and Awards

- Winner, Association for Educational Communications and Technology Graduate Intern Award, 2010.
- Co-winner Association for Educational Communications and Technology Crystal Award, 2009
- Finalist in PacifiCorp Design and Development Award Competition, October, 2009.
- Awarded USU Vice-Presidential Graduate Research Fellowship, 2007-2008.
- Elected and served as President of USU Instructional Technology Student Association, 2007-2008.
- Recognized as Top Performer and Trainer of the Month while at Discover Card, 2006.
- Won 3rd place out of 60 finalists in DEX international business competition by analyzing case study and proposing effective solutions, 2002.
- Named Snow College *Spanish Student of the Year,* 2002.
- Co-produced nationally broadcast, award-winning Public Service Announcement outlining the problems of drug abuse, 2001.

Research

My goal as a researcher is to synthesize, use and discover principles and methods of instruction in real instructional design settings. I have listed below the projects that demonstrate my grasp and execution of research in teaching and instructional design settings.

Testing the Efficacy of First Principles of Instruction in Teaching Microevolution, *in progress*

In this study I compare a web-based module using First Principles of Instruction with a traditional web-based module. Students will be tested at the remember and understand levels of Bloom’s Revised Taxonomy and at the ability to solve microevolution problems.

Using Concept Maps to Teach Gene Expression, *fall 2008-present*

I am currently working with Dr. Greg Podgorski of the Department if Biology at USU and Instructional Designer Tae Jeon to develop instructional products using cognitive maps to teach gene expression more effectively. Pilot studies show improvements in student learning.

How Award-winning Professors Use First Principles of Instruction, *fall 2008-present*

For this study, I am interviewing, observing, and evaluating award-winning university professors to determine how they are using First Principles of Instruction in the classroom.

Creating a Contextualized Design Process for Higher Education, *June 2008-June 2009*

Concepts, theories and models all have a context in which they operate. I have been working with two other Instructional Designers at Utah State to create a contextualized design process for higher education.

Using Task-Centered Instruction to Teach Banner, *May 2008-January 2009*

In this study, Instructional Designer Tae Jeon and I created an online task-centered training designed to train employees to use Banner, a university administrative suite. We encountered several obstacles in designing and developing the training and creatively solved these problems using theory and practical design.

Evaluating Online Courses Using First Principles of Instruction, *Feb 2007-October 2007*

This study evaluated ten online courses on how they implemented First Principles of Instruction in their instructional strategies. Several colleagues and I compared the findings from the First Principles rubric with those of three other rubrics, as well as student ratings for the courses. Results showed that strong scores in student ratings and other rubrics tend to correlate with the use of First Principles of Instruction.

Teaching Experience

Instructor (Online), *COMP 107 Introduction to Web Programming, fall 2010*
- Taught basic principles of web design and HTML.
- Used problem-centered activity to enhance and improve student experience.

Co-Instructor (online), *INST 6870 Evaluating Online Courses*, summer 2007
- Designed and developed hybrid course teaching students the knowledge and skills of evaluating courses effectively.
- Centered instruction on real-world tasks, including evaluation of 10 fully online courses.
- Course provided students with real-world experience, giving them with a foundation for course design and evaluation in the workforce.

Teaching Assistant (online), *INST 6870 First Principles of Instruction*, summer 2010
- Will work as Teaching Assistant to Dr. David Merrill, author of First Principles of

Instruction

Faculty Workshops Manager/Trainer, *Faculty Assistance Center for Teaching*, spring 2009-July 2010

- Organize, manage and teach technology and instructional design principles to USU faculty.
- Design and coordinate the activities of other IT trainers.
- Workshops provide knowledge and skills to hundreds of USU faculty and staff.

English Teacher, *Rose Education Foundation,* May- Oct 2002

- Designed and implemented daily and weekly lesson plans and evaluations.
- Taught and tutored English to Spanish speakers in Guatemala, resulting in increased student proficiency at speaking English.

Instructional Design Experience

In my previous work, I designed and developed several fully online courses in Blackboard Vista at Utah State University. I have also developed online components for dozens of face-to-face courses. Below are brief descriptions of some of my work with faculty as a full-time Instructional Designer at USU.

Biology I (BIOL 1610), *Utah State University*, fall 2009

- Co-designed and developed instructional concept map teaching gene expression to introductory biology students.
- Created interactive map that embodies theory-based instructional strategies.
- Initial findings suggest a large increase in learning for students using the map.

Women in Islam (HIST 4910), *Utah State University*, fall 2009

- Worked with professor to create new, fully-online history course.
- Used HTML, CSS, JavaScript, Photoshop, to develop course interface in Blackboard Vista.
- Resulted in an easy-to-use, interactive course accessible to students all over the world.

Social Problems (SOC 1020), *Utah State University*, fall 2009

- Developed fully online course utilizing video-based instruction, online discussion forums, and individual personal assignments.
- Developed and aligned logical course structure with professor's pedagogy.
- Resulted in easy-to-use course that has satisfied the professor and met student needs.

Sign Language I (COMD 2910), *Utah State University*, fall 2008

- Co-designed and developed the first fully online higher education American Sign Language course.
- Developed video-based teaching module that dynamically displays the signs to be learned for the course.
- Student performance has improved through use of the online module.
- Winner of Association for Educational Communications and Technology

2009Crystal Award.

Grant Writing INST 6760, *Utah State University*, summer 2007

- Redesigned and developed course using a problem-centered instructional strategy.
- Created a structured process for learning and applying grant writing skills.
- Resulted in a fully-online course available to students throughout the state of Utah

Beginning Mathematics (Math 101), *Ogden Weber Applied Technology College*, spring 2007

- Co-designed and co-developed beginning mathematics course.
- Worked with team to create Flash-based tools that help students learn math concepts.
- Resulted in useful supplemental materials for students learning basic math concepts.

Presentations

Conference Presentations

Gardner, J., Jeon, T., Clark, R., Belland, B., Podgorski, G. (October 2010). Testing the Efficacy of Merrill's First Principles of Instruction. A paper presented at the annual meeting of the Association for Educational Communications and Technology, Anaheim, CA.

Gardner, J. (March 2010). Why Many Online Courses Stink. A presentation at Southwest Blackboard Vista Users Group, Logan, UT.

Jeon, T., Clark, R., Gardner, J. (March 2010). Interactive Concept Map. A presentation at Southwest Blackboard Vista Users Group, Logan, UT.

Joeckel, G., Jeon, T., Gardner, J. (June 2009). Context-specific Instructional Design in Higher Education. A paper presented at the Teaching with Technology Idea Exchange, Orem, UT.

Fitt, Melynda, Bentley, J., & Gardner, J. (November 2008). Rays of Change: Towards a Better Framework for Doctoral Dissertation Literature Reviews in Instructional Technology. A featured research paper presented at the annual meeting of the Association for Educational Communications and Technology, Orlando, FL.

Robertshaw, M. B., Gardner, J., Leary, H., Bentley, J. P. H., & Eastmond, N. (November 2007). Experiential Lessons From a Five-Year Program Evaluation Partnership. A paper presented at the annual meeting of the American Evaluation Association, Baltimore, MD.

Cropper, M., Bentley, J., & Gardner, J. (October 2007). Where's the Oscar Award for Outstanding Online Instruction? A paper presented at the annual meeting of the Association for Educational Communications and Technology, Anaheim, CA.

Poster Presentations

Jeon, T., Gardner, J., Podgorski, G. (2009). Do Concept Maps Help in Learning Biology? Poster presented at Biology Leadership Conference. Tucson, AZ March 20-22, 2009

Jeon, T., Gardner, J., Podgorski, G. (2009). Do Concept Maps Help in Learning Biology? Poster presented at Transforming Undergraduate Biology Education: Mobilizing the Community for Change, Washington, DC July 15 – 17, 2009. Meeting sponsored by NSF and AAAS.

Jeon, T., Gardner, J. (2009). Teaching Banner: Online Training That Actually works. Poster presented at Intermountain Graduate Research Symposium of 2009. Logan, UT, April 1, 2009.

Service

President, *Instructional Technology Student Association, USU,* 2007-2008

- Elected by fellow students to organize student-led learning activities.
- Organized weekly presentations from leaders in the field of Instructional Design.

Acting President, *Snow College Spanish Club*, 2002

- Planned and organized fundraiser for children in Guatemala.

Service and News Director, *The Kage, KAGJ 89.5 FM*, 2001-2002

- Planned and organized radio service project collecting over 500 books for rural community and school libraries.
- Managed and trained team of station news reporters.

Part-Time Ecclesiastical Volunteer, 2000-present

- Served and volunteered in several ecclesiastical positions, including teacher, music director, organizational leader, and youth leader.

Full-Time Ecclesiastical Volunteer, 1997-1999

- Led and tracked activities and effectiveness of peer volunteers.
- Trained peer volunteers on service, communication, and teaching skills.

Professional Certifications

- AleSys, Adult Learning System, 2005. Week-long certification course designed to teach trainers how to use the principles of adult learning when training.
- Training, Presentation and Facilitation Skills, 2005. Four-day certification course designed to teach trainers how to train and present effectively.
- Achieve Global, 2005. Four-day course designed to teach trainers to effectively facilitate Achieve Global management and communication courses.

Skills

- Effectively use various instructional design models to solve complex design problems.
- Skillfully apply principles of learning and instructional theory to design and teaching, including online and face-to-face instruction.
- Excellent ability to learn and communicate knowledge quickly and effectively.
- Superb problem-solving, teamwork, leadership, and self-management abilities.
- Skillfully use Camtasia, Blackboard Vista, PowerPoint, HTML, XML, and many other technologies in designing courses.