INCREASING STUDENT COMPREHENSION OF EVOLUTIONARY BIOLOGY BY USING A HANDS-ON TEACHING APPROACH

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ABSTRACT

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Evolution is surrounded by controversy, and studies show that opposition to evolutionary concepts begins in childhood (Branch and Scott, 2008). Throughout their formative years, children compile many misconceptions surrounding this topic, which directly influences their views on science and their willingness to learn about evolution. So the issue at hand is not just what we teach students regarding evolutionary biology, but also how we teach them. Students in this study were taught evolutionary concepts in a hands-on, activity based style of learning. They worked individually and within large and small groups. According to a one-tailed paired t-test, the results show that this hands-on approach is a significant way to increase both student interest and knowledge of the content.

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INTRODUCTION

"Do you believe in evolution?" This question is one that students often pose to me or to each other the minute that the word evolution is uttered in the classroom. More than any other topic that is covered in a high school biology class, students come in with a vast array of ideas regarding evolution. But the problem is that a lot of this prior knowledge is incorrect, leading to incorrect assumptions about the nature of science, and what one must believe or not believe in. As the question of "belief in evolution" shows, children have very little knowledge of the differences between faith and science. They are asking the wrong question when they ask if others "believe in evolution," since evolution is not a belief system. According to one poll, 45 percent of twelve hundred college freshmen, from ten different colleges, reject the theory of evolution (Hanson, 2000). And it's not just students that feel this way. A 2004 Gallup poll found that only one-third of Americans thought the theory of evolution was well supported with evidence (Collins, 2006). Other polls suggest that about a quarter of Americans believe in the literal biblical account, (Lerner, 2000) and 38 percent of Americans would prefer the teaching of creationism instead of evolution (Berkman, Pacheco, and Plutzer, 2008).

So, while statistics show that the majority of Americans don't seem to agree with / understand the theory of evolution by natural selection, it seems that most have little to no scientific knowledge of what it is that they disagree with. According to an informal study conducted by Steven Jakobi, a professor of introductory biology at Alfred State College, only five percent of his 306 freshmen students could actually provide a correct scientific definition for the theory of evolution (2010).

Most students enter my classroom thinking that they have all the facts regarding evolution, and their minds are made up. However, what they actually have is a pile of misconceptions about evolution, in which they are forced to pick a side either for or against science. These misconceptions include, but are not limited to the following statements. “Supporting evolution is the same as supporting atheism.” “Humans evolved from chimpanzees.” “Evolution is just a theory.” (Cavanagh, 2009) “Evolution occurs purely by chance.” (Rennie, 2002) If this is what people actually think about evolution, there is no wonder that people don’t “believe in” it.

The “controversy” surrounding the topic of evolution has a deep history. Charles Darwin’s *On the Origin of Species* was first published in November of 1859. It sold out on the first day, and has been raising “controversy” ever since (Bryson, 2003). But the idea of change over time and relatedness of all species was not first developed by Charles Darwin. What Darwin did was provide evidence for both of these notions, and propose a mechanism for how change might occur, namely natural selection (Gregory, 2008). Back in the late 1800s, scientists debated whether or not Darwin’s ideas were supported by evidence. Now, there is no question that evidence from the fields of paleontology, genetics, zoology, molecular biology, and others have shown evolution through natural selection to be true. This is something that scientists and the majority of the worldwide general population accept. However, the general population of the United States thinks differently. In fact, Turkey is the only developed nation that doubts evolution more than the U.S. (Branch and Scott, 2008)

Ultimately, the “controversy” isn’t about science at all, but about religion and politics. Kenneth Miller, a molecular biologist at Brown University, says, “Public acceptance of evolution – or any other scientific idea – doesn't turn on the logical weight of carefully considered scientific issues. It hinges instead on the *complete* effect that acceptance of an idea, a world view, a scientific principle, has on their own lives and *their* view of life itself." (1999) And so because of a perceived threat to their worldview, millions of Americans buy into non-scientific explanations for scientific phenomenon, explanations such as creationism and intelligent design, both of which claim supernatural rationalizations for natural events.

This battle between evolution and non-scientific explanations for the origin of species has played out in courtrooms across the country for almost a century. The most famous of these cases in 1925, the Scopes Monkey Trial, found a first year science teacher guilty of teaching evolution in his high school biology classes. In teaching evolution, John Scopes had broken the Tennessee Butler Act, which had banned the teaching of evolution in all public schools (Hanson, 2000). The debate within the courtroom raged on, as similar trials were held. However, in 1968 the U.S. Supreme Court ruled that any state law that forbade the teaching of evolution was unconstitutional (Braun, 2005). Creationists were responsible for the passing of these state laws, which were now forbidden, so they needed to take a different approach. Rather than trying to ban the teaching of evolution, they proposed that creationism was a "scientifically credible alternative," thus calling it "creation science" and "scientific creationism." The early 1980s saw legislation introduced in 27 different states that wanted equal time within science classrooms devoted to the teaching of evolution and "creation science." The state of Louisiana passed a law, requiring that if teachers taught evolution, they also had to teach "creation science." This law was later overturned by the U.S. Supreme Court on the grounds that it violated the separation of church and state (Branch and Scott, 2009). Again, a different approach was needed to fight the intense battle against evolution. It was at this point, in the late 1980s that the term "intelligent design" was first introduced. The idea behind intelligent design was to reduce the religious undertones inherent in creationism, and present itself as a viable scientific alternative to evolution. Intelligent design supporters claim that as long as they don't identify the designer as God, there is no violation between church and state, thus making intelligent design suitable for public schools. A 2005 court ruling said otherwise. In the case of Kitzmiller vs. Dover Area School District, Judge John E. Jones III ruled that intelligent design is not science, and therefore does not belong in the science classroom (Bathija, 2011).

Despite all that has been said and done, the debate goes on. Failure to get their views supported as practical scientific alternatives has not stopped creationist and intelligent design supporters. At this point in time, their main objective is to cast doubt in the public sphere about the legitimacy of evolution itself. Antievolutionists, such as Philip E. Johnson, a professor of law at the University of California at Berkeley, openly admit, in the now famous *Wedge Document*, that their hope in presenting intelligent design theories is to have discussions of God within science classrooms (Rennie, 2002). To this end, entire organizations, such as the Discovery Institute and the Creation Studies Institute, have been formed to cast dispersion over evolution, making the general American public doubt the legitimacy of this scientific fact. Take for example, the booklet *Darwin Under the Microscope* (2008), which is filled with inaccurate, unjustified "scientific" claims. Or the movie *Expelled: No Intelligence Allowed* (2008), which presents a conspiracy theory that involves the scientific community persecuting scientists for their views on evolution and

God. The propaganda now being presented by creationists does nothing but confuse Americans about where they stand in this ongoing "controversy," which is exactly what creationists are hoping it will do.

Studies have shown that people's thoughts about scientific ideas in general are related to three factors: education, religion, and political views. A 2006 survey indicated that half of those polled did not agree with the "Big Bang" origin of the universe. The majority of this same group of people also did not agree with human evolution. The number one predictor of both disbeliefs was religious fundamentalism, followed by low education, and political conservatism. However, interestingly enough, only 10 percent of Americans doubt the current scientific understanding of plate tectonics, even though it requires millions of years for continental drift to occur (Mazur, 2010). So, why the difference in views between evolution and plate tectonics, even though both go against a literal interpretation of the Bible? Could the answer be as simple as one involves humans and the other does not? There is something about the human component to evolution that makes some Americans uneasy. They don't like the idea that humans are just one of the billions of different types of species of organisms on Earth, and we got here the same way that everything else did. Continents moving around the Earth are fine, but humans changing over time are not.

As the "controversy" surrounding evolution is played out, there are two very different things that each field is fighting for. Scientists and educators care about science education and protecting the validity of science. However, creationists care about winning an ideological war over the theological implications of accepting evolution (Braun, 2005). This is exactly why the debate itself is unnecessary. Both fields (science and theology) answer totally different questions about the world that we live in. The National Academy of Sciences clearly states that there need not be any tension between science and religion. They state, "At the root of the apparent conflict between some religions and evolution is a misunderstanding of the critical difference between religious and scientific ways of knowing. Religions and science answer different questions about the world. Whether there is a purpose to the universe or a purpose for human existence are not questions for science. Religious and scientific ways of knowing have played, and will continue to play significant roles in human history." (Miller, 1999) As humans search for purpose in the universe and within their lives, any field of study that claims the meaninglessness of human life will be taken as a threat to this basic human need. Evolution has been set up in this way by both antievolutionists and atheists. However, the question of meaning and purpose is not one that science can even begin to address because science has limits. Francis Collins, the head of the Human Genome Project, says, "The scientific and spiritual worldviews both have much to offer. Both provide differing but complementary ways of answering the greatest of the world's questions, and both can coexist happily within the mind of an intellectually inquisitive person living in the twenty-first century." (2006)

So while the evolution / religion debate rages on, its implications are seen almost solely within the classroom. An informal survey given in March of 2005 to members of the National Science Teachers Association showed the pressures that teachers face because of this controversy. Of the people interviewed, 31 percent said they felt pressure to include non-scientific alternatives to evolution in their classroom. Another 30 percent said that they experienced pressure to skip over or downplay evolution in their classroom instruction (Branch and Scott, 2008). And according to professor Steven Jakobi, "The end result of these obstacles to good science education is that students are confused and are left with some murky concepts of dinosaurs and ice ages that they acquired from watching Disney movies." (2010) Uninformed and confused students can become uninformed and confused adults. This is exactly the predicament that we as Americans find ourselves in today.

In the past, Lakeshore High School biology teachers (myself included) have glossed over the main ideas of evolution. We live in a conservative small town in West Michigan, and in order to avoid controversy and difficult conversations with students and parents, we completely ignored human evolution and spent very little time on the concepts of natural selection and descent with modification. It is for this reason that I chose the topic of evolution on which to focus my research efforts.

THEORETICAL FRAMEWORK

American high school seniors are the third worst industrialized nation regarding both science and math scores (Fisher, 1998). In a global economy, where students no longer only compete for jobs among fellow Americans, but among citizens of every nation, how will our students be able to keep up? According to President Barack Obama, "Our success as a nation depends on strengthening America's role as the world's engine of discovery and innovation… lending resources, expertise, and enthusiasm to the task of strengthening America's leadership in the 21st century by improving education in science, technology, engineering and math." (Presidential Executive Office, 2010) With a growing population that has little knowledge of important scientific issues such as nuclear proliferation, climate change, loss of biodiversity, human cloning, stem cell research, and more, how can America possibly expect to remain a world-class leader of scientific discoveries? Maybe the answer lies in how we educate our students. A fourth grade student says, "See, in class we learn what all these scientific things mean and I get that I have to know what those things mean. But I don't always get *why* I have to know what they mean, you know?" (Diamond, 2005) Science within the classroom needs to be relevant and engaging. It is not surprising that the number of American students going into scientific fields is decreasing. It is related to educators failing to connect scientific concepts with daily life (Eisen and Westmoreland, 2009). And in a fast-paced, high tech world, it is getting tougher and tougher to keep students engaged with traditional lecture-style teaching methods.

Students learn most when they are actively engaged, are participating in groups, have interaction with and feedback from the teacher, and are able to connect what they are learning to everyday events (Williams, 2009). This is important when teaching any scientific topic, but is absolutely vital when approaching a "controversial" topic, such as evolution. Studies show that opposition to evolutionary concepts begins in childhood, and through their formative years, children compile a mountain of misconceptions regarding this topic (Branch and Scott, 2008). So, the approach that educators use to teach kids evolutionary biology is just as important, if not more important, than what they are taught. If not approached in an engaging way that is applicable to everyday life, we will do nothing more than perpetuate the stigma surrounding evolution.

The overall goal in teaching evolution to high school students is to allow them to analyze the evidence for themselves and then evaluate its significance. Science educators are not necessarily out to teach students what evolution is, but more so to allow them to explore how evolution occurs and why that matters (Gaspar, 2008). And any scientist will tell you that the reason why it matters is because evolution is the center of all of the biological sciences. According to Kenneth Miller, "Evolution remains the focal point, the organizing principle, the logical center of every discipline in biology today." (1999) Teaching biology without evolution leads to students memorizing lots of disconnected facts about organisms and life itself, with nothing connecting all of these seemingly random facts together. It is no wonder that students are unable to see the significance of biology in the everyday world when there is no big picture being presented unifying all of life. Evolution is that unifying process. Arthur Landy, a molecular and cell biologist and biochemist at Brown University says, "Without evolution, modern biology, including medicine and biotechnology, wouldn't make sense." (Branch and Scott, 2009) And Harvard evolutionary biologist Stephen Palumbi states, "HIV is one of the world's most aggressively evolving organisms. If it weren't for the virus's adaptability, which helps it foil the body's defenses and many drugs, we would have kicked HIV in the teeth 15 years ago. But doctors don't learn about evolution in medical school, leaving them about as well prepared to combat HIV as a flat-Earth astronomer would be to plan a moon shot. Somewhere in high school in this country is a student who's going to cure AIDS. That student is going to have to understand evolution." (Hayden, 2002) How's that for a real world application?

In general, most states realize the importance of teaching evolution and have therefore included this is in their state content standards. Michigan is no exception. There is an entire section (B5) in the State of Michigan benchmarks (Appendix A1) that covers evolution and biodiversity (High School Science Content Expectations / Biology, 2006). However, studies have shown that the evolution standards of many states are not up to par. More than a third of all the states in the U.S. do a less than satisfactory job covering evolutionary principles in their standards (Lerner, 2000). The main reason for this is pressure from school board members, legislatures, and the general population, all of whom have little knowledge of what should be included in a scientific curriculum. Research has found that different states respond in different ways to shaping their curricula around these anti-evolution pressures. One common shortcoming is that states will include evolutionary principles in their standards, but will completely avoid using the word evolution. Other deficiencies include eliminating any references to the billions of years it took for the Earth to form, completely ignoring human evolution, or requiring textbooks to carry a disclaimer on the "controversial" nature of evolution. And even among states that have satisfactory evolution standards, 65 percent of them either gloss over or don't cover human evolution at all, Michigan included (Lerner, 2000).

Despite the efforts, or lack thereof, of individual states to come up with a solid biology curriculum that centers on the teaching of evolution, research indicates that it is not state standards that truly influence what is taught in the classroom. The real indicator of how and what will be taught regarding evolution is the teacher. The amount of knowledge and excitement a teacher brings to the material directly impacts student learning and achievement (Sparks, 2010).

State standards, court decisions, and textbooks can only do so much for advancing the teaching, or non-teaching, of evolution. It is teachers who are on the front lines, and who ultimately make decisions about what topics will be covered, how they will be covered, and with what detail they will be covered. And according to Michael Berkman and his collegues, all professors of political science at Penn State University, "There are many reasons to believe that scientists are winning in the courts, but losing in the classroom." (Berkman, Pacheco, and Plutzer, 2008) The teaching of evolution across the country is inconsistent to say the least. A poll conducted in 2007 asked a sample of public high school biology teachers about their personal views on evolution, how much classroom time they devoted to the teaching of evolution, and what particular aspects of evolution they most focused on. The results varied widely; however, there was a correlation between those teachers who viewed evolution as a central organizing principle of biology and those who spent the most time teaching evolution. The average amount of time spent covering evolution was 13.7 hours, but 36 percent of the teachers surveyed spent only between zero to five hours teaching evolution in general, and a whopping 77 percent spent only that same amount of time covering human evolution. Thirteen percent of the teachers surveyed agreed with the statement that, "an excellent biology course could exist without mentioning Darwin or evolutionary theory at all." (Berkman, Pacheco, and Plutzer, 2008) This same group of teachers was asked their views on intelligent design and creationism, and whether or not they address it in their classrooms. Twenty-five percent said that they do cover intelligent design and creationist principles in some form, and of that twenty-five percent, nearly half agreed that they teach it as a "valid scientific alternative to Darwinian explanations for the origin of species." Nearly just as many teachers said that when they teach intelligent design and creationist ideas they stress that "many reputable scientists view these as valid alternatives to Darwinian Theory." (Berkman, Pacheco, and Plutzer, 2008)

All of this begs the question, "What is the cause of all of the inconsistency among teachers throughout the United States?" Research shows that it has nothing to do with state standards and everything to do with teachers' personal beliefs and college science education (Berkman, Pacheco, and Plutzer, 2008). Amidst all of the controversy, pressure, court battles, misconceptions, and ignorance of the general population, teachers seem to be no exception. Without a better trained, more informed, more prepared population of biology teachers, it won't matter how many court cases are won for evolution. Teachers are an important factor in what children will, or will not, learn within our classrooms. Studies show that how prepared teachers are when going into the field, and the quality of their continued professional development can make a significant difference in math and science learning, including approaches to teaching evolution (Fisher, 1998). Most teachers admit that they do not have a plan for how they should teach, or even what they should teach, regarding evolution. State standards provide an outline of the outcomes that must be reached, but how to get to those outcomes is not specified. For experienced, trained teachers with knowledge of evolutionary concepts this is not a problem. However, most teachers don't fall into this category. One study showed "widespread concerns among high school biology teachers that centered on their need for more information about how to teach evolution." (Oliver, 2011) Because the reality is that when teachers have inadequate knowledge, use sloppy language, and can't articulate what it is they are teaching, and more importantly, why they are teaching it, it is kids who suffer.

Perhaps the starting point for the teaching of evolution is to simply acknowledge the "controversy." I am not claiming that we should "teach the controversy" as anti-evolutionists desire, but just acknowledge its existence, and then work to flush out the reasons why it exists. This specifically includes informing students that this is not a scientifically made controversy. There is no controversy among scientists about core concepts in any scientific field, and students need to be let in on this insight. Many of the reasons why kids fear the topic of evolution deal with inaccuracies, misinformation, and misconceptions that they have picked up on through the course of living in the "controversy." Ignoring the "controversy" does nothing more than make kids think that science has something to hide. Exposing the "controversy" and the misconceptions behind it allows students to get an accurate view of evolutionary biology.

The first misconception that must be addressed within the classroom is that, "evolution is just a theory." Evolution itself is a fact, and students need to be told this. There is no question that species change over time, and this is supported by ample amounts of evidence. The theory of natural selection is no less true than the fact of evolution. There are ample amounts of evidence supporting this as well. The confusion comes into play simply because the language of science differs from everyday language. In everyday language, the word theory often means the same as guess or speculation. Scientists use the word hypothesis to refer to a considered guess or speculation, not the word theory. The scientific definition of a theory, according to the U.S. National Academy of Science is, "a well-substantiated explanation of some aspect of the natural world that can incorporate facts, laws, inferences, and tested hypotheses." (Gregory, 2008) So when students hear that evolution, or even natural selection, is a theory, they automatically assume that means it is not backed by evidence. This couldn't be further from the truth, and expresses not only ignorance in regard to biological evolution, but also confusion about the nature of science itself. Whereas facts describe *what* the outcome of an event will be, theories explain *how* these events occur, and both are well founded and well supported with evidence.

Opponents of evolution claim not only that evolution is "just a theory," but also that it is a "theory in crisis." This is yet again another statement that is just not true, and pointing this out to students early on in their study of evolution can do much to advance the general nature of how the scientific community operates. The idea of a "theory in crisis" has arisen because of the reality that scientists regularly disagree with each other. That is the nature of science. It is part of the process, is extremely healthy, and is just the way that the field works (Thanukos, 2010). Non-scientists use the questions that scientists are asking about the process of natural selection as a way to raise doubt about the theory itself. These scientific questions include things such as, "Is evolution always gradual, or can it follow a more punctuated pattern? Are chance mechanisms such as genetic drift ever as important as the nonrandom process of natural selection? Did mammals diversify as a consequence of the extinction of dinosaurs?" (Gregory, 2008) The reason that scientists are asking these questions is because these are exactly the types of questions that a scientist would ask.

This is science at its best, and at no point in raising these questions are scientists implying that evolution through natural selection may no longer be a valid theory. Students will never understand this unless they are taught it.

It is not only what we are teaching students that is important, but also how we are teaching them. Students in today's classrooms are more disengaged than ever. David Zeigler says, "Curiosity can be a hard sell because, sadly, many of today's students seem to lack curiosity about the world and universe outside their personal spheres of relevance." (2009) So the task for teachers then, is to make the content that is being presented to students relevant to their everyday lives. Research shows that there is no better way to do this than with hands-on learning (MacLellan, 2010). Rather than just having students observe what is happening, they are able to actually engage in the process of science. By allowing students to look at the evidence for themselves and be able to manipulate it, teachers provide a setting where not only will students be more likely to comprehend the underlying evolutionary concepts, but also will hopefully be more open-minded to what they are discovering for themselves, namely that evolution is supported by evidence and there is really nothing "controversial" about it.

The curriculum that is presented to students needs to challenge them, allow them to actively explore the data, and reflect on what it is that they have explored. Especially in an area of study where students come in with all sorts of preconceived notions, active engagement is what allows them to modify and reconstruct their existing ideas (Oliver, 2011). Success in this area happens not only as students work individually, but also as they work in collaborative groups. Studies show that traditional methods of science instruction, such as lecture, do not work towards changing students' preconceived evolutionary ideas

(Williams, 2009). The way to change students' misconceptions is to identify the misconceptions for what they are, namely errors in thinking, and then present the material in such a way that students must critically analyze all of the evidence. It is these types of hands-on teaching methods that allow students the freedom to sort out their own personal beliefs from science, and to begin to look at scientific processes in a scientific way. It has been found that bringing about change in a student's understanding of evolution takes time (Oliver, 2011). By giving students the skills to scientifically problem solve, we provide a backdrop that will one day prove useful for them to be able to analyze any given situation. They will be able be able to look at scientific findings for what they are: evidence. They will ultimately know that they don't have to choose between faith and science, because science is not a belief system.

GOALS AND OBJECTIVES

As I began to teach this unit on evolutionary biology, the two overall goals that I had in mind were to present the material in a more in-depth manner than had been done in the past, and to spark student interest in the topic of evolution.

The objectives that I expected the students to be able to come away from this unit with included the following: 1) students should be able to summarize the major concepts of natural selection, including the role that environment, variation, and chance all play in this process; 2) students should be able to explain, using examples how the fossil record, embryonic stages, biochemistry, homologous structures, and other pieces of evidence support the theory of evolution by natural selection; and 3) students should be able to compare the DNA sequences of different species to determine kinship and common descent.

Practically, the way that I intended on accomplishing this was threefold. First, by incorporating almost all activity-based, hands-on learning, I expected that students would be more engaged, more involved, more connected to their everyday lives, and thus achieve a higher level of learning. Along with this, my plan was to lecture for less than 30 minutes per week. Secondly, in order to reflect on the students' learning process throughout the course of the unit, I intended to test their knowledge by using the student response clicker system twice a week. This would allow me to identify difficult concepts that needed to be revisited, and would allow students to reflect on what they had learned. Finally, to flush out the "controversy" surrounding the topic of evolution and to set straight misconceptions that kids came into the class with prior ideas of, students would keep a "misconceptions journal" in which we would identify each misconception, give a correct scientific explanation, and allow time for kids to write down their personal thoughts and feelings about each particular fallacy. The expectation was that this would help facilitate students beginning to think in a different, more scientific way.

DEMOGRAPHICS

Lakeshore Public Schools are located in Southwestern Michigan, along the shores of Lake Michigan. The communities of Stevensville and Baroda make up the school population, and there is an eclectic blend of many different professions in the area. Whirlpool / Maytag's World Headquarters are located in a nearby town, which attracts many professional families. We also have sections of industry and agriculture, amidst a mainly middle class population of families. The total population of the communities that flow into Lakeshore is 16,807, according to the 2000 U.S. Census (factfinder2.census.gov). Of this population, 49 percent are males and 51 percent are females. Seventy-four percent of the population is over 18 years of age. Within our community, 96 percent of the population is white, one percent is African American, two percent is Hispanic, one percent is Asian, along with trivial percentages of American Indians and Pacific Islanders. Twenty percent of the population in Stevensville and Baroda is near or under the poverty line of $22,350. Fifty-one percent of the population has an annual income ranging from $25,000 to $74,999, while the remaining 29 percent makes $75,000 or more per year.

Lakeshore Public Schools consist of three kindergarten through fifth grade buildings, one sixth through eighth grade middle school, and one high school. All five schools received an A on their Education YES report for 2010. There are currently 2908 students enrolled in Lakeshore Public Schools, and 909 of those students are at the high school. Within the high school population, 26 percent of the students are freshmen and sophomores, respectively, 25 percent are juniors, and 23 percent are seniors. Ninety percent of the student body is white, six percent is African American, three percent is Hispanic, one percent Asian, and 0.1 percent is American Indian and Pacific Islander, respectively. At the high school 24 percent of the students are on free and reduced lunch programs, 11 percent are enrolled in a gifted and talented program, seven percent are in special education, six percent are school of choice students, and one percent are homeless. This past year there were also five foreign exchange students at Lakeshore High School.

There were 122 students involved in this study, all of whom signed the *Parent Consent and Student Assent Form* (Appendix A2). This represented 13 percent of the entire school population. Of these students, 95 percent were freshmen and the other five percent were sophomores. Biology is a freshmen level course, but there are occasionally sophomores in the class either because they failed it as freshmen or because they moved into the district after their freshmen year. In this study, 89 percent of the students were white, three percent Hispanic, four percent African American, two percent Asian, and one percent Pacific Islander. This mirrors the overall school population quite well. Fifty percent of the students in the study were males, and fifty percent females. Three percent of the population in the study was made of up special education students who were either learning disabled or emotionally impaired, and two percent were foreign exchange students, from Thailand and China.

The study also involved four different teachers, all of whom were teaching freshmen level biology, and all of whom did the same activities and presented identical material. My classroom was the target classroom, while the other three teachers represented auxiliary classes. All of the anecdotal data presented was from the target classroom. Objective data was collected from all four classrooms and is presented separately for each.

IMPLEMENTATION

To begin the unit on evolution, students took the pre-survey and the pre-test on two different days. This took place in all four teachers' classrooms. As students were filling these out, many of the students in the target classroom asked questions along the lines of, "How am I supposed to know this?" Also, there were a lot of students in the target classroom who were afraid of giving the wrong answer, even though it was stressed for them to just try their best. A few students in my classroom asked for clarification on words they didn't know or questions that they didn't understand the wording of. Overall, most students in the target classroom were willing to do this and did their best. However there were several students who were defiant that they "hate learning about evolution," and that they "don't believe in it." After taking the pre-survey and pre-test, all students went on Spring Break. Upon return, the unit officially started. The table below diagrams what was presented on each day of the unit in all four classrooms.

Table 1: Summary of Each Day of Unit. All activities were new to the unit.

Day	Class Intro	Activity	Objectives Covered
1	Misconceptions Journal 1 & 2	Geologic Time Scale Activity	Geologic Time
2	Misconceptions Journal 3 & 4	Geologic Dating Online Activity	Geologic Time
3	Student Response System Review 1	Bead Bug Variation Activity	Variation, Adaptations & Natural Selection
4	Misconceptions Journal 5 & 6	Lecture & Finish Bead Bugs	Variation, Adaptations & Natural Selection

Table 1 Continued

5	Student Response System Review 2	Adaptations & Ecology Game	Variation, Adaptations & Natural Selection
6	Misconceptions Journal 7 & 8	Lecture & Concept of Natural Selection	Variation, Adaptations & Natural Selection
7	Misconceptions Journal 9 & 10	Speciation Story & Mutation Rate Online Lab	Mutations & Speciation
8	Student Response System Review 3	When Milk Makes You Sick Activity	Mutations
9	Limiting Factors Evolution Game	Homologous & Analogous Structures Online Activity	Evidence
10	Student Response System Review 4	Embryology Activity	Evidence
11	Misconceptions Journal 11 & 12	Lecture & Caminalcules Activity	Evidence & Phylogenies
12	Finish Caminalcules	PBS Video: "Great Transformations"	Evidence
13	Student Response System Review 5	Wolf Pack in a Bottle Activity	Evidence
14	Misconceptions Journal 13 & 14	Investigating Common Descent Activity	Evidence
15	Hands of Primates Activity	Phylogenies Based on DNA Sequences	Phylogenies & Mutations
16	Misconceptions Jour. 15, 16, & 17	Molecular Seq. & Primate Evolution Activity	Evidence
17	Student Response System Review 6	Need for Vitamin C Activity	Evidence

Table 1 Continued

18	None	Website Project	Summary of Everything Learned
19	None	Website Project	Summary of Everything Learned
20	None	Website Project	Summary of Everything Learned
21	None	Website Project	Summary of Everything Learned
22	None	Website Project	Summary of Everything Learned
23	None	Website Presentations	Summary of Everything Learned
24	Post-Survey	Student Response System Review Overall	Summary of Everything Learned
25	None	Post-Test	Summary of Everything Learned

REVIEW OF ACTIVITIES

All four classroom teachers presented the same activities over the course of the unit. The target classroom collected both subjective and objective data, and all anecdotal observations refer to only this class. The three auxiliary classes collected only objective data, and are thus only referred to when comparing pre and post scores of the t-tests.

Geologic Time – The unit began with the geologic timescale of the Earth, and there were two activities planned for this. The first was the *Geologic Time Scale Activity* (Appendix B1). This activity used two different models to give students an idea of just how old the Earth is. Timescale tends to be a tough topic simply because it is incredibly difficult, if not impossible, to envision just how big a million or a billion is. Students were given a visual example using sprinkles on how big a million actually is. They were then told that to represent the age of the Earth they would need 4,600 jars of sprinkles, each individual sprinkle representing one year. For most kids a light bulb went on at this point, as they began to appreciate that the Earth is very old. The other model that we used in this activity was a roll of receipt tape that was 46 feet long and marked out with the different geologic eras and periods. From this, students were able to better understand that the Earth is old, that it took a long time for organisms to evolve to their present forms, and that the Earth hasn't always looked like it does today. The second activity that was done to cover timescale was the *Geologic Dating Online* activity (Appendix B2). This activity used the University of Berkeley's tutorial on geologic timescale (*http://www.ucmp.berkeley.edu/education/ explorations/tours/geotime/gtpage1.html*) to reinforce what students had learned the previous day. They were also introduced to the concepts of relative and absolute dating, and learned how scientist date fossils. Students spent the entire class period on their computers. They were silent and completely engaged in what they were learning. At the end of the class period, students were asked to take home a sheet to read and answer questions on what evolution is and what it is not (Appendix B3). Students who read the attached materials did very well on this activity, based on the answers to the questions that they turned in. Students who answered the questions just using their preconceived notions did not do as well.

Variations, Adaptations & Natural Selection – The concept of variation was built into many of the activities that were done, but was first introduced with the *Variation in Bead Bug Populations* activity (Appendix B4). Students worked in pairs and gathered data on which populations of "bugs" survived and reproduced and which did not. They did this for two different environments. Some students understood right away that just because a certain color was favorable in one environment did not necessarily mean that it would help in the new environment. Other students needed to collect and analyze their data before realizing this. The Lakeshore High School science department has identified that one area of weakness in our students is in their ability to graph and interpret data. For this reason, several of the activities that were done involved kids collecting, graphing, and analyzing data. This was one of those activities, where students graphed each population of bugs over several generations. They graphed each environment on separate graphs, and then were able to compare their graphs to see how different variations helped in different environments. Kids had a lot of fun with this activity and in the end seemed to understand the overall concept of variation and adaptation, based on the daily homework assignments that they completed.

The first lecture of the unit focused on variation and natural selection, but time was also spent time discussing the nature of science, specifically the difference between a scientific fact and a scientific theory. Most students did not understand this right away because it contradicts everything that they know to be true about the word theory. This was a concept that continued to be stressed through journal questions and general conversations throughout the entire unit. Students seemed to be disengaged for most of the note taking process. This session of note taking took twenty minutes to complete, staying under the target time of 30 minutes.

The next day, another activity that dealt with variation, adaptations, and the role that the environment plays in this process was done. This was the *Adaptations & Ecology Game* (Appendix B5), and was a large group activity, with students also working in smaller groups as well. Each student was assigned a role in the environment when they walked into the classroom. They either started as an adult or an offspring and there were five different species of organisms that they could possibly be. Five different nesting sites were set up around the room and students were instructed to go to the appropriate place (bears with bears, mice with mice, etc.). There were also several different feeding stations set up around the room. Each species was given a specific tool with which they were to collect food. Students quickly found that certain tools were better adapted for certain types of food. The game itself was crazy and fun! Kids were running around the room having a great time. They were competitive and really got into playing. After each round, they did a great job within their small group of collecting data. After completing four total rounds, students shared their data of how many offspring survived with the large group, and had a good class discussion about adaptations. Students were then expected to analyze their data and summarize their experiences of what they had learned during the game.

The final activity that was done to cover the objectives of variation, mutation, and natural selection was a set of questions on *The Concept of Natural Selection* (Appendix B6). These questions were very difficult for students, and most did not do well on them, based on their answers after they had turned them in. Another shortcoming that the LHS science department has realized is that students do not see enough ACT type questions before their junior year. Because of this, we have built into each unit, a set of related (or sometimes unrelated) ACT prep questions. The questions on *The Concept of Natural Selection* filled this role in this unit.

Mutations & Speciation – The second lecture of the unit took 25 minutes to get through. It focused mainly on mutation, speciation, and phylogenies. These were new concepts for most students, as no related activities had yet been completed. Again, students were not very engaged, but listened, took notes, and asked a few questions.

Students were given a hypothetical story related to speciation to read and answer questions about. Through this *Speciation Story* (Appendix B7), students were able to distinguish the difference between when evolution has occurred and when speciation has occurred. Most kids were able to do so with no problem, as based off of their daily homework.

In order to get a deeper look at the role of mutation, students worked on the *Online Mutation Rate Lab* (Appendix B8). In this activity, they were asked to change the mutation rate several different times for a hypothetical organism over the course of 250 generations. They collected data, and then looked to see how the rate of mutation impacted the evolution of the population. They were then asked to graph and analyze their data. Students were engaged in this activity, as they usually are when they get to work on computers. Several students struggled to interpret their data, but I met with them one-on-one and talked through their areas of confusion.

After several days of covering variations and their causes (mutations), the activity *When Milk Makes You Sick* (Appendix B9) was done. This served as a transitional activity between the ideas of mutation and variation, and how these are used to show common ancestry between organisms. The *When Milk Makes You Sick* activity focused on the concept of lactose intolerance, and how the mutated form of this gene (for lactose tolerance) has been passed down from parents to offspring. It provided a great opportunity for students to recall their prior knowledge of genetics, specifically with making and analyzing a pedigree and the roles of dominant and recessive heredity. Students graphed various sets of data on population statistics regarding lactose intolerance, and then used their graphs to attempt to explain why the data are the way that they are. Kids were very interested in the topic of lactose intolerance, which kept them engaged as they worked through the data, searching for explanations. This activity then set them up for several other activities that would come later, dealing with DNA and amino acid comparisons.

Students played the *Limiting Factors Evolution Game* (Appendix B10) to summarize all that they had learned about variation, natural selection, the role of mutation, and the environment. This was a board game that gave students different scenarios in which they either evolved or didn't due to different selection pressures. The game was really fun for kids and they spent more time on it than was originally anticipated. They had great participation within their groups of four, and everyone was engaged with every step of the game. They then answered some specific questions about their particular game piece (organism) and about evolution in general. This helped to solidify all of the previous concepts that they had been learning.

<u>Evidence & Phylogenies</u> – The remainder of the activities all dealt with different types of evidence for evolution, and how to organize that evidence into a phylogeny. Students started by learning about different types of anatomical structures. The online activity dealing with *Homologous & Analogous Structures* (Appendix B11) was another tutorial from the University of Berkley's website (*http://evolution.berkeley.edu/evolibrary/article/similarity_hs_01*). This activity helped explain the differences between homologous and analogous structures, and let the students look at and manipulate evidence to come up with conclusions for themselves. They were given visual representations of each type of structure, and then asked to critically analyze how or why different species share common parts. Students learned these overall concepts quickly and easily, based off of their daily assignment, and enjoyed working through the tutorial.

The next activity was *Embryo Comparisons* (Appendix B12). Students were given the task of placing random pictures of embryos under the proper organism and in the proper stage of development. Other than the final stage, this was very difficult for students to do, especially when organisms were closely related. This helped to reinforce to them why scientists use embryology as evidence for evolution. Students were able to take this evidence and attempt to sort it out for themselves. They soon realized that the closer that two organisms were related, the more similar their embryos look during the early (and sometimes even later) stages of development.

Week three of the unit started with a lecture on the evidence for evolution. The lecture took just over twenty minutes to complete and focused on the concepts of fossils, comparative anatomy, embryology, and biochemistry. Points that had already been covered in previous activities were reinforced, such as embryology, mimicry, camouflage, and homologous and analogous structures. Some new information was also presented. Next, students worked on the activity *Creating Phylogenetic Tree Using Caminalcules* (Appendix B13). They began by identifying common traits between some of these fictitious organisms. They separated them into different categories based on these common traits, and then laid them out on a large piece of paper. Students asked a lot of questions about how to do this the right way, not wanting to be wrong, even though they were told that there were many ways that they could accomplish this task. After they had laid and glued down out all of the organisms, they connected them with lines, showing how each individual organism could have descended from the common ancestor. Students didn't understand right away that the length of the line represented the length of time to diverge, and they were also confused about not needing to directly connect every single organism to the common ancestor. After making their tree, they compared it to others in the classroom and answered questions not only regarding their tree, but other classmates' as well.

The following day we watched a PBS movie in their Evolution series, titled *Great Transformations*. This provided an opportunity for students to look at evolutionary concepts applied to real organisms, and also reinforced everything that had been presented up until this point. Students really enjoyed the movie, especially all of the detailed accounts of different animal species that were covered. The movie was stopped it at several points to discuss what was being presented, which also allowed time for students to ask questions.

The next piece of evidence that was presented was DNA comparisons. Several activities were done that stressed this concept, with the first being the *Wolf Pack in a Bottle* activity (Appendix B14). For this activity, five solutions of different colors and amounts of food coloring were set up. Each solution represented a DNA sample taken from a different species of canine. Students worked in pairs, and used chromatography paper and water to separate the solutions, simulating the process of DNA gel electrophoresis. They then measured and compared the bands of color, analyzing which species were the most closely related. Students had a lot of fun with this activity, and were amazed by the process of paper chromatography.

The *Investigating Common Descent* activity (Appendix B15) addressed DNA analysis and common kinship. In this activity, students began by comparing and contrasting characteristics of humans and apes. They were intrigued by the fact that humans did not evolve from monkeys, and were interested in learning more about this. Next, students worked in groups of four, stringing together paperclips to model strands of DNA from four different but related species. Each color paper clip represented a different nitrogenous base, so once all four strands were constructed, students were able to lay them out on their tables and count the similarities and differences in the DNA sequences of each organism. From this they were able to determine common descent and which species were the most closely related. The biggest thing that students learned from this activity, other than how scientists compare DNA strands, is that humans and chimpanzees share a common ancestor, from which each diverged.

As a follow up, students did an activity called *The Hands of Primates* (Appendix B16). In order to look at the adaptation of the opposable thumb, students worked in pairs and were asked to time themselves doing several everyday activities, like tying their shoes or sending a text message. They were then to tape their thumbs to their hands (so they were no longer opposable) and perform the same tasks, again timing to see how long each would take. This activity was incredibly fun and engaging for students, and after performing all of the tasks, they then looked at other structures (opposable toe or very long arms) from different species of primates to see how each had adapted to their environment and needs. *Creating Phylogenies Based on DNA Sequences* (Appendix B17) was a bit confusing for students, and I really had to walk them through it step by step. In the end, most of them understood what was happening. The activity started all together as a large group with a single sequence of DNA. The group split in half and based on randomly rolling a die and picking numbers and letters out of a bag, each group encountered different mutations in different locations of the DNA sequence. The groups split again and again, repeating this process each time. The end result was lots of different DNA sequences, representing how different species had diverged from the common ancestor. Students took this information and made a phylogeny based on these different DNA sequences. This was very difficult for them to do, and they needed a lot of help from each other and from me in problem solving this. One of the things that was readily apparent regarding phylogenies was that it was much easier for students to read and interpret a phylogeny than it was for them to make one on their own. They were quite capable of interpreting who diverged where and how species were related by looking at an already made phylogeny. However, they struggled with having to organize the evidence into a phylogenetic tree.

Students applied their knowledge of DNA comparisons to amino acid comparisons in the *Molecular Sequences & Primate Evolution* activity (Appendix B18). Students were given part of the amino acid sequence for hemoglobin in eight different organisms. They came to conclusions about which species were the most closely related based on this specific protein. They took that information and labeled a phylogeny with each organism and how long ago they diverged from the common ancestor. Finally, they were asked to graph the number of amino acid differences versus the amount of time it took to diverge, and then to analyze their graph. Once students understood how to read the chart of amino acid sequences and fill in their data table, this activity went smoothly.

Finally, as the last activity, students used their knowledge of both DNA and amino acid comparisons to do *The Need for Vitamin C* activity (Appendix B19). Students investigated why humans need vitamin C but certain other mammals do not by comparing the DNA sequences of several different mammals. They discovered a point where a base had been deleted in primates, but not in other mammals, and translated each DNA sequence into their respective amino acid sequences. From this, students were able to analyze the evidence to discover the specific amino acid that was missing from this protein.

ADDRESSING MISCONCEPTIONS

Most days of the unit began with students either writing in their *Misconceptions About Evolution Journals* (Appendix C1) or by using the student response clicker system to get feedback about student learning. The journal helped students dispel some of the incorrect and inconsistent ideas with which they entered the classroom. There were 17 total misconceptions addressed, ranging from the nature of science and scientific theories to the "controversy" between faith and science. Projected on the board was the scientific response to the misconception. Students were asked to summarize the scientific response in their own words. This was a difficult task for some students, as paraphrasing is a tough skill for some to master. They were then asked to write down their thoughts about the misconception and scientific rebuttal. The degree and length to which kids wrote depended on the particular student and also the particular misconception. However, for almost all students, their ideas and attitudes changed over the course of the unit. It was clear that previous misconceptions had been dispelled for some, and as time went on they felt more and more comfortable with evolutionary concepts as they began to realize that there is no need for the current "controversy."

A few students remained adamant in their stand against an evolutionary viewpoint. All of these students came from strict religious backgrounds, and most are part of religious denominations that do not agree with evolution. However, the point in this was never to try to convert kids' beliefs, it was simply to put the misconceptions out there alongside the truth, and allow kids to wrestle with the facts for themselves.

TRACKING STUDENT PROGRESS

On days when students were not writing in their misconceptions journals, class began with the student response clicker system (Appendices C2-C8) to track student learning and student progress. Kids really enjoyed this at first because it was fun to use, and they were given immediate feedback on what they knew and did not know. As time went on, students grew accustomed to it, and were not as gung-ho as when we first began. Students tended to try their best when doing this because they felt a sense of competition either with other students or just with themselves, of wanting to be successful and get the correct answer every time.

This was an incredibly helpful teaching tool for all instructors involved in the study because it immediately showed which concepts students understood and which needed to be revisited and reinforced. Some days students did very well, with class averages around 90 percent. Other days, they struggled with the concepts and the class averages were closer to 65 percent. However, even on those days were students did not score as well, the target classroom had a lot of good discussion about why certain answers were correct and why others were not.

By using the student response system on a regular basis throughout the unit, there was not as much of a need for an overall review of all of the concepts before the test. Even the concepts that were presented early on in the unit were still fresh in students' minds because they had been brought back up at different times throughout the course of these clicker reviews. Based on normal classroom observations, it appeared that students had learned and retained the material better than if they had just been memorizing it for a test. They also appeared to be more engaged, more interested, and more inquisitive about the material, wanting to know why certain concepts or phenomenon were the way that they were.

ASSESSMENTS

In order to assess student knowledge at the end of the unit, a post-survey (Appendix D1) and post-test (Appendix D3) were given. These two assessments were identical to the original pre-survey (Appendix D1) and pre-test (Appendix D3) that were given prior to the start of the unit. Data were gathered and collected from each of these assessments from all four teachers, and are shown in the results section.

Students were also asked to draw on everything that they had learned throughout the entire unit in a capstone project. This project consisted of them making a website documenting the evolution of a specific group of organisms, along with presenting evidence and information on evolution in general. Students were allowed to choose the group of related organisms that they wanted to study, for example bears, flowers, or odd-toed ungulates, and worked in groups of three to make their website. For some groups of students their organisms were related at the genus level, for other groups it was more broad and included organisms in the same family. Based on a rubric (Appendix D5), every group in all four classrooms passed this assignment. Students were given five days in class to work on this project, and then presented their work to the rest of the class. Most students enjoyed learning about their specific species and did a great job tracking how these species diverged, what structures they still share, the timeframe of when all of this happened, and much more. This was a much more subjective assessment than the post-test and post-survey, but was completed by all four classroom teachers. It served well to apply student learning to everyday life examples.

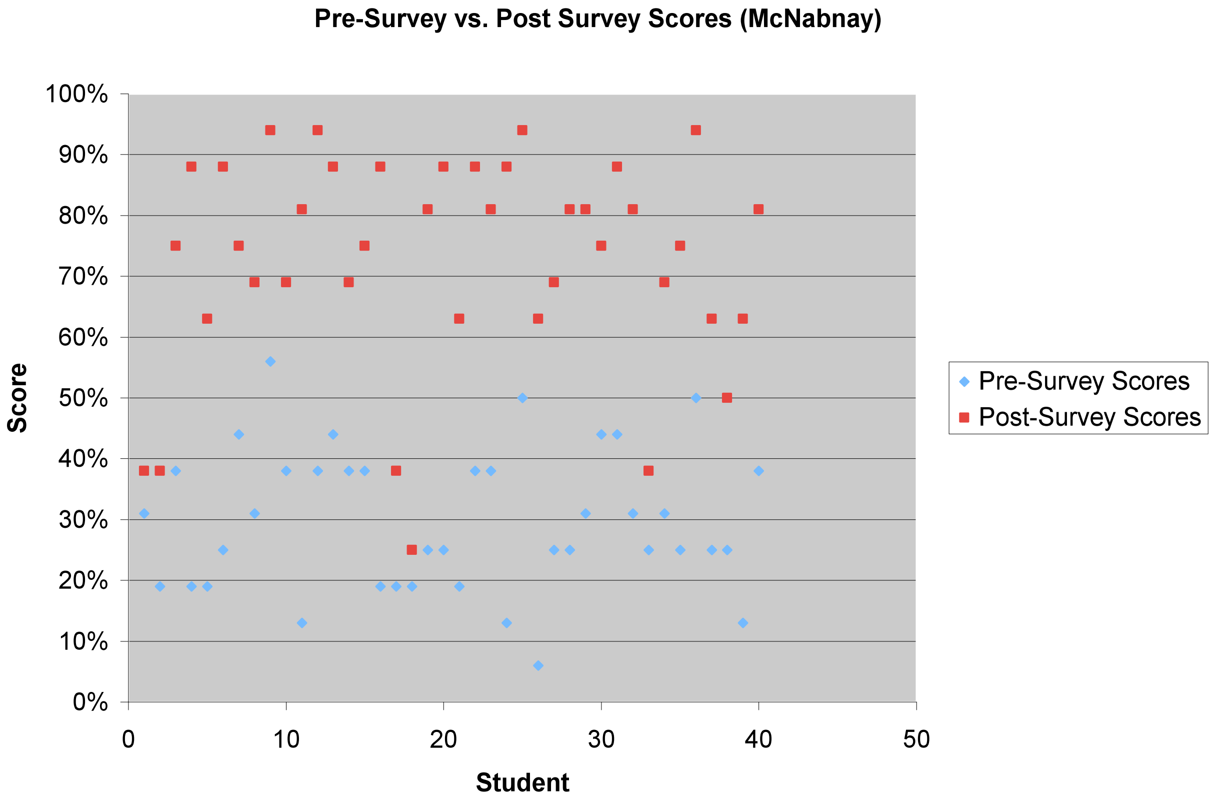
RESULTS AND ANALYSIS

Prior to the start of the unit, students were given a pre-survey and a pre-test complete. This provided a baseline of information showing what prior knowledge students had. To end the unit, students then took an identical post-survey and similar post-test. Their scores on each were analyzed, and a t-test analysis was done with $p = 0.05$. The survey targeted common misconceptions, such as what a scientific theory is and the nature of faith and science. The test addressed the material that the State of Michigan expects for students to learn in a high school biology class, along with some additional content. Most of the results for each assessment have been kept separate based on the teacher, so as not to compound too many variables.

Figures 1-4 show the overall comparisons of the pre-survey versus the post-survey for all students who had consented to participate in the study. As shown, all class averages improved from the pre-survey to the post-survey, and the majority of students improved individually as well. Surveys were graded based on a rubric that ranked answers as either scientific or non-scientific (Appendix D2). The more scientific answers that students gave, the higher the score they received. A scatter plot was chosen to represent the data to show individual improvement (in most cases) from the pre-survey to the post-survey.

Figure 1: McNabnay Pre-Survey versus Post-Survey Scores (n = 40)

Pre-Survey Class Average = 30% Post-Survey Class Average = 73%



(For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.)

Figure 1 shows that every individual student in the target classroom scored better on the post-survey than on the pre-survey. Some students did significantly better, such as student four, who earned 19 percent on the pre-survey and improved to 88 percent on the post-survey, or student 11 who went from 13 percent on the pre-survey to 81 percent on the post-survey. Other students only slightly improved, such as student one, whose score only went up by seven percent (Appendix D6).

Figure 2: Smith Pre-Survey versus Post-Survey Scores (n = 7)

Pre-Survey Class Average = 26% Post-Survey Class Average = 56%

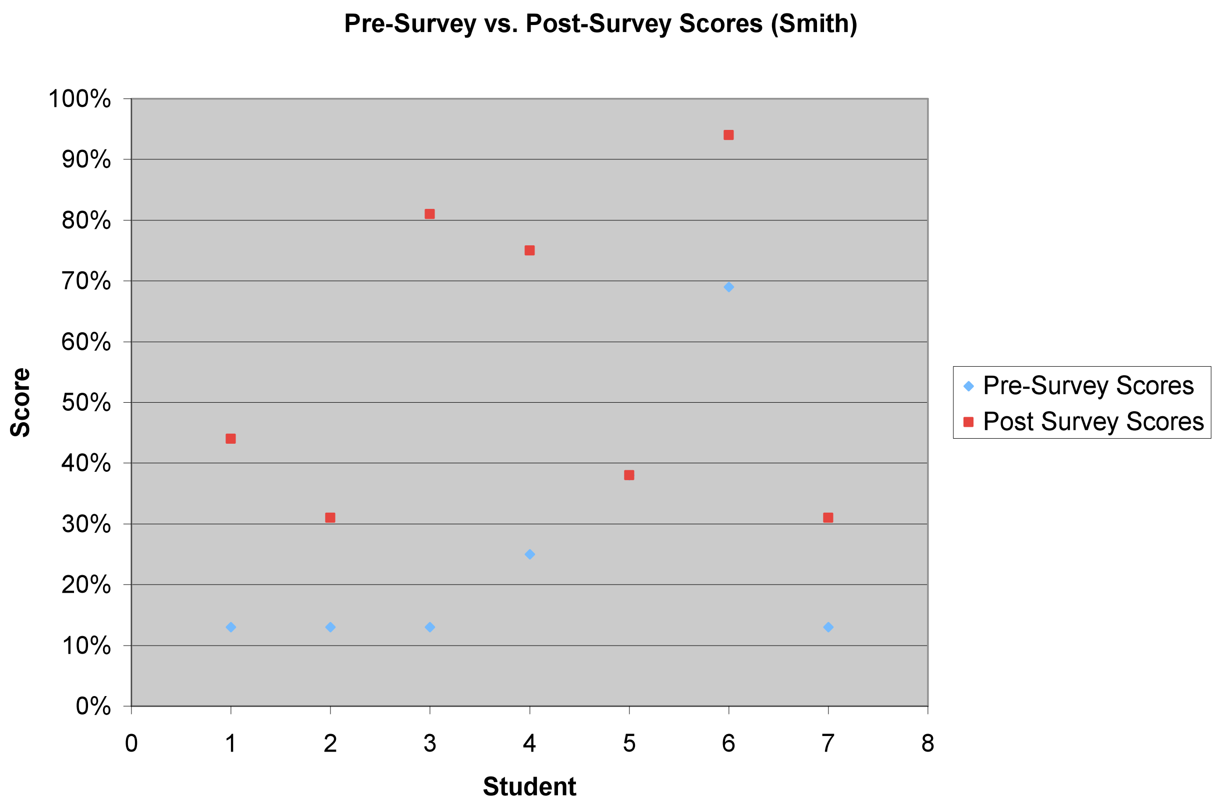
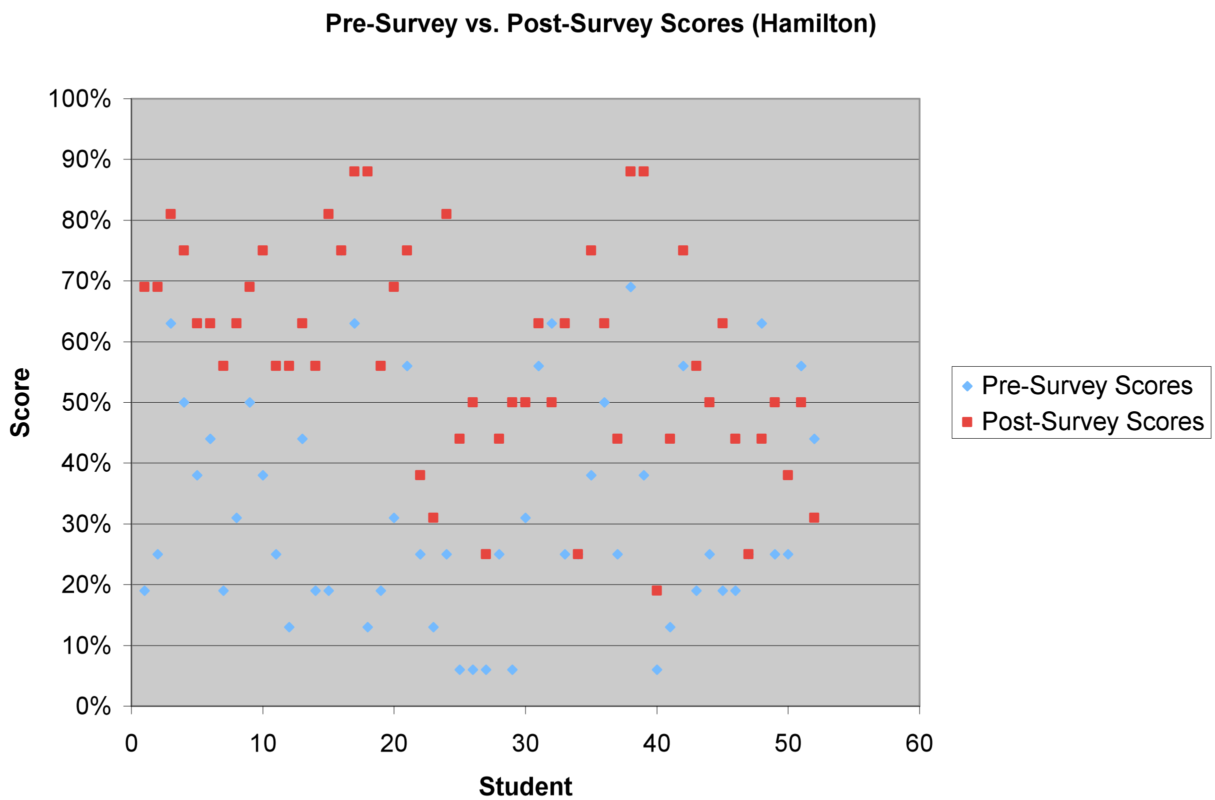


Figure 2 shows that all students in Smith's classroom scored higher on the post-survey than the pre-survey, except for student five, who scored 38 percent on both assessments (Appendix D7). Just like in the target classroom, some students did much better, improving their scores by up to 68 percent, others didn't improve quite as much.

Figure 3: Hamilton Pre-Survey versus Post-Survey Scores (n = 52)

Pre-Survey Class Average = 32% Post-Survey Class Average = 58%



Hamilton's classroom represented the largest population of students who consented to the study. Figure 3 shows that the majority of students improved from the pre-survey to the post-survey, however this is not the case for all students. Students 32, 48, 51, and 52 did worse on the post-survey, and students 16, 34, and 47 scored the same on both assessments (Appendix D8). Also, while some students improved they still did not show mastery over the material, such as student 40 who improved their score from six percent on the pre-survey to 19 percent on the post-survey. A large number of students in this classroom showed improvement, but still had scores on the post-survey below the 60 percent mark of passing.

Figure 4: Milletics Pre-Survey versus Post-Survey Scores (n = 23)

Pre-Survey Class Average = 32% Post-Survey Class Average = 51%

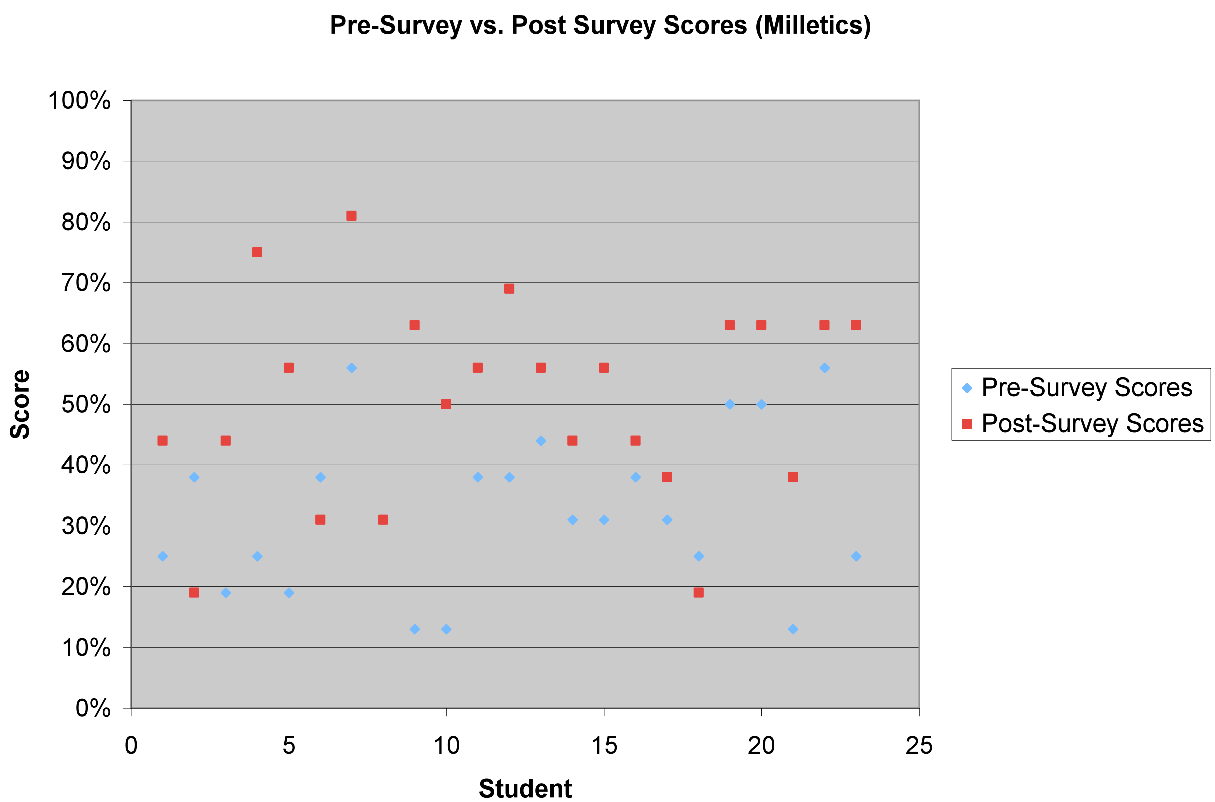


Figure 4 shows similar results to figure 3. While the majority of students scored better on the post-survey, three students scored worse and one did the same (Appendix D9). Also like figure 3, many students who showed improvement on the post-survey, still did not receive passing scores.

Figures 5-9 show how students scored on each individual survey question.

Figure 5: McNabnay Pre-Survey versus Post-Survey Individual Questions (n = 40)

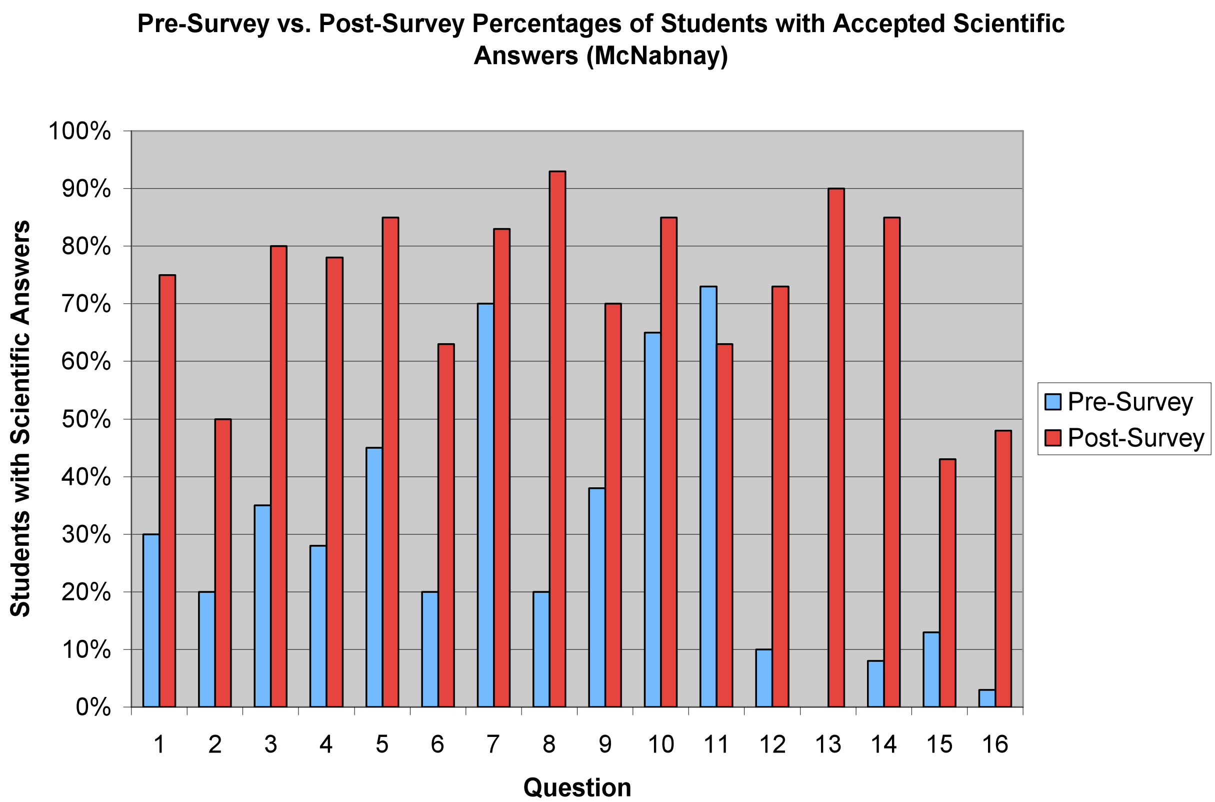


Figure 5 shows that students in the target classroom did better on every question from the pre-survey to the post-survey, with the exception of question 11.

Figure 6: Smith Pre-Survey versus Post-Survey Individual Questions (n = 7)

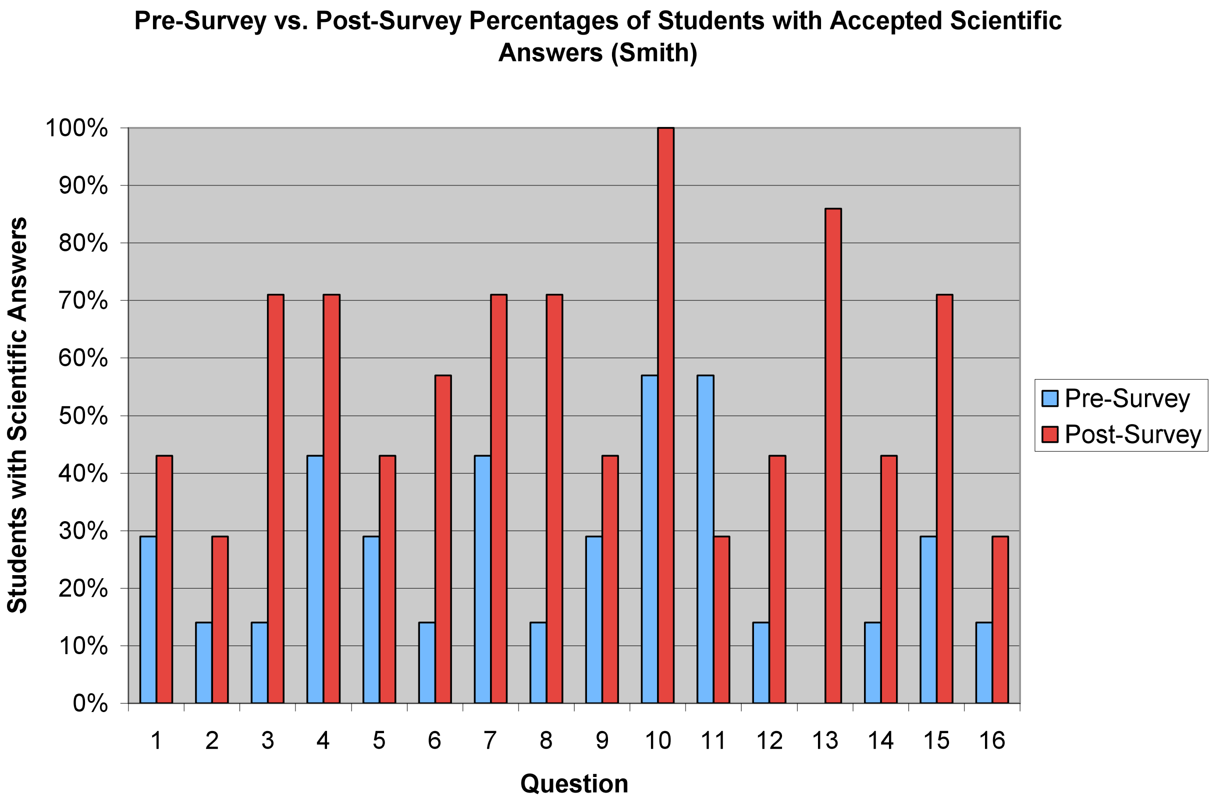


Figure 6 shows similar results to figure 5, with students improving on every question from the pre-survey to the post-survey, again with the exception of question 11.

Figure 7: Hamilton Pre-Survey versus Post-Survey Individual Questions (n = 52)

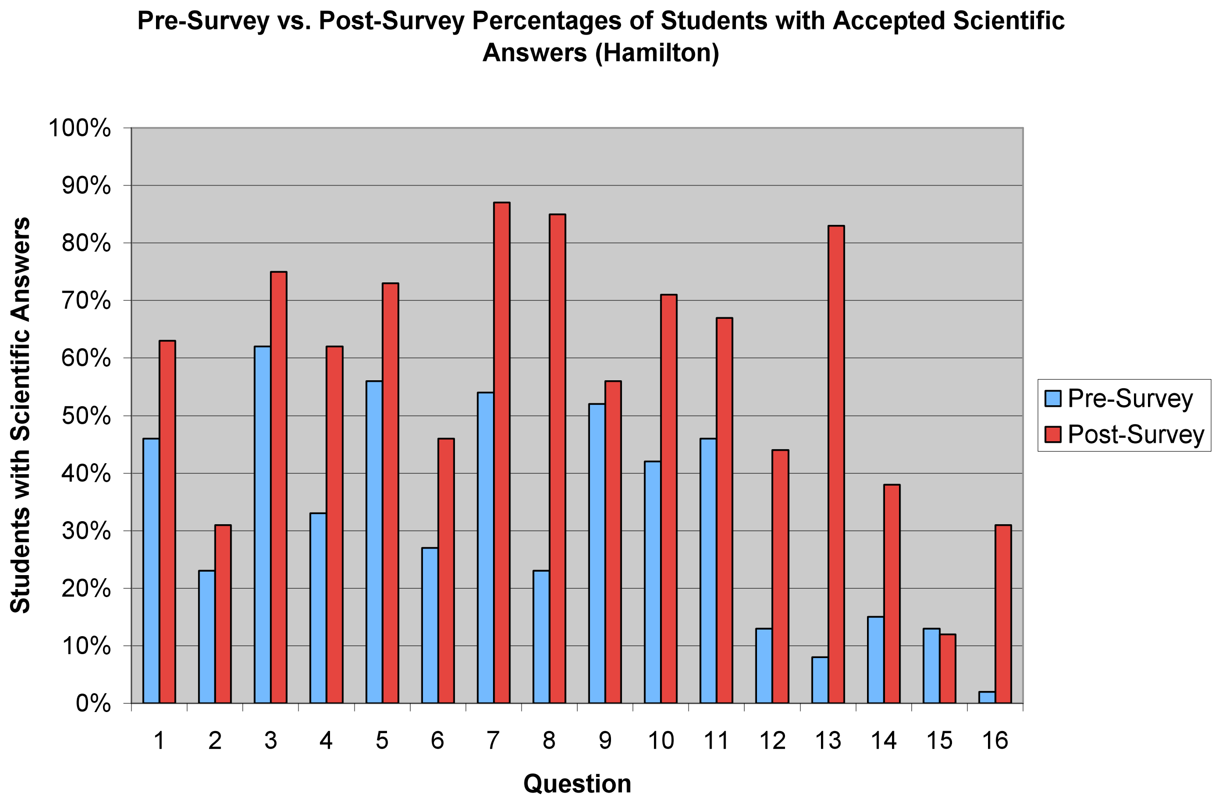
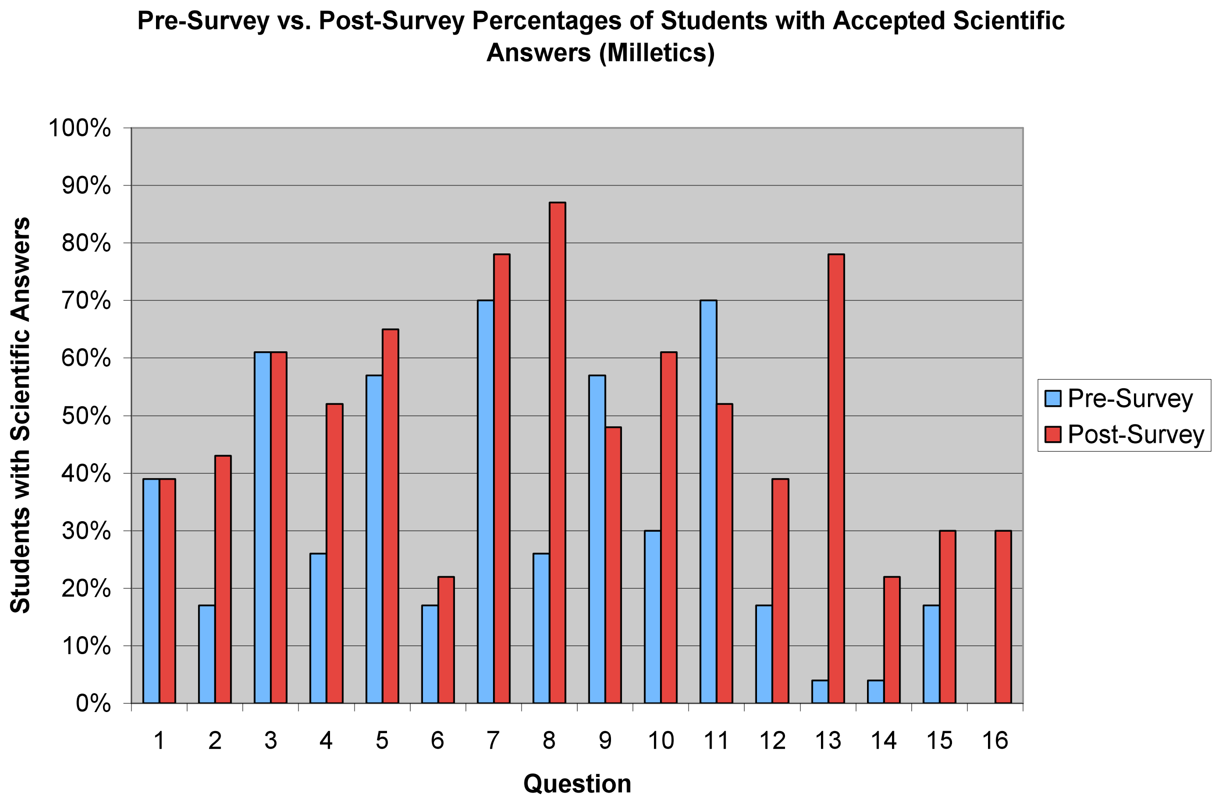


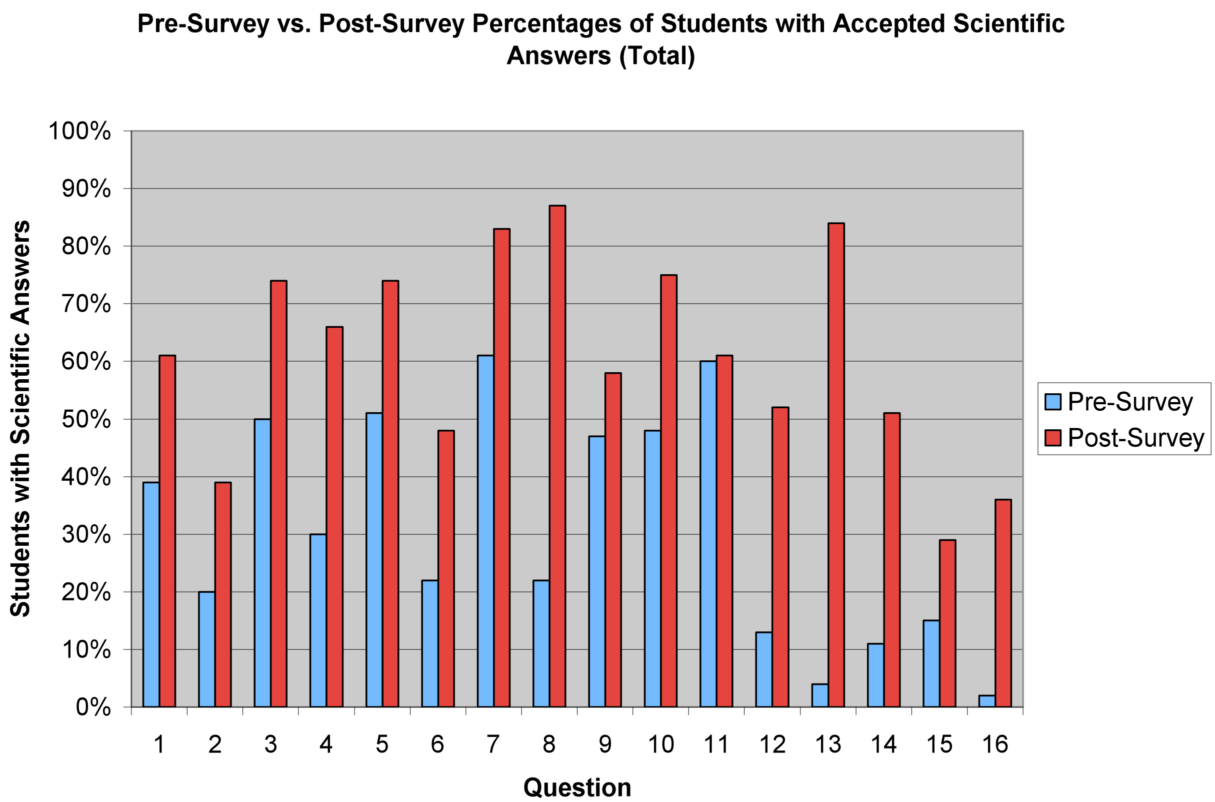
Figure 7 shows that students in Hamilton's classroom did better on every question from the pre-survey to the post-survey.

Figure 8: Milletics Pre-Survey versus Post-Survey Individual Questions (n = 23)



In Milletics' classroom, figure 8 shows that students scored the same on the pre-survey and post-survey for questions one and three. Like McNabnay and Smith's classrooms students scored worse on question 11. They improved on most other questions, with the exception being question 9.

Figure 9: Total for All Four Teachers Pre-Survey versus Post-Survey Individual Questions (n = 122)



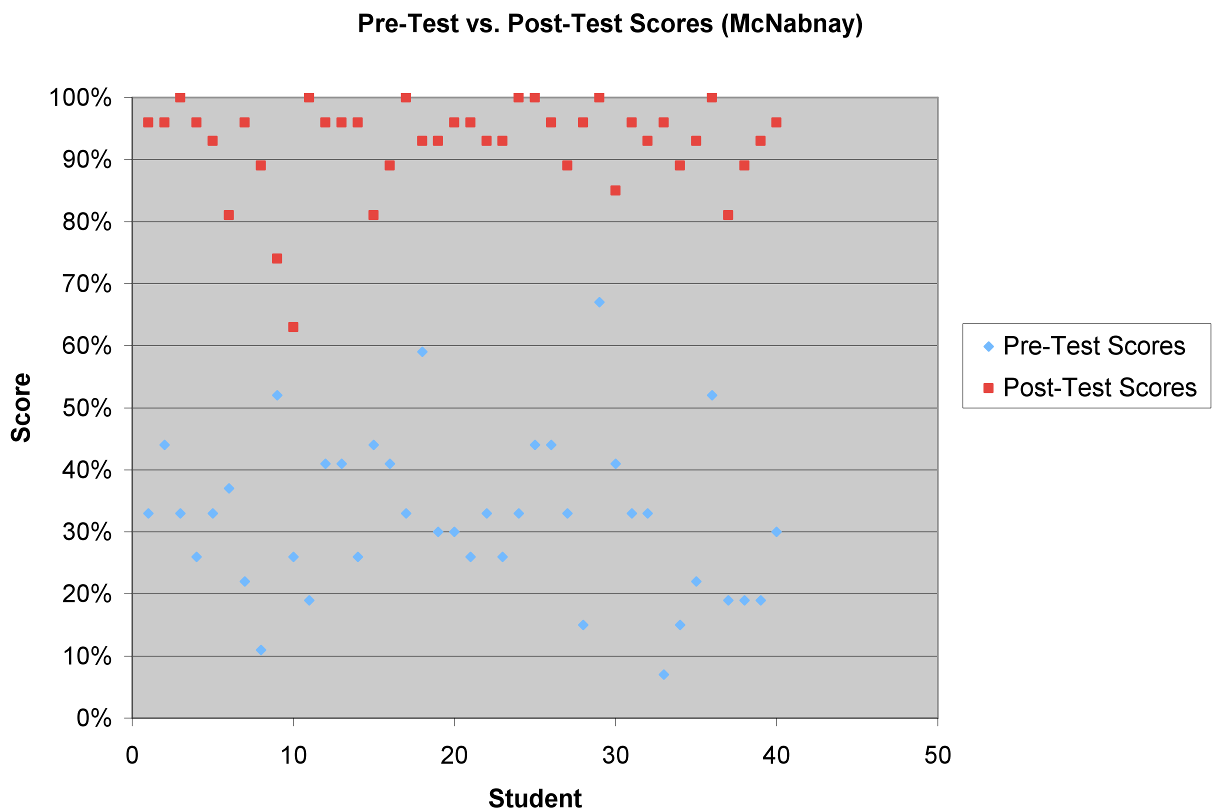
Figures 1-4 show that students did better overall on the post-survey than on the pre-survey. Figures 5-9 show this also to be true for each individual question as well, with the exception of question number 11 for all teachers except Hamilton. Question 11 asked for students to give a definition for the term evidence. On the pre-survey, many students received credit for this question by giving an answer that referred to "proof" or "proving truth." However, many students answered this question on the post-survey by giving examples of evidence for evolution, therefore not receiving credit for answering correctly. So, the drop in the number of students getting this correct from the pre-survey to the post-survey, most likely does not reflect a lapse in knowledge regarding this, but just confusion on how to best answer the question. The data also show that different teachers may stress certain concepts more than others, so one can see a few individual differences in how students in different classes responded on specific questions. Figure 9 shows that questions 15 and 16 showed the overall lowest levels of improvement in acceptable scientific answers for all classrooms combined. This is most likely because these questions dealt with topics that students tended to feel like they needed to answer in a faith-based, rather than scientific way. These questions asked about the origin of life, and specifically humans, to which the majority of kids answered that "God created all of life, especially humans." This goes back to the idea that it takes a long time for pre-conceived notions to change. Despite the fact that students demonstrated understanding of evolutionary principles, their belief in God superseded scientific explanations.

Statistical analyses were run on these data by doing a paired one-tail T-test, with p = 0.05. The t-test compared pre-survey scores with post-survey scores for each individual student. The T-test from the data from the teachers McNabnay, Milletics, and Hamilton all came back with a strong statistical probability that the two sets of data (the pre-survey and the post-survey) are different. All three tests came back with a 0.000 probability that the null hypothesis (that there is no difference between the two sets of data) is true. This shows the survey data from these three teachers to be statistically significant. The fourth teacher, Smith, only had seven of her students return consent forms to be eligible in the study. It is most likely because of this small sample size that her data came back with a probability of 0.013 of the null hypothesis being true, but her survey data are also accepted as being significant.

Data were also analyzed, comparing the pre-test to the post-test. A rubric was used (Appendix D4) that marked answers as either correct or incorrect, and there were a few questions on which students could receive partial credit, if an answer required more than one answer. Figures 10-13 show the overall scores of individual students for the pre-test and post-test.

Figure 10: McNabnay Pre-Test versus Post-Test Scores (n = 40)

Pre-Test Class Average = 32% Post-Test Class Average = 92%



For the target classroom, figure 10 shows that all students improved from the pre-test to the post-test (Appendix D6). Not only that, but all students passed the post-test, showing mastery over evolutionary concepts. Student 10 had the lowest post-test score and was the only student in the target classroom to earn less than a C grade. This particular student was absent with illness for three weeks of the unit, but their scores were still included in the study because they had completed all of the required activities.

Figure 11: Smith Pre-Test versus Post-Test Scores (n = 7)

Pre-Test Class Average = 29% Post-Test Class Average = 80%

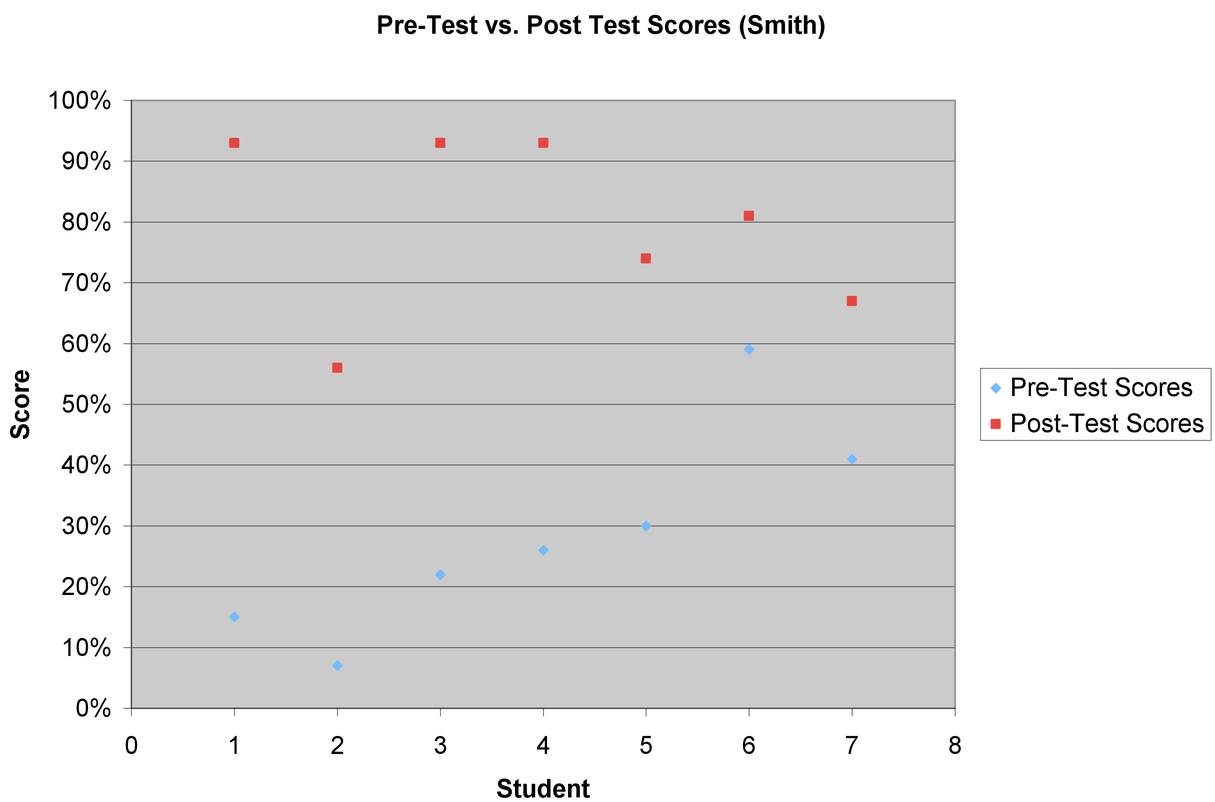


Figure 11 shows that all students in Smith's classroom improved from the pre-test to the post-test. Only one student (student two) earned a failing grade, but despite failing this student still managed to improve their score by 51 percent from the pre-test to the post-test (Appendix D7).

Figure 12: Hamilton Pre-Test versus Post-Test Scores (n = 52)

Pre-Test Class Average = 26% Post-Test Class Average = 79%

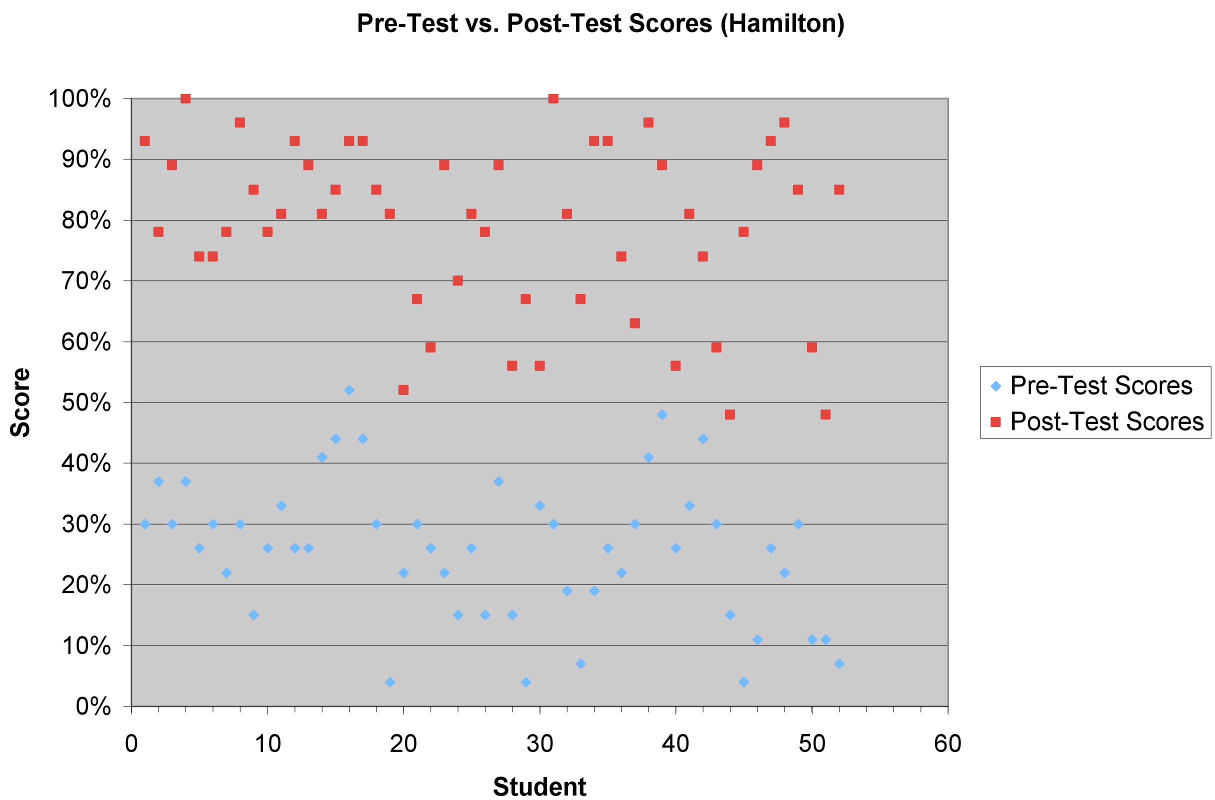


Figure 12 shows that all students in this auxiliary classroom improved from the pre-test to the post-test. Most students showed large margins of improvement by 60 to 70 percent (Appendix D8). Despite improving, nine students failed the post-survey, showing that they had not completely mastered the material.

Figure 13: Milletics Pre-Test versus Post-Test Scores (n = 23)

Pre-Test Class Average = 26% Post-Test Class Average = 76%

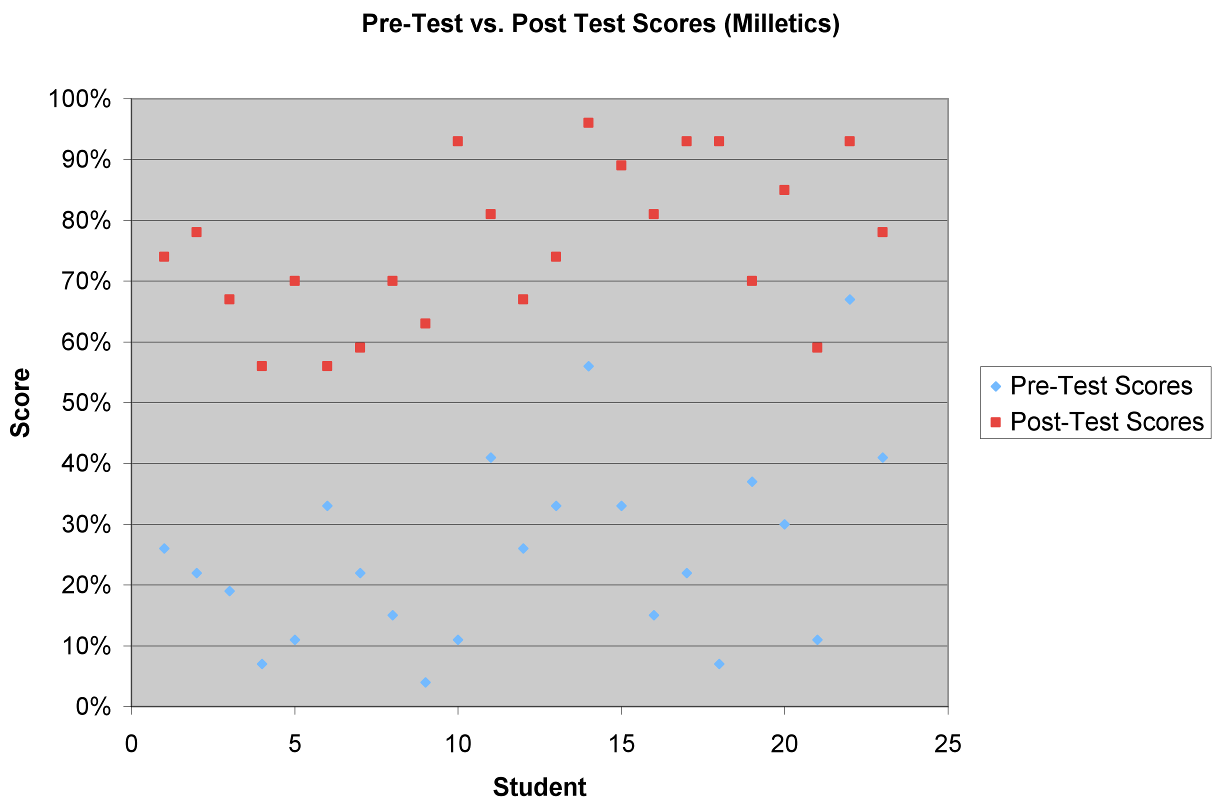


Figure 13 shows that this auxiliary classroom also showed improvement from every student from the pre-test to the post-test. Four individual students did not earn passing grades on the post-test (Appendix D9).

Figures 10-13 show that every individual student scored better on the post-test than on the pre-test, and the class averages for every teacher went up.

Figures 14-18 show how students scored on each individual test question. Questions 11, 21, 22, and 23 were worth more than one point because they required students to give more than one answer. Students who received any credit for these questions are shown on figures 14-18 as giving correct answers.

Figure 14: McNabnay Pre-Test versus Post-Test Individual Questions (n = 40)

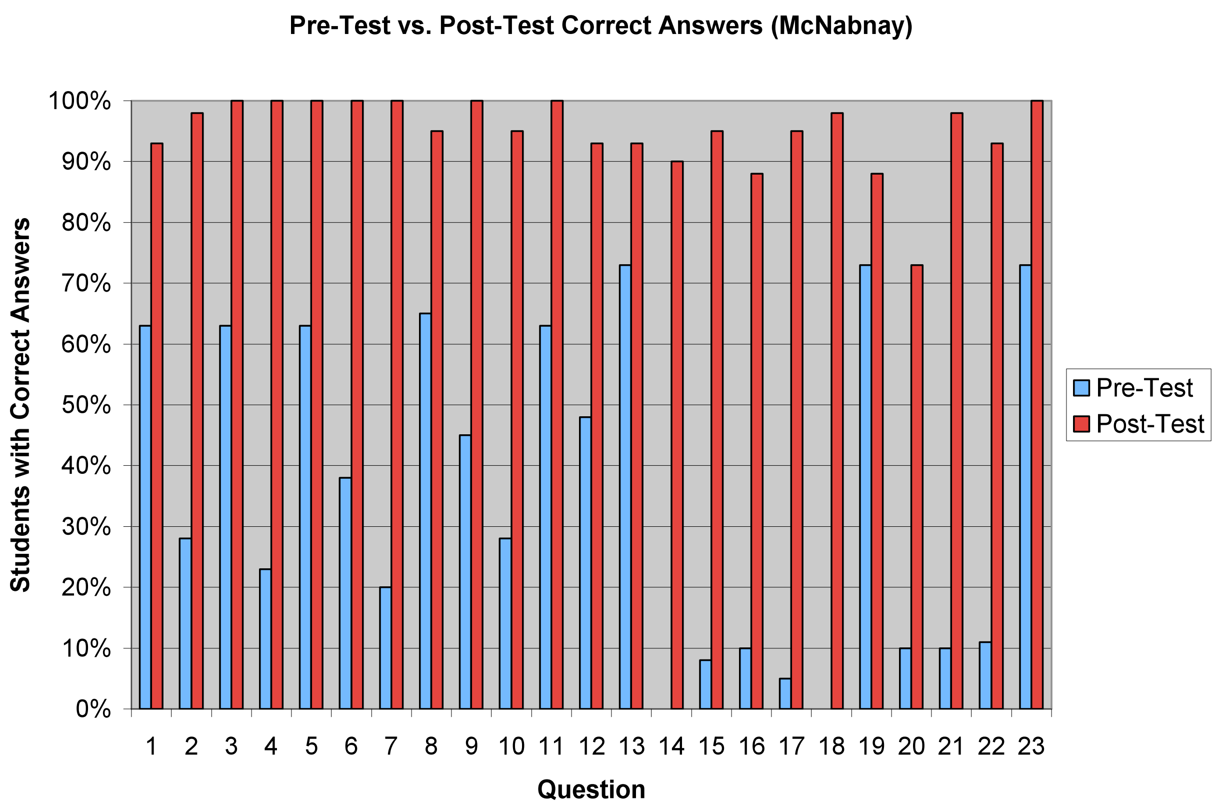


Figure 14 shows that students in the target classroom improved dramatically on every question from the pre-test to the post-test. Every student was able to answer questions three, four, five, six, seven, and nine correctly. Three students or less missed questions one, two, eight, ten, eleven, twelve, thirteen, fifteen, seventeen, eighteen, and twenty-three, showing mastery over these evolutionary concepts.

Figure 15: Smith Pre-Test versus Post-Test Individual Questions (n = 7)

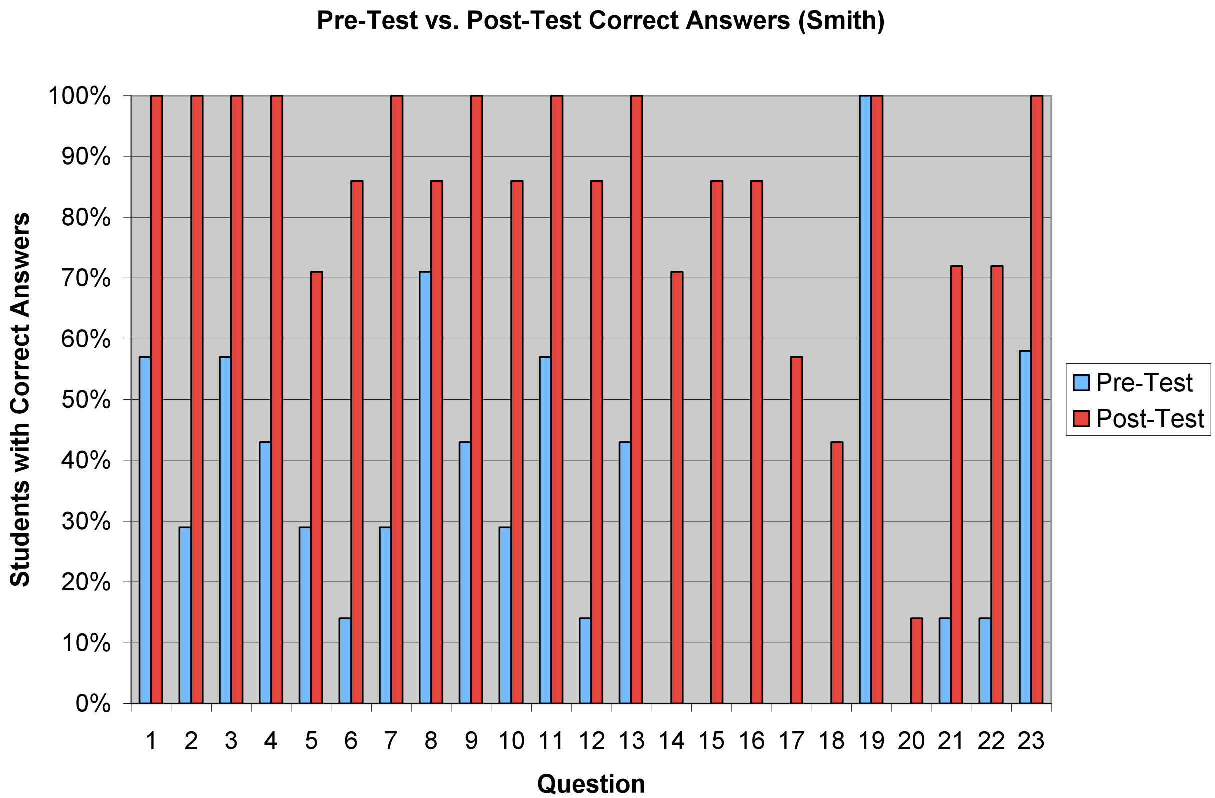


Figure 15 shows that all students in Smith's class improved from the pre-test to the post-test, with the exception of question 19 where 100 percent of students got the answer correct on the pre-test and post-test, leaving no room for improvement. This question asked students if evolution was occurring if there was not a change in alleles in the population over time. All students were able to connect the concept of evolution with change, and because no changes were occurring, evolution was not happening.

Figure 16: Hamilton Pre-Test versus Post-Test Individual Questions (n = 52)

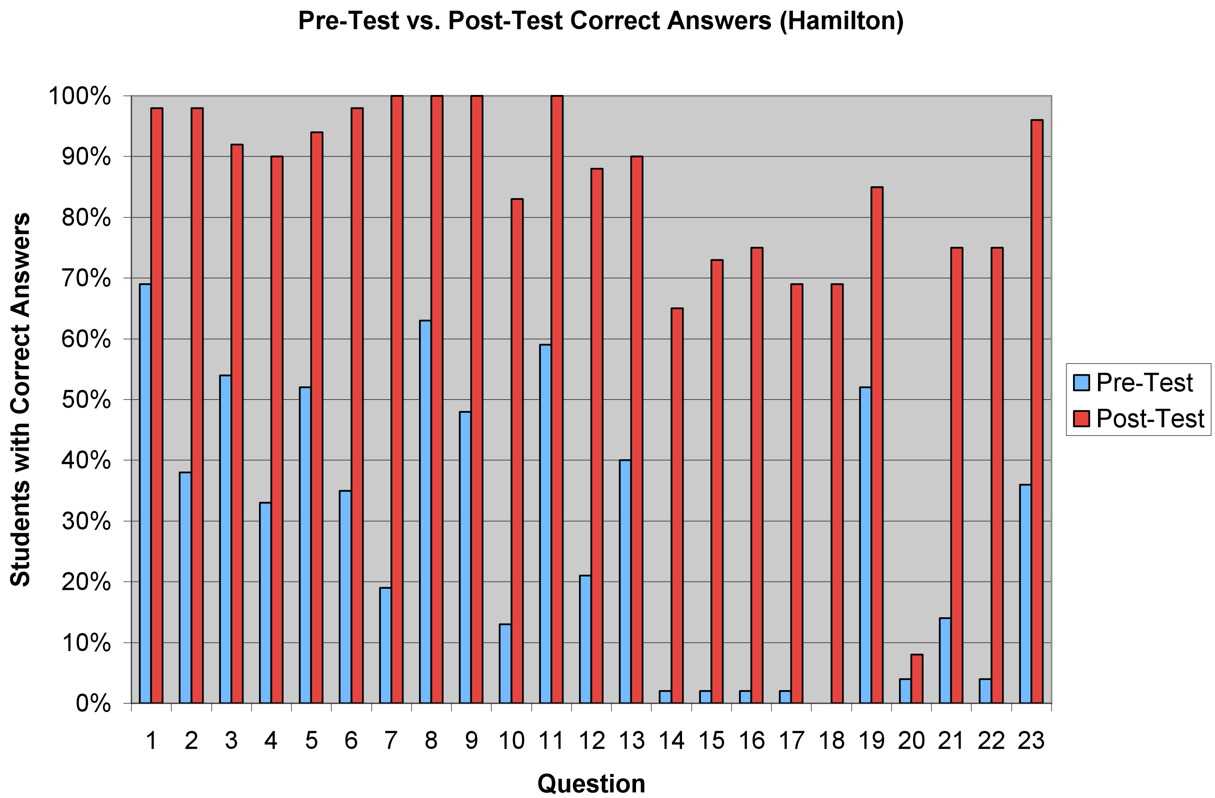


Figure 16 shows that Hamilton's students scored better on every question from the pre-test to the post-test. There was a large margin of improvement for every question, with the exception of question 20.

Figure 17: Milletics Pre-Test versus Post-Test Individual Questions (n = 23)

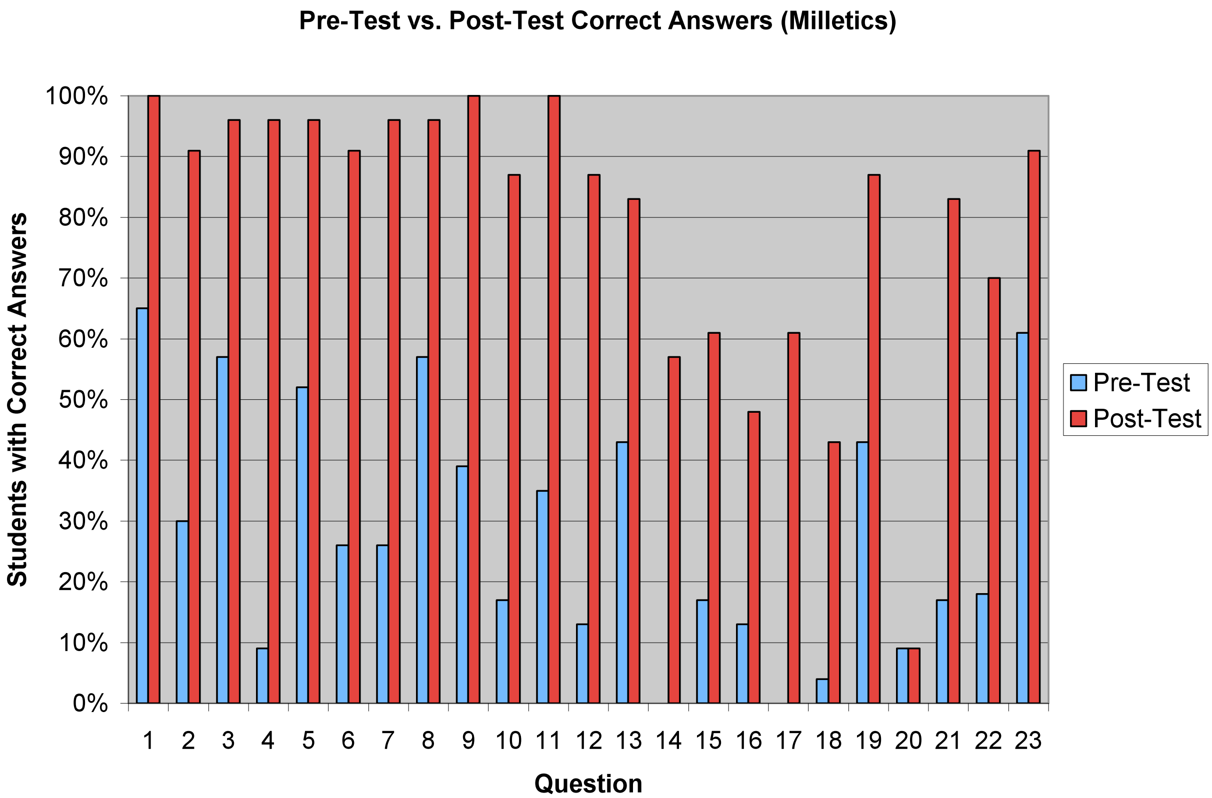


Figure 17 shows that students in this auxiliary classroom also scored better on every question, except for question 20 where the same number of students got the correct answer on the pre-test and post-test.

Figure 18: Total for All Four Teachers Pre-Test versus Post-Test Individual Questions (n = 122)

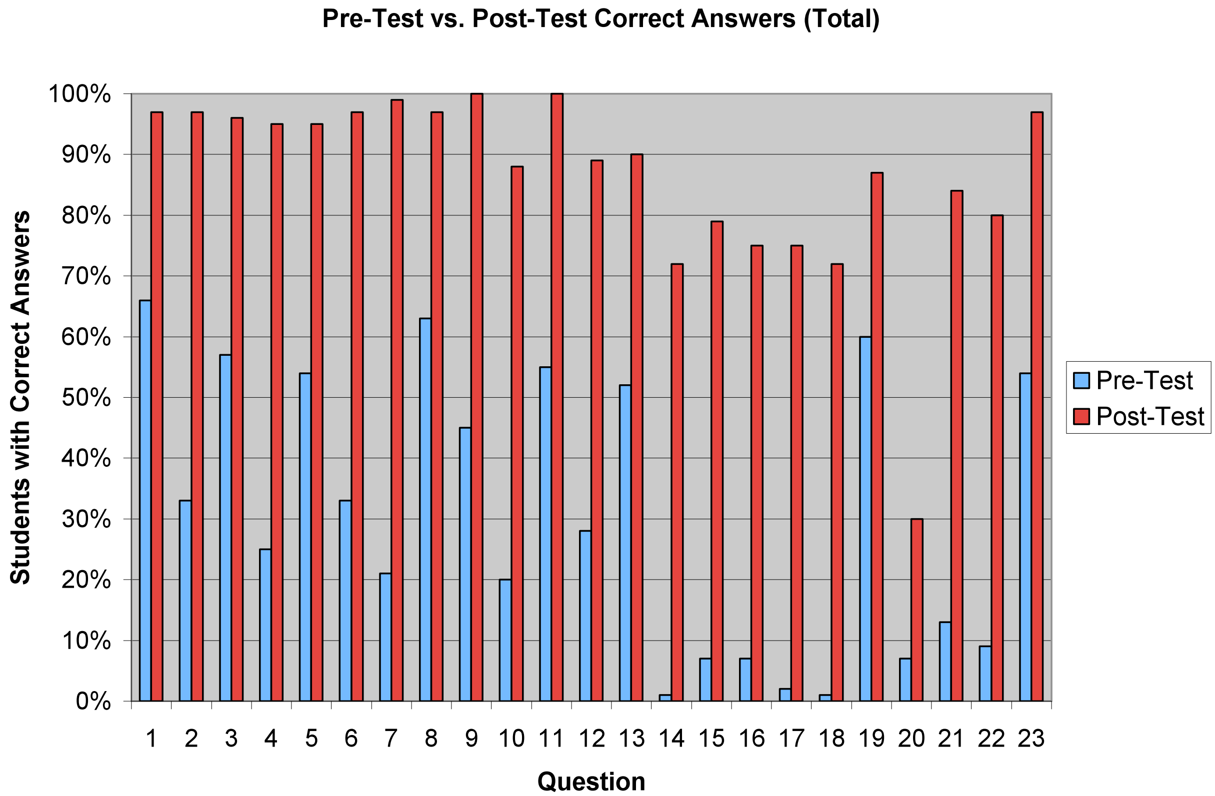


Figure 18 shows that when combined, students improved on every question from the pre-test to the post-test. For every teacher's post-test, students did the worst on question number 20. This question asked students to use the example of antibiotic resistant bacteria to explain the process of natural selection. Because this answer required students to use a process, and to apply their knowledge of natural selection to a specific organism, it was the most difficult question on the test for students to answer. It is not necessarily that students cannot define the processes of mutation, fitness, or natural selection, but they had a difficult time applying their knowledge of these processes to a specific everyday life example. Looking at the sample as a whole (figure 18) the vast majority of students answered every other question on the post-test correctly, showing proficiency in evolutionary concepts.

As with pre-surveys and post-surveys, a paired one-tail T-test ($p = 0.05$) was run to compare the pre-test scores to the post-test scores. Again, the tests from the teachers McNabnay, Milletics, and Hamilton all came back with a 0.000 probability that the null hypothesis (that there is no difference between the two sets of data) is true. Smith's data analysis came back with a probability of 0.001, again most likely because of her small sample size of only seven students. Results from all four teachers indicate that all of the data is statistically significant, showing that there is a difference between the pre-test and post-test data.

CONCLUSION

Overall, the data indicate that student comprehension was impacted by the hands-on, activity based learning that took place. Most of the activities were effective and went well in the target classroom, based on daily homework assignments completed by students. Students were much more engaged when working on an activity, either individually or in groups, than when taking notes or having class discussions. The other three classroom teachers agreed. In discussions with them, throughout the unit, they consistently commented on how much their students enjoyed participating in the activities. During almost all of the sessions of note taking in the target class, students were disengaged and disinterested. In fact, when asked to take more notes in the next unit, many students complained as they were used to and enjoyed not learning in a lecture-based way. Many evolutionary concepts that students ended up showing proficiency in were never lectured about by any of the four classroom teachers, showing that students did learn from being engaged with the material. I was very pleased with how most of the activities ran and the results that came from students working on them.

There were some differences in the results from teacher to teacher. For example, figure 14 shows that in the target classroom 73 percent of students were able to answer question 20 correctly. This question asked students to use the example of antibiotic resistant bacteria to explain the process of natural selection. This was a concept that was presented in multiple ways and at multiple times in this classroom. The three auxiliary classes did not have as many students answer this question correctly, as shown in figures 15-17. According to conversations that took place with those classroom teachers during our common Monday morning planning times, they did not cover this particular concept as frequently or as in depth as the target classroom. This indicates that even though students were engaged in the same activities, learning styles, and curriculum, the teacher remains central to exactly what students take away on a daily basis. As a result of this, not all students came away with the exact same learning experience. This is not necessarily a bad thing, as long as all of the major evolutionary concepts were learned, which appears to be the case, as shown in the total student results of figure 18.

In the case of the target classroom, teaching the unit in this way met the two overall goals. The material was covered in a deeper manner than it had been in the past, and students were interested in what they were learning. Student interest varied from topic to topic, but overall, students asked good questions, were curious, and were focused on analyzing the problems or evidence set before them. Based on the data in figures 14-18, it also appears that all of the objectives for student proficiency were met. The post-test data show that the majority of students know the role that the environment, variation, chance, and mutation play in the process of natural selection. Students are now also able to give examples of evidence for evolution and explain how individual examples point to a species changing over time. Despite being difficult, students also excelled in being able to compare DNA and amino acid sequences among organisms to determine common descent and relationships.

I also met all of my implementation goals. All four classroom teachers lectured for less than thirty minutes a week during every week of the unit. This allowed for more time for students to be engaged with the material, and for more real world connections to be brought into the classroom. Some of these examples included antibiotic resistant bacteria, insect resistance to pesticides, polar bears on the verge of extinction due to the loss of sea ice, and many more. Students were disengaged when I was up front lecturing, and were very engaged when they were participating in an activity. The use of the student response clicker systems provided another way for students to be actively engaged in the learning process while also providing all four classroom teachers with immediate feedback about what students did and did not know. On days when the student response systems were used, kids in the target classroom were generally excited to get started and wanted more questions asked, so they could prove show what they had learned.

The misconceptions journals were an invaluable tool to this whole process. These journals opened up avenues for discussions about the nature of science, the nature of the "controversy," and even the nature of faith. Students who came into the unit with closed minds and a huge pile of misconceptions wrote comments in their journals that made this apparent. In response to the misconception that evolution is a theory about the origin of life and the scientific response to it, one student wrote, "This is very different from what I always thought." Another student wrote, "I dig this. I had no idea but am now enlightened." This was exactly the point in having students write in their journals. As time went on, and more misconceptions were addressed, students in the target classroom were becoming more comfortable with thinking that it is okay to think in evolutionary terms. The more the "controversy" was flushed out, the more comfortable students became. In response to the misconception that evolution and religion are incompatible, one student wrote, "I used to think it conflicted with the Bible and now that I'm learning more I realize they're different." Another student said, "I admit, before this I thought they conflicted. Guess not!" And yet another student wrote, "I didn't know this. I'm glad this is true 'cause I'd not be willing to learn evolution if this wasn't the case." The goal was not to change what kids believed, but to open a door to let them see past their beliefs and to see how unnecessary the conflict between faith and science is. For most students this happened. For others, however, my goal was that they are now scientifically educated, and will continue to wrestle with the scientific evidence and with their faith to see that they don't need to pick a side, like so many uneducated people are telling them they need to do.

This is one of the first units that I taught where students completed a capstone project at the end of the unit. I was very pleased with this, and expect to implement it with more units throughout the course of the year. This showed me more about student learning than the post-test or post-survey could. On tests and surveys, often times students are able to memorize concepts and specific answers and recite those facts for the day of the test, forgetting them the next day. Although I don't necessarily think this is what happened on the post-survey (kids didn't even know they would be taking it) or even the post-test, it is possible. However, building the website required students to apply their knowledge of general evolutionary concepts to specific organisms. This is a much higher order thinking skill than rote memorization, and showed student competency in these concepts. It also provided many applications and gave students a new sense of appreciation for their specific group of organisms.

Overall, I will repeat most of what I documented here again in the future. In future implementation of this unit, I will consider not lecturing at all, finding more activities to replace that content. It was very disheartening to see students in the target classroom who were involved, inquisitive, and completely engaged on days that they were doing activities, become completely disinterested and disengaged when they took notes. The activity based learning also proved that a teacher need not stand up front and lecture for students to learn, and that they actually learn more by discovering things for themselves than by just being told. Taking on the role of guiding students through the process of discovery and learning was an enjoyable way to teach.

In future revisions of this unit some of the activities that repeated the same key concepts, like the DNA comparison activities, should be deleted or edited. However, students really enjoyed almost every activity and were engaged in what they were learning. The overall goal is to be able to apply this style of teaching to more of the units that I teach. It was effective, engaging, and worked with the content that students most often reject. If it worked with evolutionary biology, it should work even more effectively with cellular biology, ecology, genetics, taxonomy, and biology topics.

APPENDICES

APPENDIX A1

Michigan High School Science Content Expectations

STANDARD B5: EVOLUTION AND BIODIVERSITY
Students recognize that evolution is the result of genetic changes that occur in constantly changing environments. They can explain that modern evolution includes both the concepts of common descent and natural selection. They illustrate how the consequences of natural selection and differential reproduction have led to the great biodiversity on Earth.

L5.p1 Survival and Extinction *(prerequisite)*
Individual organisms with certain traits in particular environments are more likely than others to survive and have offspring. When an environment changes, the advantage or disadvantage of characteristics can change. Extinction of a species occurs when the environment changes and the characteristics of a species are insufficient to allow survival. Fossils indicate that many organisms that lived long ago are extinct. Extinction of species is common; most of the species that have lived on the Earth no longer exist. *(prerequisite)*

L5.p1A Define a species and give examples. *(prerequisite)*

L5.p1B Define a population and identify local populations. *(prerequisite)*

L5.p1C Explain how extinction removes genes from the gene pool. *(prerequisite)*

L5.p1D Explain the importance of the fossil record. *(prerequisite)*

L5.p2 Classification *(prerequisite)*
Similarities among organisms are found in anatomical features, which can be used to infer the degree of relatedness among organisms. In classifying organisms, biologists consider details of internal and external structures to be more important than behavior or general appearance. *(prerequisite)*

L5.p2A Explain, with examples, that ecology studies the varieties and interactions of living things across space while evolution studies the varieties and interactions of living things across time. *(prerequisite)*

B5.1 Theory of Evolution
The theory of evolution provides a scientific explanation for the history of life on Earth as depicted in the fossil record and in the similarities evident within the diversity of existing organisms.

B5.1A Summarize the major concepts of natural selection (differential survival and reproduction of chance inherited variants, depending on environmental conditions).

B5.1B Describe how natural selection provides a mechanism for evolution.

B5.1c Summarize the relationships between present-day organisms and those that inhabited the Earth in the past (e.g., use fossil record, embryonic stages, homologous structures, chemical basis).

B5.1d Explain how a new species or variety originates through the evolutionary process of natural selection.

B5.1e Explain how natural selection leads to organisms that are well suited for the environment (differential survival and reproduction of chance inherited variants, depending upon environmental conditions).

B5.1f Explain, using examples, how the fossil record, comparative anatomy, and other evidence supports the theory of evolution.

B5.1g Illustrate how genetic variation is preserved or eliminated from a population through natural selection (evolution) resulting in biodiversity.

B5.2x Molecular Evidence
Molecular evidence substantiates the anatomical evidence for evolution and provides additional detail about the sequence in which various lines of descents branched.

B5.2a Describe species as reproductively distinct groups of organisms that can be classified based on morphological, behavioral, and molecular similarities.

B5.2b Explain that the degree of kinship between organisms or species can be estimated from the similarity of their DNA and protein sequences.

B5.2c Trace the relationship between environmental changes and changes in the gene pool, such as genetic drift and isolation of subpopulations.

B5.r2d Interpret a cladogram or phylogenetic tree showing evolutionary relationships among organisms. *(recommended)*

B5.3 Natural Selection
Evolution is the consequence of natural selection, the interactions of (1) the potential for a population to increase its numbers, (2) the genetic variability of offspring due to mutation and recombination of genes, (3) a finite supply of the resources required for life, and (4) the ensuing selection from environmental pressure of those organisms better able to survive and leave offspring.

B5.3A Explain how natural selection acts on individuals, but it is populations that evolve. Relate genetic mutations and genetic variety produced by sexual reproduction to diversity within a given population.

B5.3B Describe the role of geographic isolation in speciation.

B4.3C Give examples of ways in which genetic variation and environmental factors are causes of evolution and the diversity of organisms.

B5.3d Explain how evolution through natural selection can result in changes in biodiversity.

B5.3e Explain how changes at the gene level are the foundation for changes in populations and eventually the formation of new species.

B5.3f Demonstrate and explain how biotechnology can improve a population and species.

APPENDIX A2

INCREASING STUDENT COMPREHENSION IN EVOLUTIONARY BIOLOGY
PARENTAL CONSENT AND STUDENT ASSENT FORM

Dear Students and Parents/Guardians:

I am currently enrolled as a graduate student in Michigan State University's Department of Science and Mathematics Education (DSME). My thesis research is on improving student comprehension of evolutionary concepts. My reason for doing this research is to learn more about improving the quality of science instruction.

Data for the study will be collected from standard student work generated in the course of teaching this unit, such as pre and post-tests, lab activities, and surveys. I am asking for your permission to include your child's data in my thesis. Your child's confidentiality is a foremost concern. During the study, I will collect and copy student work. These assignments will have the students' names removed prior to use in the study. All of the work being collected will be stored and locked in the high school office until completion of my thesis research, and will be shredded after that time. In addition, your child's identity will not be attached to any data in my thesis paper or in any images used in the thesis presentation. Instead, the data will consist of class averages and samples of student work that do no include names. Confidentiality of records will be maintained throughout the course of my study and beyond. MSU requires that research records must be maintained for a minimum of three years following completion of the study. During this time, only myself, my advisor, and the Institutional Review Board will have access to these records. Your child's confidentiality will be protected to the maximum extent allowable by law.

Participation in the study is completely voluntary, and you may change your mind at any time and withdraw. If either the student or the parent requests to withdraw, the student's information will not be used in this study. All students will be required to complete all of the given class assignments and activities. There are no unique research activities – participation in this study will not increase or decrease the amount of work that students do. I will simply make copies of students' work for my research purposes. Students who do not participate in the study will not be penalized in any way. In fact, I will not know who is or is not included in the study until the end of the school year, after grades have been submitted.

There are no known risks associated with participating in this study. In fact, completing course work should be very beneficial to students. I will minimize any risk that may exist by having another person collect and store the consent forms (where you say "yes" or "no") in a locked file cabinet that will not be opened until after the end of the school year. That way I will not know who agrees to participate in the research until after grades are issued. In the meantime, I will save all written work for this unit. Later I will analyze the written work only for students who have agreed to participate in the study and whose parents/guardians have consented.

If you are willing to allow your child to participate in the study, please complete the attached form and return it to Mrs. Woodard in Room 130. Please seal it in the provided envelope with your child's name on the outside of the envelope. The envelopes will be stored in a locked cabinet and opened after the completion of the school year.

If you have any concerns or questions about this study, such as scientific issues, how to do any part of it, or to report an injury, please contact me by email at jmcnabna@remc11.k12.mi.us or by phone at (269) 428-1402 ext. 2132. Questions about the study may also be directed to Dr. Merle Heidemann at the DSME by email at heidema2@msu.edu, by phone at (517) 432-2152, or by mail at 118 North Kedzie, East Lansing, Michigan 48824. If you have any questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – the Michigan State University's Human Research Protection Program at (517) 355-2180, Fax (517) 432-4503, e-mail irb@msu.edu, or regular mail at 207 Olds Hall, MSU, East Lansing, Michigan 48824.

Thank you,

Miss Jill McNabnay

Lakeshore High School Biology Teacher

Parents/guardians should complete this following consent information:

I voluntarily agree to allow ____ to participate in this study. *(print student name)*

Please check all that apply:

<u>Data:</u>

__________ I give Miss McNabnay permission to use data generated from my child's work in this class for her thesis project. All data from my child shall remain confidential.

__________ I do not wish to have my child's work used in this thesis project. I acknowledge that my child's work will be graded in the same manner regardless of their participation in the study.

Photography and Videotaping:

__________ I give Miss McNabnay permission to use pictures or videos of my child participating in various activities while in biology class. I understand that my child will not be identified by name in either photos or videos.

__________ I do not wish to have my child's images used at any time during this thesis project.

Signatures:

____ __________________________

(Parent/Guardian Signature) (Date)

I voluntarily agree to participate in this thesis project.

____ __________________________

(Student Signature) (Date)

*****Important*****

Return this form to Mrs. Woodard in Room 130.

APPENDIX B1

Geologic Time Scale Activity

Adapted from Elizabeth Roettger's Toilet Paper Geologic Time Scale

http://www.nthelp.com/eer/HOATPtime.htm

Background:

Geologists describe the Earth's geologic history through a temporal system known as the **geologic time scale.** On this scale, time is measured using the following four units of time: **eons**, **eras**, **periods**, and **epochs**. All of these temporal subdivisions are established on the occurrence of some important geologic event. For example, ***Hadean Eon*** represents the time on Earth when life did not exist. During the ***Archean Eon,*** life started and was dominated by one-celled **prokaryotic** life forms. **Eukaryotic** one-celled organisms became dominant in the ***Proterozoic Eon***. Multicellular organisms ruled the planet during the **eon** known as the ***Phanerozoic***.

Objectives:

At the end of this activity, students will be able to:

- Explain important events in the Earth's history
- Describe when these important events occurred
- Explain why it is difficult to directly observe evolution based on long periods of time
- Visualize how long 4.6 billion years is

Procedure:

1. Students will be shown a model and will be asked to answer the Pre-Activity questions.

2. Students will work alone or with a partner and will be assigned an epoch or period of the Earth's history.
3. They will be given a short description of this time period and will be asked to summarize it in their own words.
4. As a class, we will go outside and place our 46 meter long timeline on the sidewalk. Using chalk, students will be asked to draw pictures to represent their time period.
5. Each student will then share the important events of their time period with the rest of the class. Other class members will have a blank geologic time scale diagram to fill in with the information presented by other class members.

<u>Pre-Activity Questions:</u>

1. How many sprinkles do you think are in the jar?
2. How many millions are there in a billion?
3. The Earth is 4.6 billion years old. Our sample timeline is 46 meters long. How many years = 1 meter on our timeline?

<u>Analysis:</u>

*Please answer the following questions using **COMPLETE SENTENCES.***

1. Why do you think it is so difficult for people to observe the evolution of a new species?
2. What was the "Cambrian Explosion"?
3. In what periods did two mass extinctions occur?
4. What animal group was most successful during the Mesozoic Era?
5. What major obstacle did mammals face in the Quaternary Period?

6. Why do you think there was so much time from the formation of the Earth until the development of the first Prokaryotes?
7. Did humans and dinosaurs ever co-exist? What evidence is there?
8. Which era lasted the longest? How long?
9. How old are the Earth's oldest known rocks?
10. In general, does evolution occur quickly? Explain your answer.

Table 2: Geologic Time Scale Chart

Eon	Era	Period	Years Ago	Evolutionary Events
Phanerozoic	Cenozoic	Quaternary		
		Tertiary		
	Meso.	Cretaceous		
		Jurassic		
		Triassic		
	Paleozoic	Permian		
		Pennsylvanian		
		Mississippian		
		Devonian		
		Silurian		
		Ordovician		
		Cambrian		
Proter-ozoic	Precambrian			
Arc-hean				
Had-ean				

APPENDIX B2

Geologic Dating Online

Created by J. McNabnay

Go to the website:

http://www.ucmp.berkeley.edu/education/explorations/tours/geotime/gtpage1.html

Please answer the following questions using ***COMPLETE SENTENCES****.*

1. How many years old is the Earth?
2. If you could read two pages of "A History of Earth" every second, how long would it take you to read the entire book?
3. How long ago did the earliest life appear on Earth?
4. How long ago did early land plants develop?
5. When was the Permian extinction (the largest mass extinction)?
6. When did the dinosaurs go extinct?
7. Number these events from 1-6 indicating earliest (1) to most recent (6).

    _______ Sliced Bread

    _______ 1st U.S. Olympics

    _______ Skateboards

    _______ Internet

    _______ The Slinky

    _______ Titanic Sinks

8. What is the difference between relative dating and absolute dating?
9. What year did the Titanic sink?

10. Number these fossils from 1-7 indicating earliest (1) to most recent (7).

    _______ Archaeopteryx – an early bird

    _______ A Fossil Skate – related to sharks

    _______ Early Synapsid – mammal ancestor

    _______ Triceratops – ornithischian dino

    _______ 'Lucy' – a hominid

    _______ Ptilophyllum – a fossil fern

    _______ Fossil Trilobite – an arthropod

11. Where would the oldest layer of rock be found?
12. Explain the Law of Superposition.
13. Does the Law of Superposition give relative dating or absolute dating? Why?
14. What kind of dating is used to absolutely date fossils?
15. What are flora and fauna?
16. During which era were dinosaurs abundant?
17. During which period did the dinosaurs go extinct?
18. Scientific evidence suggests that the Earth is how old?
19. Evidence for past events in the Earth's ancient history are provided by what?
20. What does the Law of Superposition allow us to determine?
21. What does radiometric dating allow us to determine?
22. What do the divisions of time in the Geologic Time Scale represent?

APPENDIX B3

WHAT EVOLUTION IS *NOT*

http://www.indiana.edu/~ensiweb/lessons/ev.not.html

Biological Evolution…

1. is NOT a theory… (it is a FACT; it has been observed directly, and its extension to all life is supported by more evidence than there is for the spherical shape of the planets, and there is ***no*** evidence against it.)
2. is NOT something one should ***believe*** in… (it's based on science, not faith).
3. is NOT concerned with the origin of life… (it deals only with the origin of ***species***).
4. is NOT just concerned with the origin of humans… (no more than any other species).
5. was NOT discovered or first explained by Charles Darwin… (there were others)
6. is NOT the same thing as natural selection… (which is the ***how*** evolution, the real "*Theory* of Evolution… by Natural Selection", also deeply confirmed).
7. is NOT something that happened only in the past… (it's still going on).
8. is NOT something that happens to individuals… (it happens to populations).
9. is NOT an accidental or random process… (there are built-in limited options and selective aspects). Its complex patterns are just as natural as the randomly generated and diverse patterns of snowflakes and crystals.
10. does NOT have any evidence against it… (***all*** observations support it).
11. was NOT contrived to undermine religion… (rather, our awareness of it grew as we tried to make sense of many observations of life in a testable way).

12. does NOT deny the existence of God… (It is neutral; God is neither required nor eliminated; for all we know, evolution could be part of God's creation, or it might not, but science cannot determine that).
13. does NOT conflict with any religion… (It can't, since it is only another way of trying to make sense of the natural world, based on scientific observation and critical analysis. Most religions have no problem with evolution, and those that do base their objections on an inaccurate view of science and evolution).

If these popular misconceptions about evolution are all wrong,

then what IS evolution?

Continue on…

WHAT EVOLUTION *IS*

Biological Evolution is essentially the process whereby new species arise from earlier species by accumulated changes. This is often referred to as "descent with modification." At the species level, this *speciation* process is sometimes called *microevolution*.

By extension, as this process of speciation proceeds with time, increasing numbers of species appear, becoming increasingly different. The pattern of this, over time, looks like a branching tree; all the species we see today are like the growing tips of that tree, except that each tip is a little different from the other (unlike a real tree). Close clusters of tips have most recently branched (evolved); more distant tips can be traced to much lower (earlier) branchings in the tree. What we call a "genus" would be a close cluster of tips. The "family" level of classification (which may include several genera) refers to a group of several closely branched clusters. And so on. Evolution at these "higher" levels is sometimes call *macroevolution*, but it should be obvious that this simply results from continuous microevolution repeated over long periods of time.

The recognition of this pattern of change of life-forms over time was developed from many observations. It has even been directly observed in some species, and inferred in many others from clear independent evidence mainly in comparative anatomy, embryology, paleontology, geology, and molecular biology. Although there are some curious examples of evolution, there are no empirical observations of life, living or extinct, that evolution cannot explain, and there is ***no*** evidence against evolution.

The mechanism for *how* evolution happens has been largely explained by natural selection. Natural selection is observed constantly, and its role as the main driving force of evolution (the *Theory of Evolution by Natural Selection*, essentially as Charles Darwin proposed) has been observed, tested and challenged many times and in many ways, and has survived largely intact. There are also many independent lines of evidence that are consistent with natural selection as the main mechanism of evolution. There is NO observed evidence against this as a working mechanism for evolution. Efforts by some to point out "evidence against evolution" always turn out, under critical examination, to be totally without merit.

The Theory of Evolution by Natural Selection (or, more accurately, the Theory of Natural Selection), therefore, holds the high status of near certainty: it is a scientific theory.

In short, evolution as a real phenomenon is scientifically solid; it is a scientifically demonstrated fact; and the scientific *theory* for *how* evolution happens is so well documented by the evidence that this explanation is as close to a scientific fact as any explanation can be. Remember: ***scientific facts*** refer to *observed* or demonstrated natural phenomena, e.g., evolution; ***scientific theories*** are the best *explanations* we have for *how* those phenomena occur, e.g., the theory of natural selection.

Please answer the following questions using ***COMPLETE SENTENCES*** *after reading the information provided.*

1. Is evolution something that one should "believe in"? Why or why not?
2. Is there evidence against evolution? Explain.
3. Does evolution conflict with one's views of God / religion? Explain.
4. What is biological evolution?
5. Explain the difference between microevolution and macroevolution.
6. Give five scientific fields that all provide evidence for evolution.
7. What does natural selection help to explain, in terms of evolution?
8. What is the difference between a scientific fact and a scientific theory?
9. Is evolution a scientific fact or theory?
10. Is natural selection a scientific fact or theory?
11. Is there any evidence against natural selection?

APPENDIX B4

Variation in Bead Bug Populations

Adapted from Merle K. Heidemann

Science and Math Education Professor, Michigan State University

Background:

Variation within a population is the raw material for natural selection and thus for the occurrence of evolution. In order for natural selection to act as an evolutionary force, there must be variability in populations of the same species and between populations of different species. Variability does NOT arise as a response to natural selection, allowing an organism to “match” certain environmental circumstances. Rather, variability allows some populations to survive better in certain environmental circumstances than other populations.

Intro to Bead Bugs:

In the land of paisley and prints live the Bead Bugs. Bead Bugs are small creatures who eat and breed in various kinds of meadows that closely resemble brightly colored fabrics. One characteristic of this species is that it has adapted to these wild and bright habitats by existing in various colored forms. These different forms include white, red, light blue, dark blue, black, green, and orange.

This variation in color is extremely important because Bead Bugs live in a patchy environment that has become split up due to human activity. These environments can differ quite markedly from one another. Some colors of Bead Bugs are prevalent in some environments but do rather poorly in others.

The biology of Bead Bugs is quite interesting. They live in groups of 48 individuals; each group can be made up of all one color or made up of mixed colors. They eat brightly colored flowers or candy. They reproduce slowly, producing only one offspring in each generation.

Their primary predator is a bird, the Bead Bug Boogie. It zooms over meadows, keeping a sharp eye out for Bead Bugs. It catches only one prey at a time, taking it back to its next to feed its young. Each day, each Boogie captures 24 Bead Bugs for its young. At the end of each day, each Bead Bugs left on the meadow reproduces one offspring (of the same color).

Procedure:

1. In your group of 2, decide which of you will be the Bead Bug Boogie (predator), capturing and taking back Bead Bugs to the nest one-by-one.
2. The other person will record the data from each round and will "reproduce" and redistribute the Bead Bugs on the meadow.
3. You will need to set up your nest (cup) in the lab, away from your table. This is important so that the Boogie looks away from the meadow each time they grab a Bead Bug. *(Hint: The best way to survey the meadow is to stand right over it.)*
4. You will need 1 background meadow and 3 different colors of Bead Bugs. Pick out 16 of each color of Bead Bug and place them on your meadow. (You should have a total of 48 Bugs on the meadow.)
5. The Boogie will then take 24 Bead Bugs off of the meadow one-by-one. Remember, you have to take each Bead Bug back to your nest before choosing another.
6. Once 24 Bead Bugs have been removed. Fill in the First Data Table for Generation1.

7. All of the Bead Bugs that remain on the meadow now reproduce. Add the appropriate colors back onto your meadow. (For example, blue reproduces blue.)
8. Repeat steps 5-7 until you have completed all 5 Generations on your First Data Table.
9. Now you will choose a new meadow, where you think that the color variant that ended up with the highest number surviving will do worse than the color that had the lowest number surviving.
10. Using the same color beads in the new meadow, repeat steps 4-8 for your new meadow and record your results in the Second Data Table.

Table 3: Bead Bug Data Table 1

Gen.	Color:	Color:	Color:
1	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
2	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
3	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
4	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
5	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __

Table 4: Bead Bug Data Table 2

Gen.	Color:	Color:	Color:
1	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
2	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
3	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
4	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __
5	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __	Initial Pop: __ Number Eaten: __ Survivors: __

Analysis:

*Please answer the following questions using **COMPLETE SENTENCES**.*

1. Did any specific color of Bead Bug go extinct? If so, explain why extinction occurred using the concept of natural selection. If no extinction occurred, explain why all colors survived using the concept of natural selection.
2. In your first meadow, which Bead Bug was most fit? Explain why this particular variation was advantageous.

3. Was there a change in the distribution of Bead Bug colors when you switched habitats? If so, explain what this change in habitat represents in the real world.
4. In this situation, what is doing the selecting?
5. In this situation, what is the adaptation?
6. Is this situation an example of mimicry or camouflage? Explain.
7. If you started with a population of only green Bead Bugs, would you see any change take place in this population over time? Why or why not?
8. If you only had green Bead Bugs, explain whether or not this population would be able to adapt in the future if the organisms had to change habitats again.
9. Predict what the population of Bead Bugs in the second habitat would look like in 10 generations. Explain why you think the population may or may not change.
10. Graph your results for your **1ST DATA TABLE** on a sheet of graph paper.

    This should be a **LINE GRAPH** with **3 LINES**.

    The X-axis is "**Generations**" and the Y-axis is "**Surviving Bead Bugs**."

    Make sure each of your lines is a **different color** (for different Bead Bug Color).

    Include a key.

    Also, remember that all graphs have a **title** and **labels** on each axis.
11. Graph your results for your **2ND DATA TABLE** on a sheet of graph paper.

    This should be a **LINE GRAPH** with **3 LINES**.

    The X-axis is "**Generations**" and the Y-axis is "**Surviving Bead Bugs**."

    Make sure each of your lines is a **different color** (for different Bead Bug Color).

    Include a key.

    Also, remember that all graphs have a **title** and **labels** on each axis.

12. In your own words, explain what each graph shows. (Specifically explain the trends in each graph.)
13. Describe a real-life situation where this type of selection might occur.

APPENDIX B5

Adaptations & Ecology Game

Adapted from Al Janulaw and Judy Scotchmoor's "Clipbirds"

http://www.ucmp.berkeley.edu/education/lessons/clipbirds/

Background:

Evolution is the result of natural selection acting upon variation within a population. Given a set of environmental circumstances, organisms with favorable traits have a selective advantage over individuals with less favorable traits. It is important to understand that favored traits are only advantageous within a particular situation and may not aid in survival if the circumstances change.

We will be looking at several different species of organisms. Each species has a different adaptation for acquiring food for its young. Different species require different amounts of food in order to survive. Also, each species has a specific nesting ground that has been claimed as their own. Listed below are the details for each species:

Finches: Forks; Offspring need 12 pieces of food each

Robins: Tweezers; Offspring need 4 pieces of food each

Bears: Knives; Offspring need 12 pieces of food each

Deer: Magnet; Offspring need 20 pieces of food each

Mice: Spoon; Offspring need 15 pieces of food each

Objectives:

Students will be able to:

- Describe factors that make specific traits adaptations
- Give examples of situations where one organism may be more fit than another

Materials:

- M&Ms
- Mini Marshmallows
- Red Hots
- Paper Clips
- Forks
- Magnets
- Knives
- Spoons (Regular, Baby, Large)
- Gummy Bears
- Tweezers
- Plastic Cups

Hypothesis:

Which of the above organisms do you think will be the most fit? Why?

Which organism will be the least fit? Why?

Procedure:

1. Parents will be given one minute to forage for food for their offspring. Food must be brought back to the nest and put into the offspring's cups. Offspring are not allowed to leave the nest.
2. After one minute, all offspring that have not received the proper amount of food die. They become part of the environment and are left to manage the nest.
3. Offspring that survive (received enough food) are now able to hunt with the parents. Each group will also draw a number to see how many offspring have been born in the new season.
4. This will be repeated 3 more times with variations being introduced in each round.

Table 5: Populations Data Table

Organism	Season 1	Season 2	Season 3	Season 4
Finches	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 2: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 3: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 4: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 5: _
Robins	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 2: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 3: __	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 4: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 5: _
Bears	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 2: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 3: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 4: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 5: _
Deer	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 2: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 3: __	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 4: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 5: _
Mice	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 2: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 3: _	Initial Pop: _ Survivors: _ Offspring: __ Total to Season 4: _	Initial Pop: _ Survivors: _ Offspring: _ Total to Season 5: _

Analysis:

Please answer the following questions using ***COMPLETE SENTENCES****.*

1. Do certain tools lend themselves to specific food types? How does this compare to real life?
2. What organisms experience the most competition? Which experience the least? Why?
3. Does territory placement make a difference? If you could choose a new nesting site, would you? Where would it be?
4. What types of personality traits lead to more fit organisms?
5. What group of organisms had the highest fitness? (Remember this includes both survival and reproduction.)
6. What adaptation(s) provided this high level of fitness?
7. What group of organisms had the lowest fitness?
8. What adaptation(s) provided this low level of fitness?
9. Certain offspring were radically different from their parent(s). What was the source of this difference?
10. How did the differences in offspring (from question 9) affect survival?
11. Prey are also living organisms and therefore have a certain level of fitness. What prey had the highest level of fitness? What adaptation was this high fitness level a result of?
12. Was there a change of the highly fit prey during our simulation? If so, what caused it?
13. Do catastrophic events cause changes in what makes an organism fit? Explain.

APPENDIX B6

The Concept of Natural Selection

Adapted from D.L. Anderson, K.M. Fisher, and G.J. Norman

Anderson, D.L., Fisher, K.M., & Norman, G.J. (2002). Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching, 39*, 952-978.

Galapagos Finches

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

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

1. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived? Given enough time,
    a. The finch population would stay small because birds only have enough babies to replace themselves
    b. The finch population would double and then stay relatively stable
    c. The finch population would increase dramatically
    d. The finch population would grow slowly and then level off

2. Finches on the Galapagos Islands require food to eat and water to drink.
    a. When food and water are scarce, some birds may be unable to obtain what they need to survive.
    b. When food and water are limited, the finches will find other food sources so there is always enough food.
    c. When food and water are scarce, the finches all eat and drink less so that all birds survive.
    d. There is always plenty of food and water on the Galapagos Islands to meet the finches' needs.
3. Once a population of finches has lived on a particular island with an unvarying environment for many years,
    a. The population continues to grow rapidly
    b. The population remains relatively stable, with some fluctuations
    c. The population dramatically increases and decreases each year
    d. The population will decrease steadily
4. In the finch population, what are the primary changes that occur gradually over time?
    a. The traits of each finch within a population gradually change.
    b. The proportions of finches having different traits within a population change.
    c. Successful behaviors learned by finches are passed on to offspring.
    d. Mutations occur to meet the needs of the finches as the environment changes.

5. Depending on their beak size and shape, some finches get nectar from flowers, some eat grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?
    a. Most of the finches on an island cooperate to find food and share what they find.
    b. Many of the finches on an island fight with on another and the physically strongest ones win.
    c. There is more than enough food to meet all the finches' needs so they don't need to compete for food.
    d. Finches compete primarily with closely related finches that eat the same kind of food, and some may die from lack of food.
6. How did the different beak types **first** arise in the Galapagos finches?
    a. The changes in the finches' beak size and shape occurred because of their need to be able to eat different kinds of food to survive.
    b. Changes in the finches' beaks occurred by chance, and when there was a good match between beak structure and available food, those birds had more offspring.
    c. The changes in the finches' beaks occurred because the environment induced the desired genetic changes.
    d. The finches' beaks changed a little bit in size and shape with each successive generation, some getting larger and some getting smaller.

7. What type of variation in finches is passed on to the offspring?
    a. Any behaviors that were learned during a finch's lifetime
    b. Only characteristics that were beneficial during a finch's lifetime
    c. All characteristics that were genetically determined
    d. Any characteristics that were positively influenced by the environment during a finch's lifetime.
8. What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?
    a. The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
    b. All finches are essentially alike and there are **not** really 14 different species.
    c. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.
    d. Different lines of finches developed different beak types because they needed them in order to obtain the available food.

Venezuelan Guppies

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

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

9. A typical natural population of guppies consists of hundreds of guppies. Which statement best describes the guppies of a single species in an isolated population?
    a. The guppies share all of the same characteristics and are identical to each other.
    b. The guppies share all of the essential characteristics of the species; the minor variations they display don't affect survival.
    c. The guppies are all identical on the inside, but have many differences in appearance.
    d. The guppies share many essential characteristics, but also vary in many features.
10. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the "most fit"?
    a. Large body size and ability to swim quickly away from predators
    b. Excellent ability to compete for food
    c. High number of offspring that survived to reproductive age
    d. High number of matings with many different females

11. Assuming ideal conditions with abundant food and space and no predators, what would happen if a mating pair of guppies were placed in a large pond?
    a. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to replenish the population.
    b. The guppy population would grow slowly at first, then would grow rapidly, and thousands of guppies would fill the pond.
    c. The guppy population would never become very large, because only organisms such as insects and bacteria reproduce in that manner.
    d. The guppy population would continue to grow slowly over time.
12. Once a population of guppies has been established for a number of years in a real (not ideal) pond with other organisms including predators, what will likely happen to the population?
    a. The guppy population will stay about the same size.
    b. The guppy population will continue to rapidly grow in size.
    c. The guppy population will gradually decrease until no more guppies are left.
    d. It is impossible to tell because populations do not follow patterns.
13. In guppy populations, what are the primary changes that occur gradually over time?
    a. The traits of each individual guppy within a population gradually change.
    b. The proportions of guppies having different traits within a population change.
    c. Successful behaviors learned by certain guppies are passed on to offspring.
    d. Mutations occur to meet the needs of the guppies as the environment changes.

Canary Island Lizards

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent (Thorpe & Brown, 1989). Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.

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

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

15. What do you think happens among the lizards of a certain species when the food supply is limited?
    a. The lizards cooperate to find food and share what they find.
    b. The lizards fight for the available food and the strongest lizards kill the weaker ones.
    c. Genetic changes that would allow lizards to eat new food sources are likely to be induced.
    d. The lizards least successful in the competition for food are likely to die of starvation and malnutrition.
16. A well-established population of lizards is made up of hundreds of individual lizards. On an island, all lizards in a lizard population are likely to…
    a. Be indistinguishable, since there is a lot of interbreeding in isolated populations
    b. Be the same on the inside but display differences in their external features
    c. Be similar, yet have some significant differences in their internal and external features
    d. Be the same on the outside but display differences in their internal features

17. Which statement best describes how traits in lizards will be inherited by offspring?

    a. When parent lizards learn to catch particular insects, their offspring can inherit their specific insect-catching-skills.

    b. When parent lizards develop stronger claws through repeated use in catching prey, their offspring can inherit their stronger-claw trait.

    c. When parent lizards' claws are underdeveloped because easy food sources are available, their offspring can inherit their weakened claws.

    d. When a parent lizard is born with an extra finger on its claws, it offspring can inherit six-fingered claws.

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

Table 6: Lizard Characteristics

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

    a. Lizard A

    b. Lizard B

c. Lizard C

d. Lizard D

19. According to the theory of natural selection, where did the variations in body size in the three species of lizards most likely come from?

    a. The lizards needed to change in order to survive, so beneficial new traits developed.

    b. The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.

    c. Random genetic changes and sexual recombination both created new variations.

    d. The island environment caused genetic changes in the lizards.

20. What could cause one species to change into three species over time?

    a. Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.

    b. Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.

    c. There may be minor variations, but all lizards are essentially alike and all are members of a single species.

    d. In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

APPENDIX B7

Speciation Story: Peter Rabbit Meets Charles Darwin

Adapted from Jane Y. Meneray

Woodrow Wilson Biology Institute, Access Excellence

http://www.accessexcellence.org/AE/AEPC/WWC/1995/rabbit.php

Here's the story: Imagine a happy rabbit population living on the banks of a river. The population varies in ear length. Allele A is dominant and it codes for long ears. Allele a is recessive and codes for short ears. The alleles in this rabbit population are equally distributed: 50% A and 50% a. Suddenly (oh horror!) an earthquake occurs. The river changes course and the rabbit population is split in half. Rabbits don't swim well and the populations are effectively isolated. The allele frequencies in ear length remain the same, however. The earthquake has disrupted things and the southern population of rabbits migrates further south in search of food. The northern population of rabbits migrates further north in search of food. The rabbits reproduce (that's what rabbits do best) and many generations pass. Things have changed, however. The climate in the south is very hot, and allele A (long ears) gives the southern rabbits a selective advantage. Long ears mean more heat loss, less energy expended, and more time for fun and greater reproductive success. The allele distribution for the southern rabbit population becomes: 75% A and 25% a. The northern climate has become very cold. Here, short ears mean less heat loss, more energy conserved, more time for fun and greater reproductive success. The allele frequencies for the northern rabbit population becomes: 25% A and 75% a.

Questions:

1. Are long or short ears dominant?

2. Has evolution occurred in this situation? How do you know?

3. Has speciation occurred in this situation? How do you know?

4. Are short ears an adaptation for all rabbit populations? Explain.

APPENDIX B8

Mutation Rate Online Lab

Adapted from Leif Saul

http://www.biologycorner.com/worksheets/evolutionlab.html

Purpose:

In this lab, you will use a computer simulation to track a population of organisms as they evolve. You will take data on the number and varieties of the organisms and graph them to show change over time and determine how the MUTATION RATE affects how populations evolve.

Procedure:

1. Go to **www.biologyinmotion.com** and click on the link that says "**evolution lab**."
2. Read the introduction and the contents to learn about the imaginary creatures you will be studying and how to operate the simulator. **Answer analysis questions 1-6 below as you read.**
3. The purpose of this simulation is to determine how the mutation rate affects the evolution of your population. You will run 4 different trials with varying settings for mutation rate.
4. When looking at the Natural Selection Simulation screen, click on "**settings**" (at the far right).
5. For the first trial, leave the **Selection Strength = 0.8** and set the **Mutation Rate = 0** and click "**ok**".
6. Click on "**Go one cycle**" and record the "**Mean Phenotype**" (at the far left) in your data table.

7. Follow along with the data table to see which "**Go**" button to click on next.
8. Record all of your "**Mean Phenotypes**" in the data table.
9. Click "**Reset**" after completing **250 cycles**.
10. Repeat Steps 4 – 9 for all four trials. The "**Mutation Rate**" for each trial is listed at the top of each data table.

Analysis: Please answer the following questions using COMPLETE SENTENCES.

1. What is evolution all about?
2. What is the primary way that organisms become better adapted to their environment?
3. Why can't all individuals contribute equally to the number of offspring in the next generation?
4. Individuals with phenotypes that are better suited to a specific environment are more likely to do what two things?
5. In this simulation, who dies?
6. What is the cause of variation that this simulation focuses on?
7. Explain how this simulation shows natural selection at work.
8. Explain **HOW** the mutation rate affects the evolution of your populations.
9. Explain **WHY** the mutation rate affects the evolution of your populations.
10. Graph your results on a sheet of graph paper. This should be a **LINE GRAPH** with **4 LINES**. The X-axis is "**Cycles**" and the Y-axis is "**Mean Phenotype**." Make sure each of your lines is a **different color** (for different trial) and include a key. Also, remember that all graphs have a **title** and **labels** on each axis.
11. In your own words, explain what the graph shows.

12. Describe a situation where this type of selection might occur.

Data:

Table 7: Mutation Rate Lab Data Table 1

Trial 1 Mutation Rate = 0	
Cycles	Mean Phenotype
1	
2	
3	
4	
5	
10	
15	
20	
50	
100	
150	
200	
250	

Table 8: Mutation Rate Lab Data Table 2

Trial 2 Mutation Rate = 0.2	
Cycles	Mean Phenotype
1	
2	
3	
4	
5	
10	
15	
20	
50	
100	
150	
200	
250	

Table 9: Mutation Rate Lab Data Table 3

Trial 3 Mutation Rate = 0.5	
Cycles	Mean Phenotype
1	
2	
3	
4	
5	
10	
15	
20	
50	
100	
150	
200	
250	

Table 10: Mutation Rate Lab Data Table 4

Trial 4 Mutation Rate = 1.0	
Cycles	Mean Phenotype
1	
2	
3	
4	
5	
10	
15	
20	
50	
100	
150	
200	
250	

APPENDIX B9

When Milk Makes You Sick

Adapted from Therese Passerini

http://www.indiana.edu/~ensiweb/lessons/tp.milk3.html

Background:

According to statistics, approximately one third of all Americans feel ill after consuming milk and other dairy products. Parents constantly tell their children to "drink their milk" because milk "does a body good." It is well known that the calcium in milk helps to build strong teeth and bones. Overall, milk is a good source of nutrients, like calcium and protein.

Most animals stop drinking milk after they are weaned from their mother, and their body chemistry changes so that they can no longer digest the sugar found in milk. Worldwide, this is also true for the human population. This is considered normal. It is actually unusual for adults to be able to digest milk easily.

The sugar found in milk is called lactose and is a disaccharide. Lactose intolerance is the inability to break down this sugar. People who are unable to break down lactose are missing, or have a non-functioning enzyme called lactase. When lactose intolerant people consume milk, they often feel bloated and experience gas and diarrhea. As mentioned earlier, most adult animals are not able to break down lactose. Somewhere along the way, some adult humans might have developed a mutation that allows them to digest lactose as adults (lactose tolerant).

Purpose: To hypothesize where lactose tolerance might have developed and why, and to determine the mode of inheritance for the gene.

<u>Part A: Pedigrees</u>

You will make three pedigrees based on each of the scenarios below to determine how lactose intolerance is inherited. **Shade in the circles or squares of individuals that are <u>lactose INTOLERANT</u>.**

<u>Pedigree 1:</u>

Mike and Donna Miller are both lactose tolerant. They have four children. Fred, Nick, and Linda are all lactose tolerant. Their daughter Jane is lactose intolerant. Draw the pedigree for this family below.

<u>Pedigree 2:</u>

Mary is married to John. Mary is lactose intolerant; John is not. They have five children. Ann, David, and Dan are lactose intolerant. Nancy and Scott are lactose tolerant.

<u>Pedigree 3:</u>

Joe and Lucy Anderson are both lactose intolerant. They have four children: Alicia, Eric, Ben, and Rodney. All of their children are lactose intolerant.

<u>Analysis of Pedigrees:</u>

*Please answer the following questions using **COMPLETE SENTENCES**.*

1. Does it appear that lactose intolerance is an inherited characteristic? Explain.
2. How can two parents who are both lactose tolerant produce children who are lactose intolerant? Explain.
3. Is lactose intolerance dominant or recessive? Explain, giving reasons.

Part B: Populations and Lactose Intolerance

Graph the information in the charts below that provide percentages for lactose intolerant populations in different countries. You may use a **bar graph**. **The x-axis should be the "country of origin" and the y-axis should be the "percentage of lactose intolerance."** Remember that all graphs need a **Title and Labels** on each axis.

Table 11: Percent of Lactose Intolerant People by Country

Country of Origin	% of Lactose Intolerance	Country of Origin	% of Lactose Intolerance
China	98	Iraq	71
Greenland	85	Russia	16
Mexico	53	Australia	20
Brazil	60	England	15
Italy	55	Kenya	88
South Africa	95	United States	30
India	60	Nigeria	22

Ethnicity in the United States also plays a part in lactose intolerance. Graph the information found in the table below in a **bar graph**. **The ethnicity should go on the x-axis and the percent of intolerance should go on the y-axis.** Don't forget the **title and labels** on each axis.

Table 12: Lactose Intolerance in the United States

Ethnicity	% of Lactose Intolerance	Ethnicity	% of Lactose Intolerance
African Americans	75	Eskimos	80
Asian Americans	90	Hispanic Americans	53
Caucasians	15	Native Americans	90

Analysis of Population Data:

Please answer the following questions using ***COMPLETE SENTENCES****.*

1. Formulate a hypothesis as to where lactose **tolerance** originated and explain why tolerance would occur in this location.
2. How can migration and gene flow (people / genes moving into or out of a population) affect a population and cause it to evolve?
3. When the body does not secrete lactase enzyme in the intestine, the lactose sugar is not digested. Bacteria that are a normal part of the colon use the lactose for food and produce gas. How does this contribute to the symptoms of lactose intolerance?
4. During the past 5,000 years, agriculture has been important to human populations. In some isolated areas, crops did not perform as well or the climate did not permit growing crops year round. In these places, animals and their milk were the main food supply. Use your knowledge of evolution and natural selection to explain how some populations may have become lactose tolerant.
5. What would explain the statistics that approximately 30% of all Americans are lactose intolerant compared to other parts of the world where that number is more than 80%?
6. Compare the percentages of populations in African countries (South Africa, Nigeria, and Kenya) that are lactose intolerant. Form a hypothesis to explain why Nigeria is so different from the other African countries. You should include an explanation with your hypothesis.

APPENDIX B10

Limiting Factors / Evolution Game

Adapted from Amy Quillen and Gail Corey

http://www.accessexcellence.org/AE/AEPC/WWC/1995/limiting.php

Background:

The success of a population is dependent on the limiting factors impacting its environment. A limiting factor may be abiotic or biotic. These critical factors may restrict an organism in its development and productivity. Limiting factors play a crucial role in directing evolutionary pathways.

Objectives:

Students will be able to:

- Explain the relationship between limiting factors and evolution
- Hypothesize possible evolutionary pathways for modern day organisms

Procedure:

1. Each student should select a mammal as their "game piece."
2. Play begins with a student selecting a card from the pile. If the card does not relate to the student's mammal, he or she loses a turn, which passes to the next individual.
3. Once a card is selected, it is returned to the bottom of the pile.
4. The game ends when the first student has evolved into his or her chosen mammal. (Landed on the mammal. They do not need to have the EXACT number to win.)

Analysis:

*Please answer the following questions using **COMPLETE SENTENCES**.*

1. Take 3 of the game cards that involve EVOLUTION. Explain what is happening on each card and explain why this is helpful.
2. Take 3 of the game cards that involve REGRESSION. Explain what is happening on each card and explain why this is helpful.
3. Using your specific mammal, describe a feature that would be particularly helpful for your mammal to survive and reproduce. Be sure to indicate what your mammal is and why this particular feature would be helpful. Be specific.

APPENDIX B11

Homologous & Analogous Structures

Adapted from http://evolution.berkeley.edu/evolibrary/home.php

Go to the website: http://evolution.berkeley.edu/evolibrary/article/similarity_hs_01

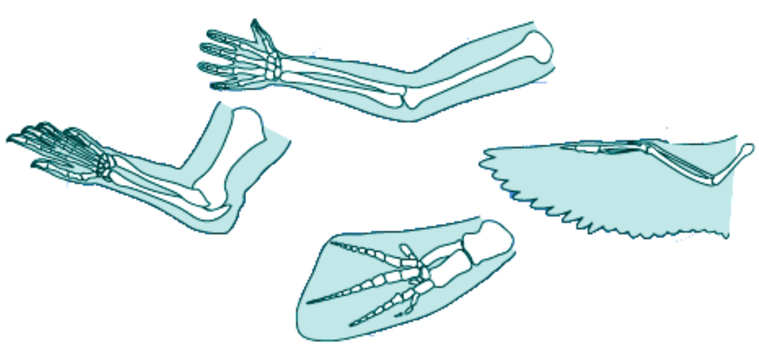
Please answer the following questions using ***COMPLETE SENTENCES.***

1. In the images below, which pair represents an analogy and which pair represents a homology? Explain why for each.

   Figure 19: Homologies and Analogies

2. Define homology.
3. Define analogy.
4. Explain when convergent evolution would occur.
5. What is a tetrapod?
6. What are two ways that tetrapod limbs are similar to each other?
7. What are the **NAMES** of the six bones found in all tetrapod legs?
8. Identify these limbs (to what animals do they belong)?

   Figure 20: Homologous Forelimbs



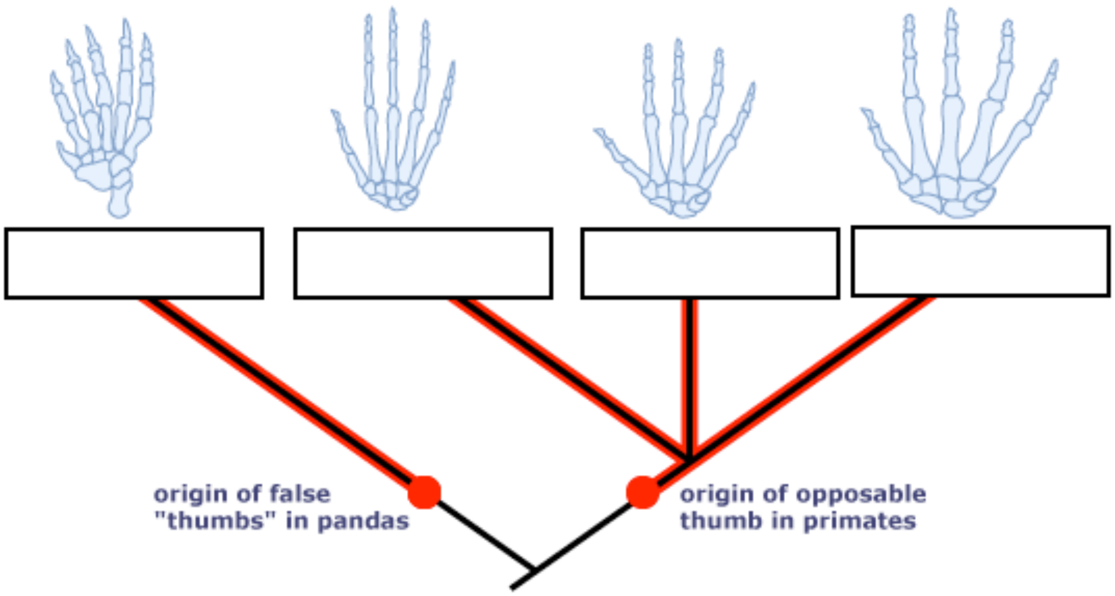
9. What did the common ancestor of all modern tetrapods look like?
10. How old is the common ancestor of the tetrapods?
11. What are structures inherited from a common ancestor called?
12. What is an example of a homologous structure between a beaver and an elephant?

    What are each of these structures used for?
13. *Click on "Take a Side Trip" at the bottom of the screen*. How are a bird and a crocodile homologous?
14. Similar structures that evolved independently are called what?
15. Give an example of an animal that a Smilodon would be related to.
16. Give an example of an animal that a Thylacosmilus would be related to.
17. Analogous structures develop in response to what?
18. Describe how two unrelated flowers could evolve to have a similar appearance.
19. What are two similarities between sharks and dolphins?
20. What are two differences between sharks and dolphins?
21. Are the similarities between sharks and dolphins homologous or analogous?

    Explain why.
22. What three criteria are used to determine whether something is a homology or analogy?

23. Fill in the blanks of the primate tree.

Figure 21: Primate Tree



24. Are homologous or analogous traits used to develop the tree above? Why?

25. Of the organisms in the tree above, which three are most closely related? How can you tell this by just looking at the tree?

26. Considering all of the evidence, are the “wings” (actually flaps of skin stretched between the legs) of sugar gliders and flying squirrels homologous or analogous structures? Explain why you would conclude this.

27. *Click on “Take a Side Trip, Examples of Homology” at the bottom of the screen.* How are a venus fly trap and a pitcher plant homologous?

28. What homology do all bowerbird species share?

29. Mammal ear bones are homologous to what in lizards?

30. *Click on “Take a Side Trip, Examples of Analogy” at the bottom of the screen.* How are barnacles and limpets alike? How can these similarities be explained?

31. How are anteaters and echidnas similar? Why are they similar?

32. Are human and panda thumbs homologous or analogous? Explain.

APPENDIX B12

Embryo Comparisons

Adapted from Odyssey of Life Part 1 The Ultimate Journey

http://www.pbs.org/wgbh/nova/teachers/activities/2317_odyultim_01.html

Background:

Can you tell a chicken from a fish? How about a human from a pig? Sure you can, you say. Chickens have wings, fish have fins, humans have arms, and pigs have hoofs. But what about when they are just starting to form? The drawings below represent three developmental stages of five different animals. They have been all mixed up – see if you can tell what's what.

Objectives:

Students will be able to:

- Compare embryos of different organisms
- Explain how similar most living things are in the early stages of life

Materials:

- Tape / Glue
- Scissors

Procedure:

1. Cut out the pictures of the embryos.
2. Place the pictures in the correct Stages and under the correct Organism. (Starting with Stage 3 is the easiest.)
3. When you are sure of how you have placed the organisms, glue them to your paper.

Analysis:

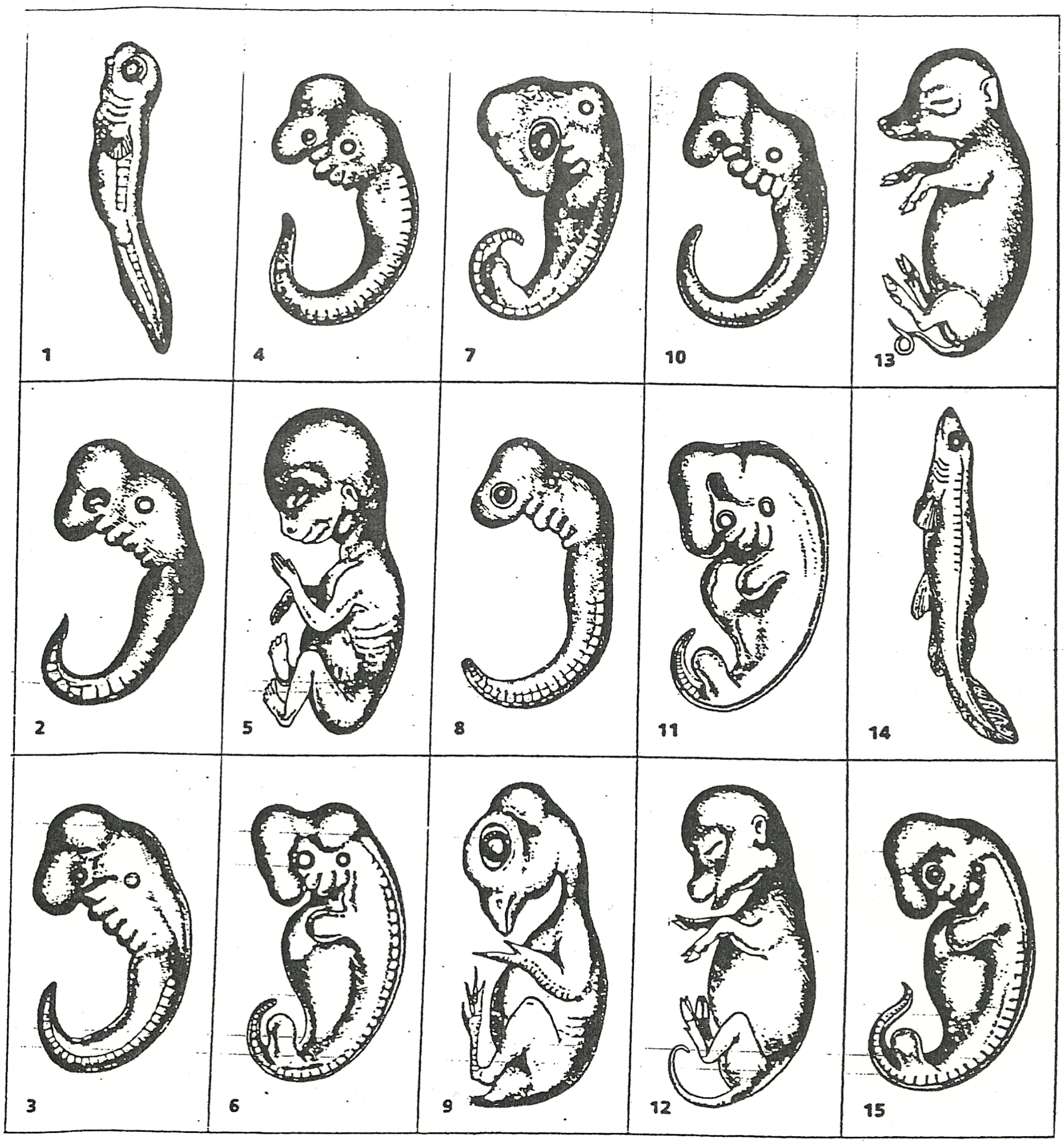
Please answer the following questions using ***COMPLETE SENTENCES****.*

1. Explain why you ordered the pictures the way that you did.
2. What are 3 similarities between the pictures?
3. What are 3 differences between the pictures?
4. What trends do you see as you go from stage 1 to stage 3?

Table 13: Embryo Comparisons Blank Data Table

	Fish	Chick	Pig	Calf	Human
Stage 1					
Stage 2					
Stage 3					

Figure 22: Embryo Pictures to Compare



APPENDIX B13

Creating Phylogenetic Trees Using Caminalcules

Adapted from Robert P. Gendron

http://nsm1.nsm.iup.edu/rgendron/Caminalcules.shtml

Background:

The Caminalcules are artificial animals created by the late Professor Joseph Camin of the University of Kansas. They were developed to study how taxonomists classify real organisms. Classifications of organisms (or taxonomic or phylogenetic trees) are the "road maps" of how organisms might have evolved; these trees are hypotheses of relatedness. Often time, in the cases of real organisms, scientists do not always agree on one tree. These trees are created by looking at specific characteristics, and finding the simplest or closest relationships between these organisms. In this activity, we will construct a phylogenetic tree based on the physical characteristics of the Caminalcules.

Objectives:

Students will be able to:

- Construct a phylogenetic tree based on physical characteristics
- Discover how taxonomists classify real organisms
- Explain how organisms have evolved from common ancestors

Materials:

- Scissors
- Tape / Glue
- Blank Paper
- Rulers
- Caminalcules Sheet

Procedure:

1. Examine the 29 Caminalcules thoroughly.

2. Choose 5 characteristics that you would like to use to classify these organisms – shell shape, eye presence, etc.
3. Using the table below, describe these 5 characteristics for each of the 29 Caminalcules. List traits 1-5 in each column. Describe each of the recent ancestors within each corresponding column; the first one is done for you.
4. Once your data table is completely filled out, cut out your 29 Caminalcules.
5. Using the data from your data table, construct what you think is the simplest tree (with the fewest number of branches) for the Caminalcules. Caminalcule # 73 is the common ancestor and should be placed at the base of your tree.
6. When you think you have made your best possible tree, tape or glue them on a clean sheet of large paper.
7. Draw in the branches connecting your Caminalcules.

Table 14: Caminalcule Characteristics

Caminalcule	Eyes				
1	Present				
2	Present				
3	Present				
4	Present				
5	Present				
6	Present				
7	Absent				
8	Absent				
9	Present				
10	Present				
11	Present				
12	Present				
13	Absent				
14	Absent				
15	Absent				
16	Present				
17	Present				
18	Present				
19	Absent (Stalks)				
20	Absent (Stalks)				
21	Present				
22	Present				
23	Present				
24	Present				
25	Absent				
26	Absent (Stalks)				
27	Present				
28	Absent				
29	Absent (Stalks)				

Analysis:

Please answer the following questions using ***COMPLETE SENTENCES.***

1. Compare your tree to several other classmates. Are your classifications identical?

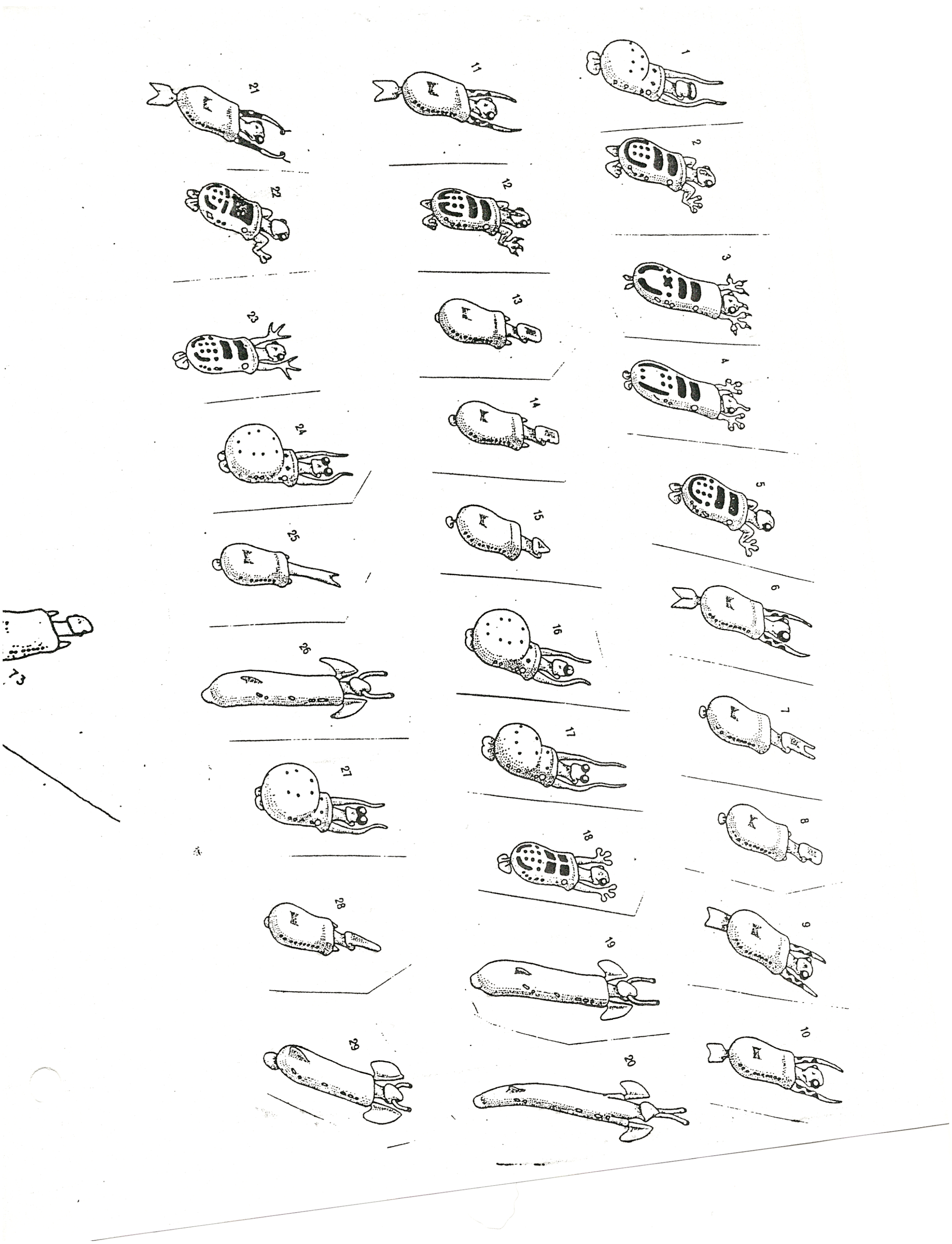
   Why or why not?

2. Explain the branching points for your tree. (Why does it look the way it does?)

3. What does your phylogenetic tree represent?

4. If two Caminalcules appear close together in your tree, what does that mean?
5. Which Caminalcule is the oldest? What characteristics does it have?
6. Which Caminalcule is most closely related to number 9? Why?
7. What is the closest ancestor to number 20? Why?
8. If scientists wanted to test this hypothetical phylogenetic tree, what other evidence could be used to analyze the relationships between the Caminalcules?
9. Are any of the Caminalcules dead end lineages (went extinct)? What could have occurred to cause this extinction?

Figure 23: Pictures of Camincules



APPENDIX B14

Wolf Pack in a Bottle

Adapted from Aleta Sullivan and JoAnne Dombrowski

http://www.woodrow.org/teachers/bi/1995/simulation_wolf.html

Background:

Scientists collected DNA samples from 5 different canines in an attempt to determine which species of canines are most closely related evolutionarily. Your task will be to separate these DNA samples into their smaller parts and then to compare the DNA strands to determine which canine species are the most closely related.

If we were using real DNA, the different DNA fragments would separate from each other because they have different weights. We will be using food coloring, which will also separate for the same reason.

Purpose:

To determine which canine species are most closely related and which have evolved the most.

Objectives:

At the end of this activity, students will be able to:

- Explain how similarities of DNA sequences show common ancestry among species
- Describe how differences in DNA sequences are evidence for evolution

Materials:

- Five Food Coloring Solutions
- Toothpicks
- Filter Paper
- Rulers

Procedure:

1. Get a piece of filter paper, a ruler, a beaker, and a pencil.
2. Fold the filter paper in half so it will be able to stand in the beaker.
3. Draw a **pencil** line about 2 cm above the lower edge of the filter paper across the entire strip.
4. Mark five locations on the line, evenly spaced, and number these locations from 1-5 **BELOW** each location.
5. Take a toothpick and dip it into Sample DNA solution #1. Using the toothpick, transfer this solution to your filter paper on your #1 mark on the pencil line.
6. Throw this toothpick away.
7. Using a new toothpick for each solution, transfer DNA samples 2-5 onto your filter paper.
8. While the filter paper dries, pour about 1 cm of water into your beaker. (The water MUST be below the pencil line that you drew on your filter paper.)
9. Put your folded filter paper into the water, making sure that it is not touching the sides of the beaker.
10. Observe what happens and after 4-5 minutes take your paper out of the water and set on a paper towel to dry.

Data:

Attach your dried filter paper in the space below.

Analysis:

*Please answer the following questions using **COMPLETE SENTENCES**.*

1. What happened to each sample when it was put in water?
2. Why did the different DNA fragments separate from each other?
3. Which samples are the most closely related species? How do you know?
4. Which samples have evolved to be different from the other samples? How do you know?
5. Do all five of these species share a common ancestor? Why or why not?

APPENDIX B15

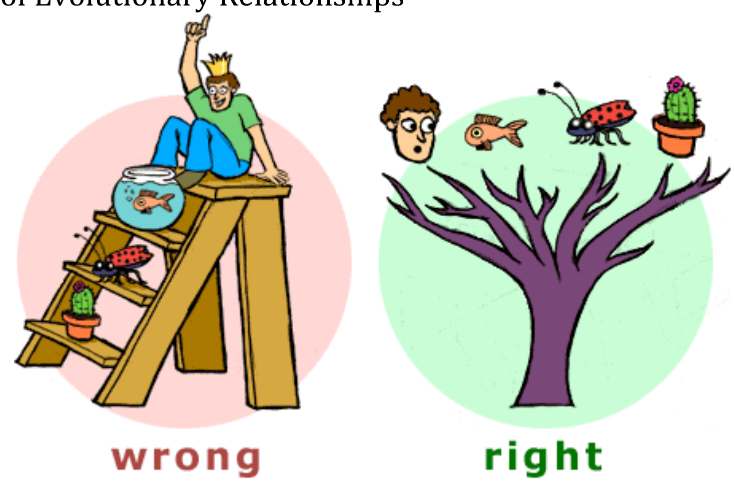
Investigating Common Descent

Modification of Activity 4*: Investigating Common Descent: Formulating Explanations and Models* from Chapter 6 of the National Academy of Sciences Publication "Teaching About Evolution and the Nature of Science."

Background:

One of the most common misconceptions about evolution is seen in the statement that "humans came from apes." This statement assumes that organisms evolve through a step-by-step progression from "lower" forms to "higher" forms of life and the direct transformation of one living species into another. Evolution, however, is not a progressive ladder. Furthermore, modern species are derived from, but are not the same as, organisms that lived in the past.

Figure 24: Picture of Evolutionary Relationships



Very few people question the idea that Charles Darwin's *Origin of Species* in 1859 produced a scientific revolution. In essence, Darwin proposed a constellation of ideas that included: organisms of different kinds descended from a common ancestor (common descent);

species multiply over time (speciation); evolution occurs through gradual changes in a population (gradualism); and competition among species for limited resources leads to differential survival and reproduction (natural selection). This activity centers on the theory of common descent.

The questions that we will explore are: Did humans evolve from modern apes? Or do modern apes and humans have a common ancestor? There is a significant difference between these two questions. This activity will give you the opportunity to observe differences and similarities in the characteristics of humans and apes. The apes discussed in this activity are the chimpanzee and the gorilla.

Objectives:

Students will be able to:

- Explain how humans and apes evolved from a common ancestor
- Build a model to help demonstrate differences and similarities in DNA sequences between different organisms

Materials:

- Paperclips (4 bags for each group)

Pre-Activity Questions:

Look at the table below and answer the following questions.

1. Are there any characteristics that are similar between apes and humans? Which ones?
2. Explain how legs, arms, and feet have adapted for apes to live in trees. Explain how these have adapted for humans to walk upright.

3. What is the difference in brain size between apes and humans? What does this mean in terms of more complex thinking processes?
4. The apes that we will be looking at are gorillas and chimpanzees. Make a hypothesis as to whether humans are more closely related to gorillas or to chimpanzees. Explain why you think the way that you do.

Table 15: Characteristics of Apes and Humans

Characteristics	**Apes**	**Humans**
Posture	Bent over or quadrupedal; "Knuckle-walking" common	Upright or bipedal
Leg and Arm Length	Arms longer than legs; Arms adapted for swinging, usually among trees	Legs usually longer than arms; Legs adapted for striding
Feet	Low arches; Opposable big toes, capable of grasping	High arches; Big toes in line with other toes; Adapted for walking
Teeth	Prominent teeth; Large gaps between canines and nearby teeth	Reduced teeth; Gaps reduced or absent
Skull	Bent forward from spinal column; Rugged surface; Prominent brow ridges	Held upright on a spinal column; Smooth surface
Face	Sloping; Jaws jut out; Wide nasal opening	Vertical profile; Distinct chin; Narrow nasal opening
Brain Size	80 to 705 cm^3 (living species)	2000 to 2400 cm^3 (fossil to present)
Age at Puberty	Usually 10 to 13 years	Usually 13 years or older
Breeding Season	Estimated at various times	Continual

Procedure:

Structures between organisms might be similar because they carry out the same functions or because they were inherited from a common ancestor. Because similar structures don't always determine evolutionary relationships, scientists now look at DNA sequences to see how closely related two species are.

1. Working in your group of 4, you will make strands of DNA from 4 different organisms. (Each person will be responsible for making 1 strand.)
2. To make your DNA strands, you will use different colored paper clips. Each color represents one of the 4 nitrogen bases in DNA.

Blue = Adenine (A)	Green / Yellow = Guanine (G)
White = Thymine (T)	Red / Pink = Cytosine (C)

3. Assign each person in the group to assemble one of the following strands.

   Strand #1 – Human DNA

   A – G – G – C – A – T – A – A – A – C – C – A – A – C – C – G – A – T – T – A

   Strand #2 – Chimpanzee DNA

   A – G – G – C – C – C – C – T – T – C – C – A – A – C – C – G – A – T – T – A

   Strand #3 – Gorilla DNA

   A – G – G – C – C – C – C – T – T – C – C – A – A – C – C – A – G – G – C – C

   Strand #4 – Common Ancestor DNA (Hypothetical)

   A – G – G – C – C – G – G – C – T – C – C – A – A – C – C – A – G – G – C – C

4. Using a small piece of masking tape, label the first paper clip of each strand with the organism name.

5. Compare the human DNA to the chimpanzee DNA by matching the strands base by base (paper clip by paper clip). Count the number of bases that are the same and the number that are not the same and record this in Data Table 1.
6. Now compare the human DNA to the gorilla DNA. Count the number of bases that are the same and the number that are not the same are record this in the data table.

Biologists have determined that some mutations in DNA occur at a regular rate. They can use this rate as a "molecular clock" to predict when two organisms began to separate from a common ancestor. Most evolutionary biologists agree that humans, gorillas, and chimpanzees shared a common ancestor at one point in their evolutionary history. They disagree, however, on the specific relationships among these three species.

7. Assume that the common ancestor DNA represents a section of the hemoglobin gene of a hypothetical common ancestor. Compare this common ancestor DNA to all three samples of DNA (gorilla, human, and chimpanzee), one sample at a time. Record this information in the data table.

Data:

Table16: Comparisons of Human DNA

Human DNA Compared To:	**Number of Matched Bases**	**Number of Unmatched Bases**
Chimpanzee DNA		
Gorilla DNA		

Table 17: Comparisons of Common Ancestor DNA

Common Ancestor DNA Compared To:	**Number of Matched Bases**	**Number of Unmatched Bases**
Human DNA		
Chimpanzee DNA		
Gorilla DNA		

<u>Analysis:</u>

Please answer the following questions using ***COMPLETE SENTENCES.***

1. Which is more similar to the human DNA, the chimpanzee or the gorilla?
2. What does this suggest about the relationship between humans, gorillas, and chimpanzees?
3. Does the data support your hypothesis? Why or why not?
4. Which DNA is most similar to the common ancestor DNA?
5. When compared to the common ancestor DNA, which two DNAs were most similar in the way that they compared to it?
6. Which of the following statements is most accurate? Explain your answer.
    a. Humans are more closely related to the common ancestor than gorillas are.
    b. Gorillas are more closely related to the common ancestor than humans are.
7. Which of the following statements is most accurate? Explain your answer in a short paragraph.
    a. Chimpanzees and humans have a common ancestor.
    b. Chimpanzees are the direct ancestors of humans.

8. A comparison of many more DNA sequences indicates that human DNA and chimpanzee DNA are 98.8% identical. Does this mean that humans evolved from chimpanzees? Explain.

APPENDIX B16

The Hands of Primates

Adapted from Susan S. Plati

http://www.accessexcellence.org/AE/AEPC/WWC/1995/thumbs.php

Background:

Only apes and primates have hands capable of grasping objects. The grasp is made possible by the opposable thumb, so called because it moves opposite to the rest of the fingers. One of the differences between human beings and other primates is the structure of the hand. Being bipedal, or able to walk on two limbs, has freed the arms and hands of humans for other tasks, such as making and using sophisticated tools. The human hand has a totally opposable thumb adapted for refined movements. In addition, the human hand can be rotated. The opposable thumb and the rotation of the hands enable humans to grasp and hold a variety of objects in many different ways.

In this activity, you will compare the hands of several different primates. You will also compare your performance of a series of different tasks using your thumb and fingers together with your performance of the same tasks without the aid of your thumb.

Objectives:

Students will be able to:

- Compare similarities and differences between primate hands
- Explain why the development of opposable thumbs is an adaptation for humans

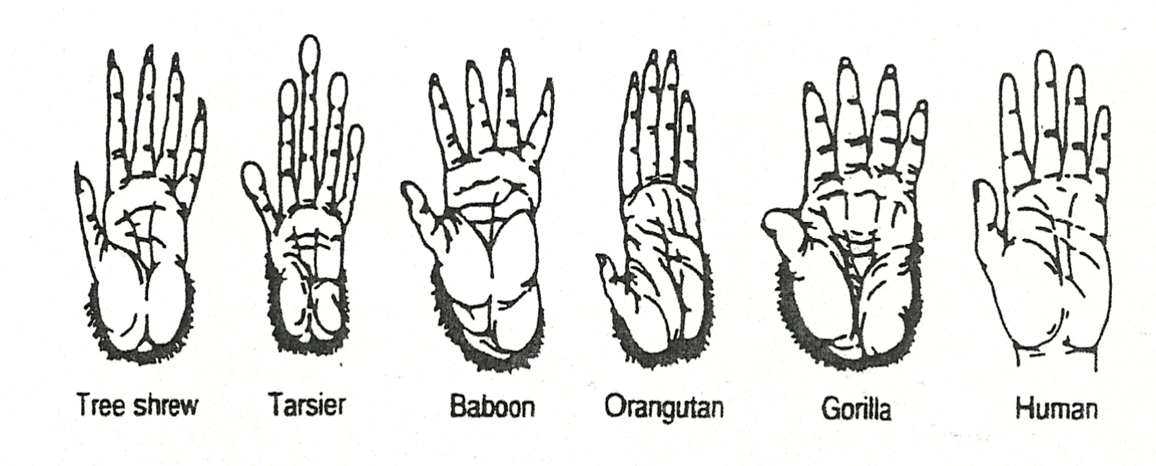
Materials:

- Masking Tape
- Mini Marshmallows
- Pennies
- Chopsticks
- Two-Liter Bottles

Procedure:

1. Study the six different primate hands below. After carefully examining the diagrams, answer Analysis questions 1 and 2.

   Figure 25: Hands of Primates

2. Do each of the activities listed in the Data Table. Your partner will time how long it takes for you to complete each task in a normal manner (using your thumbs).
3. Switch roles and time your partner doing the tasks in a normal manner (using thumbs).
4. Using masking tape, have your partner tape each of your thumbs to its adjacent index finger, so that your thumb points in the same direction as your fingers.
5. After your thumbs are securely taped, try each of the activities in the Data Table again. Have your partner time how long it takes for you to do each without the use of your thumbs. (If an activity takes longer than 5 minutes, record the word "unsuccessful" in your Data Table.)
6. Switch roles and time your partner doing the tasks without their thumbs.

Table 18: Time to Complete Activities

Activity	**Time Needed With Thumbs**	**Time Needed Without Thumbs**
Untie and Retie a Shoe		
Unscrew a Bottle Cap and Screw It Back On		
Open and Close a Door		
Write Your Name and Address		
Send a Text Message to Someone in our Class that Says "I love Biology"		
Pour a Glass of Water		
Pick Up 5 Marshmellows Using Chopsticks (one at a time)		
Pick up 10 Pennies (one at a time)		

Analysis:

*Please answer the following questions using **COMPLETE SENTENCES**.*

1. What are two of the features that all of the hands have in common?
2. Name one feature that is unique to each of the hands.
3. What are two features of the tree shrew's hand that make it well adapted for the environment in which it lives?
4. Based on the structure of its hand, in what type of environment would you expect the tarsier to live? Explain.

5. The amino acid sequence of the hemoglobin molecules in humans and gorillas is very similar, indicating an evolutionary closeness. Do the structures of the gorilla and human hands support this idea? Explain.
6. Many scientists believe that the opposable thumb has helped humans adapt to their environment and survive. Based on the activities that you tried and timed with your thumbs free and taped down, give at least three reasons why an opposable thumb would enable humans to better survive in their environment.
7. Many primates also have an opposable toe on each foot. How is this a useful adaptation?
8. The hands of many primates are connected to very long arms. For what type of environment are these primates well adapted? Explain.
9. Besides the activities conducted in this lab, what are three other activities that would be difficult for you to accomplish without opposable thumbs?

APPENDIX B17

Phylogenies Based on DNA Sequences

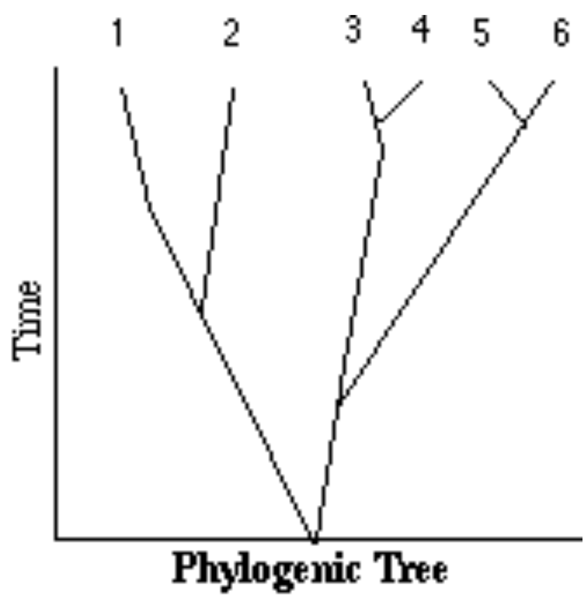
Adapted from Access Excellence

http://www.accessexcellence.org/AE/AEPC/WWC/1995/simulation_tree.php

Background:

To study the evolutionary relationships between organisms alive today, various methods can be used to estimate when those organisms may have diverged from a common ancestor. Having this information for a group of organisms would allow one to construct a ***phylogenetic tree***. This tree depicts in graphic form these divergences over time and could possibly look like the sample tree below.

Figure 26: Example Phylogeny



In the past, making phylogenetic trees was done by using observations of anatomy and physiology and by comparing fossils. However, sometimes organisms look similar because they evolved in similar environments even though they are only distantly related. This is called ***convergent evolution.*** For example, the North American Woodchuck looks very similar to the Australian Wombat. Based on appearance alone, the two would likely be classified as very closely related.

More recently, though, techniques have been developed in molecular biology for performing such comparisons. One method involves comparing the nucleotide sequence in a particular segment of DNA common to two or more living organisms. This method is often referred to as a ***molecular clock***. When classifying the woodchuck in this way, scientists have found that the woodchuck is actually more closely related to humans than to the wombat! A much more reliable method of classification than using phenotypes, is going straight to the genes and comparing DNA sequences.

<u>Objective:</u>

At the conclusion of this activity, students will be able to:

- Model phylogenetic trees based on DNA sequences.
- Explain that changes in the DNA sequences happen over different lengths of time.

<u>Materials:</u>

- DNA Sequences
- Four Bases Sheet
- Pencil / Paper
- Number Chart
- Dice

<u>Procedure:</u>

1. The entire class begins with the same DNA sequence (Ancestral DNA). This DNA represents the common ancestor that all other DNA sequences will diverge from.
2. The class now gets split into two groups.

3. Each group will now acquire changes to their DNA sequence. To do this, have one person from your group roll a die. Add 2 to whatever you roll. Record this number next to the "Round One" DNA sequence.
4. A different person from your group will now pick a number out of the number bag. This number represents the base that you will change in the DNA sequence.
5. A third person from your group will pick a base out of the base bag. You will change the base at the chosen position (step 4) to this base. (If it's the same base, do this over – you need to have a change.)
6. All group members should record these changes on the "Round One" DNA sequence.
7. Repeat steps 4-6 for as many changes necessary (as indicated by step 3).
8. After all of the necessary changes have been made to the "Round One" DNA, split your group in half.
9. Record all of the changes that you made in "Round One" onto to your "Round Two" DNA.
10. Each new group should repeat steps 3-7, and record the changes on the "Round Two" DNA.
11. Repeat until everyone has completed four rounds.
12. Add up the number of changes that you made to each sequence of DNA and record this next to each of your DNA strands.
13. We will record the class numbers on the board.

Analysis:

Please answer the following questions using ***COMPLETE SENTENCES****.*

1. Why is using DNA sequences a better method of classification than using phenotypes?
2. Suppose that each base change occurs over 1 million years. Beginning with the "common ancestor" on the left, draw a phylogenetic tree on the graph paper below of the new class groups. Be sure to indicate your time scale across the top of the graph paper. (We will number each organism on the board together.)
3. What can cause base changes in DNA?
4. Why is it that all of the horizontal lines on your tree are not the same length?
5. Use the following key as a guide to label each organism on your phylogenetic tree. (This is a very simplified example of a real tree.)

    Organism 1 = Amniota (Ancestor of all Land-Dwelling Vertebrates)

    Organism 2 = Mammal Ancestor

    Organism 3 = Reptile Ancestor

    Organism 4 = Placental Mammal Ancestor

    Organism 5 = Marsupial Mammal Ancestor

    Organism 6 = Bird Ancestor

    Organism 7 = Lizard Ancestor

    Organism 8 = Rabbit

    Organism 9 = Monkey

    Organism 10 = Opossum

    Organism 11 = Kangaroo

Organism 12 = Robin

Organism 13 = Velociraptor

Organism 14 = Frog

Organism 15 = Snake

6. Based on how you labeled your tree, which organism took the longest to evolve? How do you know this?
7. Which organism on your tree is the common ancestor?
8. What does it mean to be the common ancestor?
9. Are frogs more closely related to snakes or to robins? How do you know?
10. Did monkeys evolve from rabbits? Explain.
11. If we were to continue our tree, which organism would not have any more branches coming from it? Why?

Ancestral DNA

A T T C G C T A G C^{10} T A G C C C T G A C^{20} T C G A C C T G

G A^{30} A T C G A G C T A G^{40} C T C A C G A T C G^{50} A T C G A

T T C G C^{60} A C G T G C A C T G^{70} C A C A G G A T C A^{80} A T

C T A G G C T G^{90} A T C G A T C C G T^{100}

Round 1

A T T C G C T A G C^{10} T A G C C C T G A C^{20} T C G A C C T G

G A^{30} A T C G A G C T A G^{40} C T C A C G A T C G^{50} A T C G A

T T C G C^{60} A C G T G C A C T G^{70} C A C A G G A T C A^{80} A T

C T A G G C T G^{90} A T C G A T C C G T^{100}

Round 2

A T T C G C T A G C^{10} T A G C C C T G A C^{20} T C G A C C T G

G A^{30} A T C G A G C T A G^{40} C T C A C G A T C G^{50} A T C G A

T T C G C^{60} A C G T G C A C T G^{70} C A C A G G A T C A^{80} A T

C T A G G C T G^{90} A T C G A T C C G T^{100}

Round 3

A T T C G C T A G C^{10} T A G C C C T G A C^{20} T C G A C C T G G A^{30} A T C G A G C T A G^{40} C T C A C G A T C G^{50} A T C G A T T C G C^{60} A C G T G C A C T G^{70} C A C A G G A T C A^{80} A T C T A G G C T G^{90} A T C G A T C C G T^{100}

Round 4

A T T C G C T A G C^{10} T A G C C C T G A C^{20} T C G A C C T G G A^{30} A T C G A G C T A G^{40} C T C A C G A T C G^{50} A T C G A T T C G C^{60} A C G T G C A C T G^{70} C A C A G G A T C A^{80} A T C T A G G C T G^{90} A T C G A T C C G T^{100}

A T G C

1 2 3 4 5 6 7 8 9 10 11 12 13 14

15 16 17 18 19 20 21 22 23 24 25

26 27 28 29 30 31 32 33 34 35 36

37 38 39 40 41 42 43 44 45 46 47

48 49 50 51 52 53 54 55 56 57 58

59 60 61 62 63 64 65 67 68 69 70

71 72 73 74 75 76 77 78 79 80 81

82 83 84 85 86 87 88 89 90 91 92

93 94 95 96 97 98 99 100

APPENDIX B18

Molecular Sequences & Primate Evolution

Adapted from John Banister-Marx

http://www.accessexcellence.org/AE/AEPC/WWC/1995/simulation_molecular.php

Background:

For many years, organisms have been classified based mainly on their visible characteristics. Organisms that are in the same genus are more closely related than all of the organisms in the same kingdom. The fossil record shows that the types of organisms on Earth have changed dramatically over millions of years. However, the change is gradual, and indicates that common ancestors connect all life forms to each other. When tracing the flow of life back deep in time, many examples of gradual changes from earlier times can be seen. This leads to the understanding of descent with modification.

In addition to structural similarities and the fossil record, DNA and proteins can be used to determine patterns of ancestry and how organisms are related. Those animals that are most similar are likely to have had a recent common ancestor, while those animals that show large differences in gene sequences are presumed to have a much older common ancestor.

In this exercise, we will investigate the use of gene sequences in establishing ancestral relationships among eight different species. To do this, we will compare the amino acid sequences of their hemoglobin molecules. Hemoglobin is the iron-containing protein responsible for oxygen transport in all vertebrates and some invertebrates. Each molecule of hemoglobin consists of an iron-containing subunit with four attached proteins – 2 alpha and 2 beta subunits. In this exercise, we will use amino acid sequence data from the hemoglobin beta subunits from these eight species to determine how closely related each species is to all of the other species. We will then use this information to construct a phylogenetic tree.

Objectives:

Students will be able to:

- Compare differences and similarities in amino acid sequences for a specific protein in several primate species
- Infer ancestral relationships based on amino acid similarities
- Explain how humans and apes evolved from a common ancestor

Procedure:

Part A:

1. Below you will find a comparison of organisms that lists the amino acid sequence for beta hemoglobin for eight different species. To save time and space, only the amino acids that are different have been listed.
2. Compare species A with species B. Count the number of **differences** you see between the two sequences and record this number in the data table.
3. Compare species A with species C. Count the number of **differences** you see between the two sequences and record this number in the data table.
4. Continue comparing the species and counting the number of differences seen in each sequence. Record these differences in the data table.
5. Calculate the average number of differences for each species and record this in the data table. (Round the averages to the nearest whole number.)

6. *Note*: The S in the data table means the same species were compared, so there are obviously no differences. The X represents comparisons that overlap in the matrix.
7. A small number of amino acid differences between any two creatures implies that the two organisms share a relatively recent common ancestor, whereas a large number of amino acid differences implies that the two organisms share a relatively distant common ancestor.
8. Answer Analysis questions 1-4.

<u>Part B:</u>

9. The first seven species in the data table are primates.
10. Label each of the species A-G with their names above the data table according to the chart below.

Species A = Human	Species E = Rhesus Monkey (an Old World Monkey)
Species B = Chimpanzee	Species F = Squirrel Monkey (a New World Monkey)
Species C = Gorilla	Species G = Lemur
Species D = Gibbon	Species H = Identified Later

Table 19: Amino Acid Comparisons of Different Species

Species	A	B	C	D	E	F	G	H
A	S						25	24
B	X	S					25	24
C	X	X	S				24	25
D	X	X	X	S			23	24
E	X	X	X	X	S		22	27
F	X	X	X	X	X	S	25	24
G	X	X	X	X	X	X	S	33
H	X	X	X	X	X	X	X	S
Average	----						24	26

Table 20: Comparison of Organisms

Amino Acid	A	B	C	D	E	F	G	H
1	V	V	V	V	V	V	T	V
2	H	H	H	H	H	H	F	Q
4	T	T	T	T	T	T	T	S
5	P	P	P	P	P	G	P	G
6	E	E	E	E	E	D	E	E
8	K	K	K	K	K	K	N	K
9	S	S	S	S	N	A	G	A
10	A	A	A	A	A	A	H	A
12	T	T	T	T	T	T	T	L
13	A	A	A	A	T	A	S	A
16	G	G	G	G	G	G	G	D
20	V	V	V	V	L	V	V	V
21	D	D	D	D	D	E	E	E
22	E	E	E	E	E	D	K	E
33	V	V	V	V	L	V	V	V
43	E	E	E	E	E	E	E	D
50	T	T	T	T	S	T	S	N
52	D	D	D	D	D	D	D	G
54	V	V	V	V	V	V	I	V
56	G	G	G	G	G	N	G	G
69	G	G	G	G	G	G	S	H
70	A	A	A	A	A	A	A	S
72	S	S	S	S	S	S	S	G
73	D	D	D	D	D	D	E	E
75	L	L	L	L	L	L	L	V
76	A	A	A	A	N	A	H	H
87	T	T	T	Q	Q	Q	Q	A
94	D	D	D	D	D	D	V	D
95	K	K	K	K	K	K	A	K
104	R	R	K	R	K	R	K	R
112	C	C	C	C	C	C	I	V
116	H	H	H	H	H	H	H	R
120	K	K	K	K	K	K	N	K
121	E	E	E	E	E	E	D	D
123	T	T	T	T	T	T	S	T
125	P	P	P	Q	Q	Q	Q	E
126	V	V	V	V	V	V	T	L
129	A	A	A	A	A	A	A	S
130	Y	Y	Y	Y	Y	Y	F	Y

Analysis:

*Please answer the following questions using **COMPLETE SENTENCES**.*

1. What does the S represent in the data table? In other words, what two species are being compared? How many differences would you expect from this comparison?
2. What two species are most closely related? How can you tell?
3. What two species are least closely related? How can you tell?
4. What is the general pattern of differences among the column averages as you move from left to right across the data table? What does this suggest about the relationships of each species?
5. What two groups of primates are least similar to the others?
6. Are gorillas more similar to humans or to chimpanzees based on the sequence data? Why?
7. Explain what the similarities between the species indicate about a common ancestor.

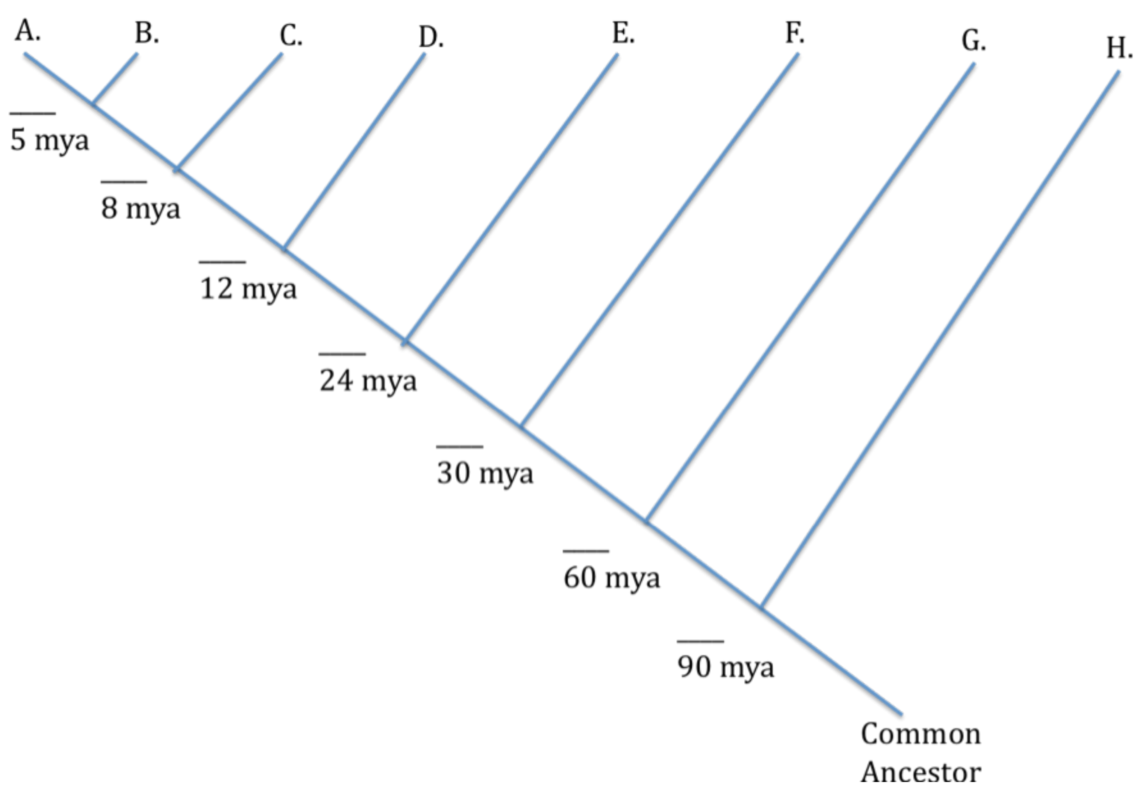
Procedure:

Part C:

Cladistics is a classification scheme that assumes every group of organisms arose by branching off from a previous group. Each branch is called a clade. That clade includes any and all subsequent branching. One clade often includes many smaller clades. All the individuals within a clade share one or more selected traits. Each trait must be identical or very similar within a clade. However, the traits appear to be modified from earlier forms of the trait. The simplest diagram showing the branches is based on the sequence of modifications and produces a cladogram.

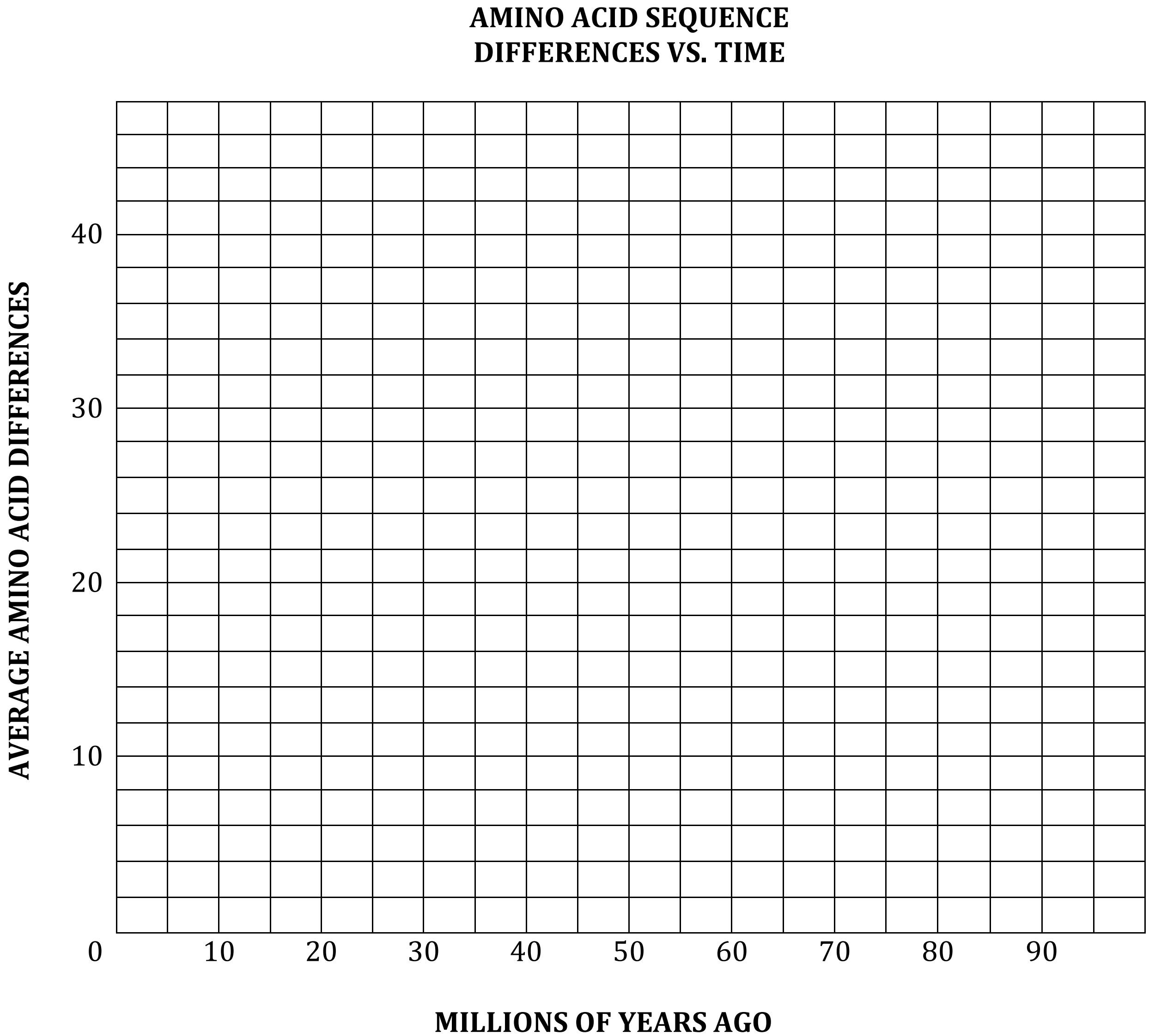
1. Place the name of the species across the top of the cladogram from A to H.
2. Species H is the Horse. Horses, of course, are not primates and are not especially close to primates. The group that includes horses diverged from the primate lineage around 90 million years ago.
3. On the left hand side, place the average number of changes that occurred. (You calculated these averages in the data table.)

Figure 27: Example Primate Phylogeny



4. On the Graph below of **Amino Acid Sequence Differences vs. Time**, plot the data for the relationship between the *average* number of amino acid differences (changes) and the time since divergence (age of the branch).

Figure 28: Graph of Amino Acid Differences versus Time



Analysis:

1. What is the general relationship between the time and average number of differences?
2. Why isn't this relationship perfectly linear? (In other words, why don't the points all fall on a straight line?)

3. At a molecular level, if humans and chimpanzees are about 99% identical, and horses and zebras are about 96% identical, what does this suggest about which pair of organisms is more closely related? Which pair shares a more recent common ancestor? Explain.
4. How long ago did chimpanzees and squirrel monkeys share a common ancestor?
5. Did humans evolve from chimpanzees? Explain.

APPENDIX B19

The Need for Vitamin C

Adapted from Mary Ball and Steve Karr

http://www.indiana.edu/~ensiweb/lessons/psa.ball.html

Background 1:

Scurvy and the Discovery of Vitamin C

In 1535, the Frenchman James Cartier sailed up the St. Lawrence River to Quebec City, Canada. Many of his sailors were suffering from “scurvy,” a disease that was common aboard ships that had been at sea for several weeks. Sufferers of scurvy experienced bleeding gums, bruising, and eventual death. The Iroquois Indians suggested a remedy made by boiling the leaves and bark of a native tree to make a sour “tea.” The remedy worked, but scurvy continued to plague sailors for the next 200 years.

By the early 1700’s, the association between scurvy and diet was well known, but it was unclear whether only certain sour substances worked as a cure. In 1747, the British physician James Lind did a study using 12 sailors suffering from scurvy. In addition to their normal shipboard diet, each received one of the following dietary supplements: 2 oranges and 1 lemon, vinegar (acetic acid), sea water, sulfuric acid, apple cider, or a mixture of drugs. Within a week, the two sailors who ate 2 oranges and 1 lemon each day showed dramatic improvement. Lind later developed a method for concentrating and preserving citrus fruit juices, and in 1795, the British Navy decreed that sailors receive a daily ration of lemon juice or lime juice. To this day, British sailors are referred to as “Limeys.”

The name Vitamin C was coined in 1913, but it wasn’t until around 1930 that its chemical structure was determined. Animal studies soon indicated that most mammals do not develop scurvy, even when there is no Vitamin C in their diet. Further research showed that most mammals actually synthesize Vitamin C and that the synthesis involves a series of enzymes, each coded by a specific gene. It was initially assumed that humans must ingest Vitamin C because we lack these genes.

In 1976, it was confirmed that humans lack the last enzyme in the series of steps needed to make Vitamin C. Imagine the surprise when, in 1988, researchers found evidence of a human DNA sequence very similar to that of the DNA sequence of the rat gene coding for the missing enzyme! In 1994, the human gene sequence, named GULO for the enzyme L-gulonolactone oxidase, was actually determined and compared to the rat GULO gene sequence, revealing a high degree of overall similarity but a number of significant differences.

Why Can't We Produce the GULO Enzyme?

Perhaps if we were to compare the human gene sequence to the rat GULO gene sequence, we would be able to identify possible reasons why human cells do not produce the GULO enzyme. Because the rat GULO gene is a very long DNA sequence, coding for a chain of 440 amino acids and containing several non-coding sequences, a complete comparison would be way to time consuming for our purposes.

Objectives:

Students will be able to:

- Compare amino acid sequences among organisms to distinguish where divergences in the genetic code have occurred
- Explain how two distinct descendants may not have similar mutations, but two more closely related species will most likely share more mutations

Procedure 1:

1. We will look at just a part of the gene, the section coding for amino acids number 337 through 353, and the corresponding sequence in the inactive human GULO gene.
2. In the data section below, translate the sequence using the Genetic Code Chart. Work from left to right and look up each 3-letter codon in the chart.
3. Place the corresponding amino acid (AA) in the space below its codon. (If you come to a TAA, TAG, or TGA, just stop translating.)
4. Then, translate the sequence from the inactive human GULO gene.
5. **Circle each amino acid** formed from the human GULO DNA sequence that is the **SAME AS** the amino acid formed by the corresponding DNA in the rat GULO gene.

Data 1:

Rat GULO Gene

TAC / CCC / GTA / GAG / GTG / CGC / TTC / ACC / CGA / GGC / GAT / GAC / ATT / CTG / CTG / AGC / CCC

Human GULO Inactive Gene

TAC / CTG / GTG / GGG / GTA / CGC / TTC / AAC / TGG / AGG / ATG / ACA / TCC / TAC / GCC / CC

Analysis 1:

Please answer the following questions using ***COMPLETE SENTENCES.***

1. How many of the amino acids match between the rat and human DNA?
2. Is there a trend in the sequences for which amino acids match and which ones don't match? Explain.

3. To see how differences in the gene sequences are related to the differences in the amino acid sequences, let's look at the two DNA sequences together, matching them letter for letter as best we can. This is called an "alignment". **Mark with a small line each nucleotide** in the human GULO sequence that **differs** from the corresponding rat GULO nucleotide. **Count these.**

   TACCCCGTAGAGGTGCGCTTCACCCGAGGCGATGACATTCTGCTGAGCCCC (rat)

   TACCTGGTGGGGGTACGCTTCACCTGGAG-GATGACATCCTACTGAGCCCC (human)

4. How are the differences in the DNA sequences related to the differences in the amino acid sequences coded by this DNA segment? Be specific.
5. Based on the observed differences between the rat gene and the human gene, propose a general scenario whereby a mutation could create a nonfunctional version of a gene.
6. Applying your knowledge of the relationship between Vitamin C and diet, propose a scenario whereby a mutation in a functional GULO gene could create a nonfunctional version of the sequence and the functional gene could, over many generations, be totally lost. (Remember, to evolve in this way, it mutations must be helpful.)

<u>Background 2:</u>

Pseudogenes

The human GULO gene is an example of a **pseudogene**, a DNA sequence that is similar to that of a known gene, but that does not yield the expected gene product. Pseudogenes can occur by a gene becoming permanently inactivated, as in the GULO example.

Pseudogenes & Common Ancestry

Suppose a mutation that inactivates a gene becomes common over generations so that eventually all the individuals (descendants of the original mutation carrier) carry only the inactive version of the gene. Since other mutations are possible over time, two distant descendants would not necessarily receive identical DNA sequences for that gene, but their sequences might still match for the original mutation that caused the gene to become inactive in the first place, or for other mutations carried in their "common ancestor." Since deletions are not likely to occur independently at the same site and are highly likely to be "undone" by later mutations, **finding the same deletion in two different individuals or two different species is highly suggestive of common ancestry.**

<u>Procedure 2:</u>

1. Given below is the alignment for the same part of the GULO gene that we examined in part 1 for Vitamin C, along with the corresponding sequences from 3 primate species that are incapable of making Vitamin C. These primates include the chimpanzee, the oragutan, and the crab-eating macaque.
2. Use a green colored pencil or highlighter to mark the positions in the sequence at which all five species are identical.
3. Use an orange colored pencil or highlighter to mark shared differences among the pseudogenes. (In other words mark where the human, chimpanzee, orangutan, macaque are all identically different from the rat.)

Data 2:

Deletion

↓

Human	**TACCTGGTGGGGGTACGCTTCACCTGGAG-GATGACATCCTACTGAGCCCC**
Chimpanzee	**TACCTGGTGGGGCTACGCTTCACCTGGAG-GATGACATCCTACTGAGCCCC**
Orangutan	**TACCCGGTGGGGGTGCGCTTCACCCAGAG-GATGACGTCCTACTGAGCCCC**
Macaque	**TAACCGGTGGGGGTGCGCTTCACCCAAGG-GATGACATCATACTGAGCCCC**
Rat	**TACCCCGTAGAGGTGCGCTTCACCCGAGGCGATGACATTCTGCTGAGCCCC**

Analysis 2:

Please answer the following questions using ***COMPLETE SENTENCES****.*

1. What do you **observe** about the similarities between the pseudogenes and the rat gene?
2. What do you **observe** about the pattern of similarities among the pseudogenes?
3. What do you **observe** about the differences in the pseudogenes?
4. How would an evolutionary biologist **explain** the **similarities between** the pseudogenes and the rat gene?
5. How would an evolutionary biologist **explain** the pattern of **similarities** among the pseudogenes?
6. How would an evolutionary biologist **explain** the **differences** among the pseudogenes?
7. Why is the shared deletion an especially strong indication of common ancestry?
8. Of the organisms listed, which one are humans most closely related to? How do you know?

9. In response to question 8, does this mean that humans evolved from this organism?

   Why or why not?

Table 21: Amino Acid Codon Chart

DNA Codon	Amino Acid	DNA Codon	Amino Acid	DNA Codon	Amino Acid	DNA Codon	Amino Acid
AAA	Lys	CAA	Gln	GAA	Glu	TAA	Stop
AAC	Asn	CAC	His	GAC	Asp	TAC	Tyr
AAG	Lys	CAG	Gln	GAG	Glu	TAG	Stop
AAT	Asn	CAT	His	GAT	Asp	TAT	Tyr
ACA	Thr	CCA	Pro	GCA	Ala	TCA	Ser
ACC	Thr	CCC	Pro	GCC	Ala	TCC	Ser
ACG	Thr	CCG	Pro	GCG	Ala	TCG	Ser
ACT	Thr	CCT	Pro	GCT	Ala	TCT	Ser
AGA	Arg	CGA	Arg	GGA	Gly	TGA	Stop
AGC	Ser	CGC	Arg	GGC	Gly	TGC	Cys
AGG	Arg	CGG	Arg	GGG	Gly	TGG	Trp
AGT	Ser	CGT	Arg	GGT	Gly	TGT	Cys
ATA	Iso	CTA	Leu	GTA	Val	TTA	Leu
ATC	Iso	CTC	Leu	GTC	Val	TTC	Phe
ATG	Met	CTG	Leu	GTG	Val	TTG	Leu
ATT	Iso	CTT	Leu	GTT	Val	TTT	Phe

APPENDIX C1

MISCONCEPTIONS ABOUT EVOLUTION JOURNAL

Adapted from http://evolution.berkeley.edu/evosite/misconceps/index.shtml

Misconception #1 – Evolution is "just" a theory.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #2 – Evolution is a theory about the origin of life.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #3 – Evolution and religion are incompatible.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #4 – The theory of evolution is flawed, but scientists won't admit it.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #5 – Evolution is a theory in crisis and is collapsing as scientists lose confidence in it.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #6 – Evolutionary theory is incomplete and is currently unable to give a total explanation of life.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #7 – Evolution leads to immoral behavior. If children are taught that they are animals, they will behave like animals.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #8 – Evolution is itself "religious," so requiring teachers to teach evolution violates the First Amendment.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #9 – Evolution means that life changed "by chance."

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #10 – Natural Selection involves organisms "trying" to adapt.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #11 – Evolution is not science because it is not observable or testable.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #12 – Natural selection gives organisms what they “need.”

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #13 – Evolution is like a climb up a ladder of progress; organisms are always getting better.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #14 – Most biologists have rejected “Darwinism,” they no longer really agree with the ideas put forth by Darwin and Wallace.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #15 – Gaps in the fossil record disprove evolution.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #16 – Evolution supports the idea that "might makes right" and rationalizes the oppression of some people by others.

Date:

Summary of Scientific Response:

Your Thoughts:

Misconception #17 – Teachers should teach "both sides" and let students decide for themselves.

Date:

Summary of Scientific Response:

Your Thoughts:

APPENDIX C2

Student Response Clicker System Review 1 Questions (Timescale)

Developed by J. McNabnay

1. Evolution occurs quickly (over short periods of time).
    a. True
    b. False
2. Modern humans (*Homo sapiens*) and dinosaurs never existed together on Earth.
    a. True
    b. False
3. How old is the Earth?
    a. 4,600 years (4.6 thousand)
    b. 4,600,000 years (4.6 million)
    c. 4,600,000,000 years (4.6 billion)
    d. Impossible for scientists to determine
4. When did life on Earth begin?
    a. 4.6 to 4.0 billion years ago
    b. 3.9 to 3.5 billion years ago
    c. 4.6 to 4.0 million years ago
    d. 3.9 to 3.5 thousand years ago
5. Which of the following places the geologic time eras in order from oldest to most recent?
    a. Precambrian, Paleozoic, Mesozoic, Cenozoic
    b. Mesozoic, Cenozoic, Paleozoic, Precambrian

c. Cenozoic, Mesozoic, Paleozoic, Precambrian

d. Paleozoic, Cenozoic, Precambrian, Mesozoic

6. During which two periods did **mass** extinctions occur? (Choose two.)

a. Archaean

b. Cambrian

c. Devonian

d. Mississippian

e. Pennsylvanian

f. Permian

g. Triassic

7. The oldest fossils would be found where in a rock?

a. Top layer

b. Middle layer

c. Bottom layer

d. Cannot be determined by layer position

8. The type of fossil dating from question 7 is called what?

a. Relative dating

b. Absolute dating

c. Layer dating

d. Early dating

9. Radiometric (Carbon) dating shows the absolute age of fossils.

a. True

b. False

10. Flora is ______________ and fauna is ______________.

    a. Plants; animals

    b. Animals; plants

    c. Prokaryotes; eukaryotes

    d. Water dwellers; land dwellers

APPENDIX C3

Student Response Clicker System Review 2 Questions (Natural Selection)

Developed by J. McNabnay

1. How many billions of years old is the Earth? (Use one decimal point in your answer.)
2. How many billions of years ago did life first appear on Earth? (Use one decimal point in your answer.)
3. Evolution is change in a population over time.
    a. True
    b. False
4. What is the basis for all variation among organisms?
    a. Mutation
    b. Genetic drift
    c. Migration
    d. Inbreeding
5. Whether or not a variation is an adaptation is dependent on the organism's
    a. Environment
    b. Genotype
    c. Phenotype
    d. Selection

6. The frequency of alleles in a population doesn't change over a long period of time. This population is evolving.
    a. True
    b. False
7. A scientific theory is proven and based on evidence.
    a. True
    b. False
8. Evolution is a theory.
    a. True
    b. False
9. Individuals with favorable traits survive, reproduce, and pass their traits onto their offspring. This is called
    a. Mutation
    b. Adaptation
    c. Evolution
    d. Natural Selection
10. Brown mice survive and reproduce better in their desert environment than white mice because owls can see and eat the white mice more easily. In this situation, what is doing the selecting?
    a. Owl
    b. Desert background
    c. Brown mice
    d. White mice

11. Individuals within a population can evolve.

    a. True

    b. False

APPENDIX C4

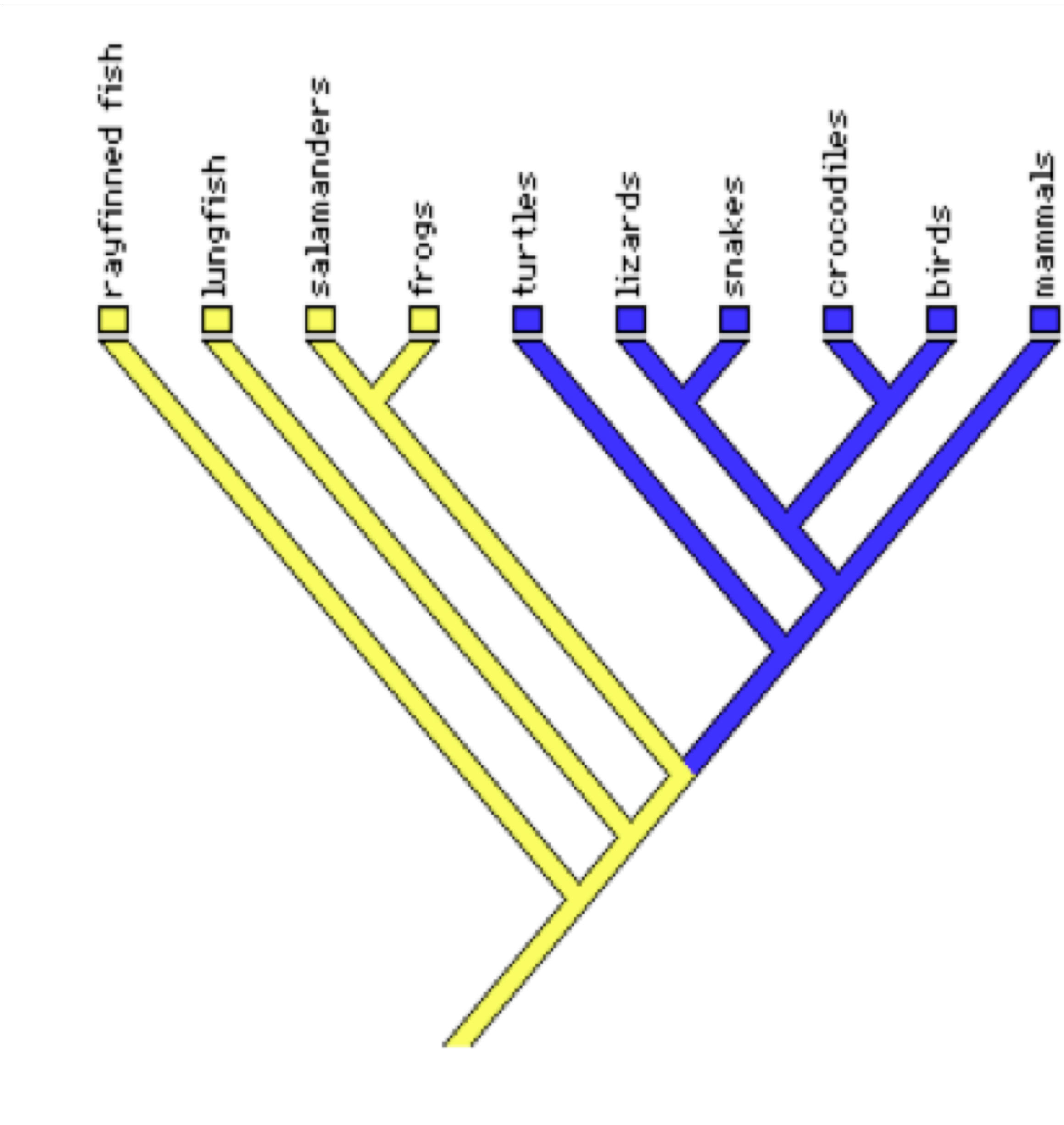
Student Response Clicker System Review 3 Questions (Variation & Speciation)

Developed by J. McNabnay

1. What is the cause for all variation within a population?
    a. Natural selection
    b. Adaptation
    c. Mutation
    d. Environmental changes
2. An organism's ability to survive and reproduce in its environment refers to its
    a. Fitness
    b. Variation
    c. Selection
    d. Mutation
3. Ten brown mice and ten white mice are placed in a desert environment. What will happen to the white population over time?
    a. It will increase
    b. It will decrease
    c. It will stay the same
    d. There is no way to tell
4. Because of an environmental change, organisms develop mutations to survive in that environment.
    a. True
    b. False

5. In terms of evolution, survival is the most important thing.
    a. True
    b. False
6. According to the diagram, who is most closely related to snakes?
    a. Lizards
    b. Turtles
    c. Crocodiles
    d. Lungfish
7. The diagram shows that snakes evolved from lizards.
    a. True
    b. False
8. According to the diagram, mammals are the most advanced organisms
    a. True
    b. False

Figure 29: Phylogeny for Review Questions



9. When has speciation occurred?
    a. When populations no longer look the same
    b. When populations no longer have the same frequency of alleles
    c. When populations are living in different environments
    d. When populations can no longer interbreed
10. Which of the following is true about antibiotic resistant bacteria? (Choose more than one.)
    a. Because there are antibiotics in the environment, they become immune
    b. They learn to fight the antibiotic
    c. A mutation results in antibiotic resistance
    d. Bacteria with antibiotic resistance are more likely to survive and reproduce
    e. Bacteria adapt because they are exposed to the antibiotic
    f. Over time, the entire population will become antibiotic resistant

APPENDIX C5

Student Response Clicker System Review 4 Questions (Structures)

Developed by J. McNabnay

1. When would convergent evolution occur?
    a. When organisms share a common ancestor
    b. When organisms live in similar environments
    c. When organisms become increasingly different
    d. When organisms experience a change in their environment
2. Structures that are inherited from a common ancestor are homologous.
    a. True
    b. False
3. Humans, birds, whales, and lizards all have similar arm bones. What is the reason for this?
    a. The function of these bones is the same in all animals
    b. They live in similar environments
    c. They have a common ancestor
    d. All organisms resemble humans
4. Bird wings and butterfly wings are an example of a(n)
    a. Homologous structure
    b. Analogous structure
    c. Mimicry
    d. Camouflage

5. Which of the following may be true about three different species that all have spikes on their skin? (Choose more than one.)
    a. They may share a common ancestor
    b. They may live in similar environments
    c. They may face a similar problem
    d. They may be adapting because of their environment
    e. They may be evolving to become the same species
    f. They may be able to successfully interbreed
6. Shark fins and dolphin fins are examples of analogous structures.
    a. True
    b. False
7. Analogous structures show common ancestry.
    a. True
    b. False
8. When did life on Earth begin?
    a. 4.6 to 4.0 billion years ago
    b. 3.9 to 3.5 billion years ago
    c. 4.6 to 4.0 million years ago
    d. 3.9 to 3.5 thousand years ago

9. Which of the following places the geologic time eras in order from oldest to most recent?
    a. Precambrian, Paleozoic, Mesozoic, Cenozoic
    b. Mesozoic, Cenozoic, Paleozoic, Precambrian
    c. Cenozoic, Mesozoic, Paleozoic, Precambrian
    d. Paleozoic, Cenozoic, Precambrian, Mesozoic
10. A scientific theory is proven and based on evidence.
    a. True
    b. False
11. Individuals with favorable traits survive, reproduce, and pass their traits onto their offspring. This is called
    a. Mutation
    b. Adaptation
    c. Evolution
    d. Natural selection
12. Individuals within a population can evolve.
    a. True
    b. False
13. An organism's ability to survive and reproduce in its environment refers to its
    a. Fitness
    b. Variation
    c. Selection
    d. Mutation

APPENDIX C6

Student Response Clicker System Review 5 Questions (Evidence)

Developed by J. McNabnay

1. Which of the following is true about antibiotic resistant bacteria? (Choose more than one.)
   a. Because there are antibiotics in the environment, they become immune
   b. They learn to fight the antibiotic
   c. A mutation results in antibiotic resistance
   d. Bacteria with antibiotic resistance are more likely to survive and reproduce
   e. Bacteria adapt because they are exposed to the antibiotic
   f. Over time, the entire population will become antibiotic resistant
2. Bird wings and butterfly wings are an example of a(n)
   a. Homologous structure
   b. Analogous structure
   c. Mimicry
   d. Camouflage
3. Humans, birds, whales, and lizards all have similar arm bones. What is the reason for this?
   a. The function of these bones is the same in all animals
   b. They live in similar environments
   c. They have a common ancestor
   d. All organisms resemble humans

4. Analogous structures show common ancestry.
    a. True
    b. False
5. Shark fins and dolphin fins are examples of analogous structures.
    a. True
    b. False
6. Looking at similarities in _______________ can show common ancestry over long periods of time.
    a. Homologous structures
    b. Embryology
    c. Fossils
    d. Biochemistry
7. The more similar body structures that two organisms have in common, the more closely related they are.
    a. True
    b. False
8. All organisms look exactly the same in the earliest stages of development.
    a. True
    b. False
9. Closely related organisms share common DNA sequences.
    a. True
    b. False

10. Biologists discover two rabbit species living on opposite sides of a large river. What could they do to test and see if these species came from a common ancestor? (Choose more than one.)
    a. Compare DNA sequences
    b. Compare body structures
    c. Find fossils
    d. Compare protein sequences
    e. Have the organisms mate
11. Because of an environmental change, organisms develop mutations to survive in that environment.
    a. True
    b. False
12. In terms of evolution, survival is the most important thing.
    a. True
    b. False
13. An organism's ability to survive and reproduce in its environment refers to its
    a. Fitness
    b. Variation
    c. Selection
    d. Mutation

14. What is the cause for all variation within a population?

    a. Natural selection

    b. Adaptation

    c. Mutation

    d. Environmental changes

15. When has speciation occurred?

    a. When populations no longer look the same

    b. When populations no longer have the same frequency of alleles

    c. When populations are living in different environments

    d. When populations can no longer interbreed

APPENDIX C7

Student Response Clicker System Review 6 Questions (Evolution)

Developed by J. McNabnay

1. The more closely two organisms are related, the more similar DNA sequences they will share.
    a. True
    b. False
2. The more closely two organisms are related, the more similar body structures they will share.
    a. True
    b. False
3. The more closely two organisms are related, the more similarities can be seen over long periods of time in their fossils.
    a. True
    b. False
4. The more closely two organisms are related, the more similar their embryos will look during development.
    a. True
    b. False
5. Humans evolved from monkeys
    a. True
    b. False

6. Structures that are shared by different species because of their common ancestor are
    a. Homologous
    b. Analogous
    c. Vestigial
    d. Common
7. How can the age of a fossil be determined? (Choose more than one.)
    a. The city it is found in
    b. The layer it is found in
    c. The organisms it is found with
    d. Carbon dating
    e. Hydrogen dating
8. How many billions of years old is the Earth? (Answer to one decimal point.)
9. How many billions of years ago did life on Earth begin? (Answer to one decimal point.)
10. Which of the following places the geologic time eras in order from oldest to most recent?
    a. Mesozoic, Cenozoic, Paleozoic, Precambrian
    b. Precambrian, Paleozoic, Mesozoic, Cenozoic
    c. Cenozoic, Mesozoic, Paleozoic, Precambrian
    d. Paleozoic, Cenozoic, Precambrian, Mesozoic

APPENDIX C8

Student Response Clicker System Review 7 Questions (Overall)

Developed by J. McNabnay

1. Evolution occurs quickly. (Over short periods of time.)
    a. True
    b. False
2. Modern humans (*Homo sapiens*) and dinosaurs never existed together on Earth.
    a. True
    b. False
3. How old is the Earth?
    a. 4,600 years (4.6 thousand)
    b. 4,600,000 years (4.6 million)
    c. 4,600,000,000 years (4.6 billion)
    d. Impossible for scientists to determine
4. When did life on Earth begin?
    a. 4.6 to 4.0 billion years ago
    b. 3.9 to 3.5 billion years ago
    c. 4.6 to 4.0 million years ago
    d. 3.9 to 3.5 million years ago
5. Which of the following places the geologic time eras in order from oldest to most recent?
    a. Mesozoic, Cenozoic, Paleozoic, Precambrian
    b. Precambrian, Paleozoic, Mesozoic, Cenozoic

c. Cenozoic, Mesozoic, Paleozoic, Precambrian

d. Paleozoic, Cenozoic, Precambrian, Mesozoic

6. What is the cause for all variation within a population?

    a. Natural selection

    b. Adaptation

    c. Mutation

    d. Environmental changes

7. An organism's ability to survive and reproduce in its environment refers to its

    a. Fitness

    b. Variation

    c. Selection

    d. Mutation

8. Ten brown mice and ten white mice are placed in a snowy environment. What will happen to the brown population over time?

    a. It will increase

    b. It will decrease

    c. It will stay the same

    d. There is no way to tell

9. Because of an environmental change organisms develop mutations to survive in that environment.

    a. True

    b. False

10. According to the diagram (Figure 29: Phylogeny for Review Questions), who is most closely related to snakes?
    a. Lizards
    b. Turtles
    c. Crocodiles
    d. Lungfish
11. The diagram shows that snakes evolved from lizards.
    a. True
    b. False
12. According to the diagram, mammals are the most advanced organisms.
    a. True
    b. False
13. When has speciation occurred?
    a. When populations no longer look the same
    b. When populations no longer have the same frequency of alleles
    c. When populations are living in different environments
    d. When populations can no longer interbreed
14. Which of the following is true about antibiotic resistant bacteria? (Choose more than one.)
    a. Because there are antibiotics in the environment, they become immune
    b. They learn to fight the antibiotic
    c. A mutation results in antibiotic resistance
    d. Bacteria with antibiotic resistance are more likely to survive and reproduce

e. Bacteria adapt because they are exposed to the antibiotic

f. Over time, the entire population will become antibiotic resistant

15. When would convergent evolution occur?

    a. When organisms share a common ancestor

    b. When organisms live in similar environments

    c. When organisms become increasingly different

    d. When organisms experience a change in their environment

16. Structures that are inherited from a common ancestor are homologous.

    a. True

    b. False

17. Humans, birds, whales, and lizards all have similar arm bones. What is the reason for this?

    a. The function of these bones is the same in all animals

    b. They live in similar environments

    c. They have a common ancestor

    d. All organisms resemble humans

18. Bird wings and butterfly wings are an example of a(n)

    a. Homologous structure

    b. Analogous structure

    c. Mimicry

    d. Camouflage

19. Which of the following may be true about three different species that all have spikes on their skin? (Choose more than one.)
    a. They may share a common ancestor
    b. They may live in similar environments
    c. They may face a similar problem
    d. They may be adapting because of their environment
    e. They may be evolving to become the same species
    f. They may be able to successfully interbreed
20. Shark fins and dolphin fins are examples of analogous structures.
    a. True
    b. False
21. Analogous structures show common ancestry.
    a. True
    b. False
22. Evolution is change in a population over time.
    a. True
    b. False
23. The frequency of alleles in a population doesn't change over a long period of time. This population is evolving.
    a. True
    b. False

24. The more closely two organisms are related, the more similarities can be seen in their fossils over long periods of time.
    a. True
    b. False
25. The more closely two organisms are related, the more similar their embryos will look during development.
    a. True
    b. False
26. Humans evolved from monkeys.
    a. True
    b. False
27. How can the age of a fossil be determined? (Choose more than one.)
    a. The city it is found in
    b. The layer it is found in
    c. The organisms it is found with
    d. Carbon dating
    e. Hydrogen dating
28. Closely related species share common DNA sequences.
    a. True
    b. False

29. Biologists discover two rabbit species living on opposite sides of a large river. What could they do to test and see if these species came from a common ancestor? (Choose more than one.)
    a. Compare DNA sequences
    b. Compare body structures
    c. Find fossils
    d. Compare protein sequences
    e. Have the organisms mate
30. In terms of evolution, reproduction is the most important thing.
    a. True
    b. False

APPENDIX D1

Evolution Unit Pre/Post-Survey

Please answer the following questions on a scale of 1-5.

1. *Strongly Disagree*
2. *Disagree*
3. *Neutral / No Opinion*
4. *Agree*
5. *Strongly Agree*

1. Evolution is as much a fact as the fact that planets go around the sun.

   1 2 3 4 5

2. Evolution is something a person should either believe in or not believe in.

   1 2 3 4 5

3. Most species on Earth were created at the same time.

   1 2 3 4 5

4. The evidence for evolution is weak.

   1 2 3 4 5

5. In order to accept evolution as a real process, you cannot believe in God.

   1 2 3 4 5

6. Most major religions have officially declared that they have no conflict with evolution.

   1 2 3 4 5

7. Evolution is not occurring in organisms today.

   1 2 3 4 5

8. According to evolution, people came from monkeys a long time ago.

1 2 3 4 5

9. Humans as a population are perfectly adapted.

1 2 3 4 5

Short Answer Questions:

10. What is the definition of a fact? Give an example.
11. What is the definition of evidence? Give an example.
12. What is the definition of a scientific theory?
13. How old is the Earth? (Give a specific number to the nearest 1,000 years).
14. What comes to your mind when you read / hear about biological evolution?
15. How did life (in general) on Earth originate? Explain your answer.
16. How did humans originate? Explain your answer.

APPENDIX D2

Pre/Post-Survey Rubric

Table 22: Pre/Post-Survey Rubric

Question	Scientific Reasoning	Non-Scientific Reasoning
1	4 or 5	1, 2, or 3
2	1 or 2	3, 4, or 5
3	1 or 2	3, 4, or 5
4	1 or 2	3, 4, or 5
5	1 or 2	3, 4, or 5
6	4 or 5	1, 2, or 3
7	1 or 2	3, 4, or 5
8	1 or 2	3, 4, or 5

Table 22 Continued

Question	Scientific Reasoning	Non-Scientific Reasoning
9	1 or 2	3, 4, or 5
10	Something demonstrated or known to exist or have existed / Supported by evidence	Something that's true Opinion / Belief I don't know / No attempt
11	Data on which to base proof or establish truth Proves something is true	Something that can be always be seen / Something you believe in / I don't know / No attempt
12	Statement that has been repeatedly tested and not found to be false	Guess / Estimate / Not true / Opinion No evidence for it I don't know / No attempt
13	4.6 billion years old	Any other number I don't know / No attempt
14	Change / Adaptation / Fitness / Survival of the Fittest / Charles Darwin / Mutation	Monkeys / False / Just a Theory / Anti-God / I don't know / No attempt
15	Bacterial cells evolved over long periods of time into many different species of organisms	God / Aliens / Big Bang I don't know / No attempt
16	Humans shared a common ancestor with chimpanzees and evolved from that line of descent	God / Aliens / Big Bang I don't know / No attempt

APPENDIX D3

Evolution Pre-Test

<u>Multiple Choice:</u>

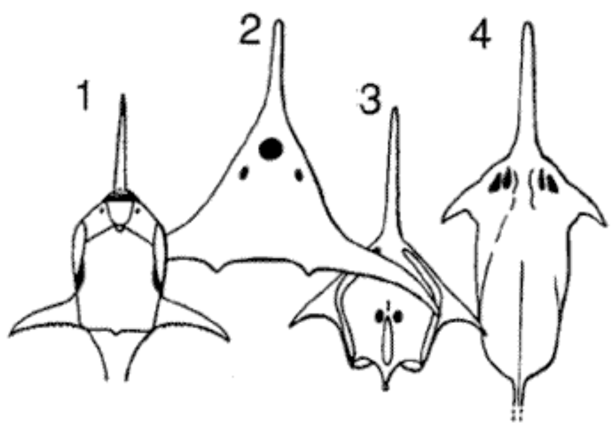
1. How old is the Earth?
    a. 10,000 years
    b. 4.6 million years
    c. 1 billion years
    d. 4.6 billion years
2. When did life on Earth begin?
    a. 4.6 to 4.0 billion years ago
    b. 3.9 to 3.5 billion years ago
    c. 4.6 to 4.0 million years ago
    d. 3.9 to 3.5 thousand years ago
3. Which of the following places the geologic time eras in order from oldest to most recent?
    a. Mesozoic, Cenozoic, Paleozoic, Precambrian
    b. Precambrian, Paleozoic, Mesozoic, Cenozoic
    c. Cenozoic, Mesozoic, Paleozoic, Precambrian
    d. Paleozoic, Cenozoic, Precambrian, Mesozoic
4. The DNA for many organisms is very similar in sequence. The basis for all variation among organisms is
    a. Mutation
    b. Genetic Drift

    c. Migration
    d. Inbreeding
5. Change in a population over time is
    a. Adaptation
    b. Mutation
    c. Evolution
    d. Mimicry
6. Which statement is the most correct?
    a. Humans evolved from monkeys.
    b. Monkeys evolved from humans.
    c. Humans and monkeys evolved from a common ancestor.
    d. Humans and monkeys are not related.
7. An organism's ability to survive and reproduce in its environment refers to its
    a. Fitness
    b. Variation
    c. Selection
    d. Mutation
8. Humans, whales, and birds all have finger bones. Which of the following best describes an appropriate reason for this finding?
    a. All of these animals have fingers
    b. Since humans have finger bones, all other creatures must have them
    c. All of these animals have a common ancestor
    d. This is a mistake; these bones shouldn't be classified as finger bones

Short Answer:

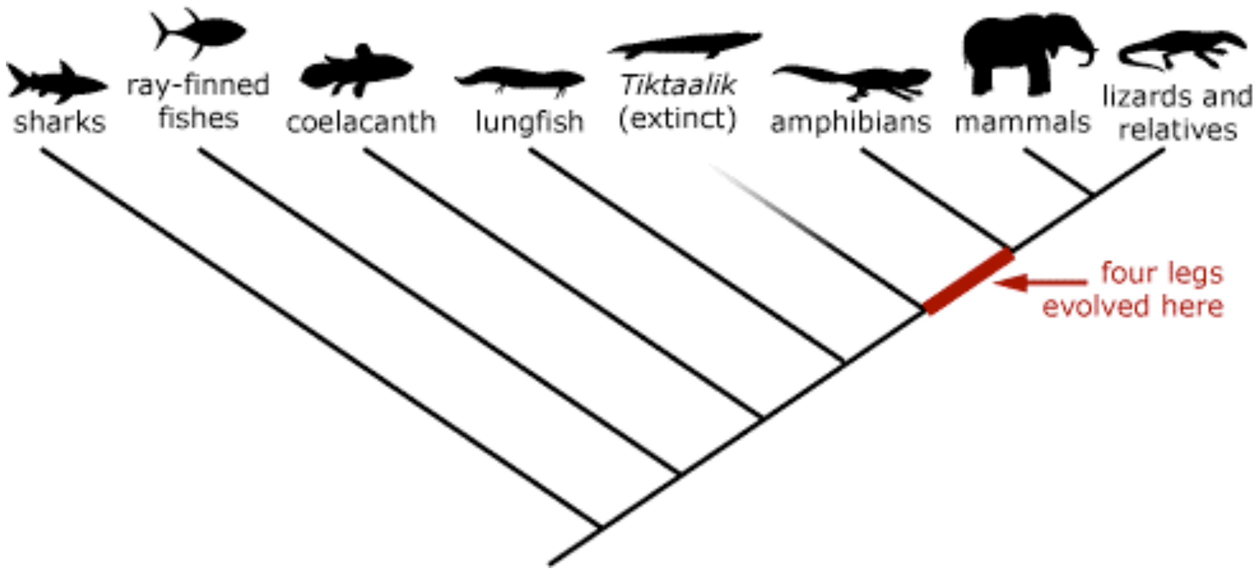
9. Explain how the age of a fossil can be determined.
10. Ten green bugs and ten red bugs in a population of the same species immigrate into a grassy field. There is a predator living in the field that feeds on both the green bugs and the red bugs. Predict what happens to the green bug population over several generations.
11. The fish species pictured below have similar mouth shapes. Give two possible explanations for this similar phenotype.

Figure 30: Fish Similarities



12. In the diagram below, to which group are lizards most closely related? How do you know this?

Figure 31: Test Phylogeny



13. Using the diagram above, which organisms have four legs? How do you know this?
14. According to the diagram above, did mammals evolve from amphibians? How do you know this?
15. Explain how biochemistry (DNA / Proteins) can be used as evidence for evolution.
16. Explain how comparative anatomy (Body Structures) can be used as evidence for evolution.
17. Explain how fossils can be used as evidence for evolution.
18. Explain how embryology can be used as evidence for evolution.
19. The frequency of alleles in a population stays the same over several generations. Is this population evolving? Explain your answer.

20. A population of bacteria is killed by a specific antibiotic. As this antibiotic is used more and more often, antibiotic-resistant bacteria develop. Explain how this is an example of natural selection at work.
21. Homologous structures are structures that are similar among different species because those species share a common ancestor. How is this evidence for evolution? Give an example of a homologous structure.
22. Analogous structures are structures that are similar among different species because those species have lived in similar environments over a long period of time. How is this evidence for evolution? Give an example of an analogous structure.
23. Biologists discovered two squirrel species living on opposite sides of the Grand Canyon. They hypothesize that the species evolved from a common ancestor. What are two methods that they could use to test their hypotheses?

Evolution Post-Test

Multiple Choice:

1. How old is the Earth?
    a. 10,000 years
    b. 4.6 million years
    c. 1 billion years
    d. 4.6 billion years
2. When did life on Earth begin?
    a. 4.6 to 4.0 billion years ago
    b. 3.9 to 3.5 billion years ago
    c. 4.6 to 4.0 million years ago
    d. 3.9 to 3.5 thousand years ago
3. Which of the following places the geologic time eras in order from oldest to most recent?
    a. Mesozoic, Cenozoic, Paleozoic, Precambrian
    b. Precambrian, Paleozoic, Mesozoic, Cenozoic
    c. Cenozoic, Mesozoic, Paleozoic, Precambrian
    d. Paleozoic, Cenozoic, Precambrian, Mesozoic
4. The DNA for many organisms is very similar in sequence. The basis for all variation among organisms is
    a. Mutation
    b. Genetic Drift
    c. Migration

d. Inbreeding

5. Change in a population over time is
    a. Adaptation
    b. Mutation
    c. Evolution
    d. Mimicry
6. Which statement is the most correct?
    a. Humans evolved from monkeys.
    b. Monkeys evolved from humans.
    c. Humans and monkeys evolved from a common ancestor.
    d. Humans and monkeys are not related.
7. An organism's ability to survive and reproduce in its environment refers to its
    a. Fitness
    b. Variation
    c. Selection
    d. Mutation
8. Humans, whales, and birds all have finger bones. Which of the following best describes an appropriate reason for this finding?
    a. All of these animals have fingers
    b. Since humans have finger bones, all other creatures must have them
    c. All of these animals have a common ancestor
    d. This is a mistake; these bones shouldn't be classified as finger bones

Short Answer: *Please use **COMPLETE SENTENCES** to answer the following questions.*

9. Explain two ways that the age of a fossil can be determined.
10. Ten green bugs and ten red bugs in a population of the same species immigrate into a grassy field. There is a predator living in the field that feeds on both the green bugs and the red bugs. Predict what happens to the green bug population over several generations. Why does this happen?
11. The fish species pictured (in Figure 30) have similar mouth shapes. Give two possible explanations for this similar phenotype.
12. In the diagram (Figure 31), to which group are "lizards & relatives" most closely related? How do you know this?
13. Using the diagram (Figure 31), which organisms have four legs? How do you know this?
14. According to the diagram (Figure 31), did mammals evolve from amphibians? How do you know this?
15. Explain how biochemistry (DNA / Proteins) can be used as evidence for evolution.
16. Explain how comparative anatomy (Body Structures) can be used as evidence for evolution.
17. Explain how fossils can be used as evidence for evolution.
18. Explain how embryology can be used as evidence for evolution.
19. The frequency of alleles in a population stays the same over several generations. Is this population evolving? Explain your answer.
20. Explain how bacteria becoming resistant to antibiotics is an example of natural selection at work.

21. What is a homologous structure? How are homologous structures evidence for evolution? Give an example of a homologous structure.
22. What is an analogous structure? How are analogous structures evidence for evolution? Give an example of an analogous structure.
23. Biologists discovered two squirrel species living on opposite sides of the Grand Canyon. They hypothesize that both species evolved from a common ancestor. What are three methods that they could use to test their hypotheses? Explain how each method works.

APPENDIX D4

Pre/Post-Test Rubric

Table 23: Pre/Post-Test Rubric

#	Correct Answer(s)	Incorrect Answer(s)
1	d. 4.6 billion years	a. 10,000 years b. 4.6 million years c. 1 billion years
2	b. 3.9 to 3.5 billion years ago	a. 4.6 to 4.0 billion years ago c. 4.6 to 4.0 million years ago d. 3.9 to 3.5 thousand years ago
3	b. Precambrian, Paleozoic, Mesozoic, Cenozoic	a. Mesozoic, Cenozoic, Paleozioc, Precambrian c. Cenozoic, Mesozoic, Paleozoic, Precambrian d. Paleozoic, Cenozoic, Precambrian, Mesozoic
4	a. Mutation	b. Genetic Drift c. Migration d. Inbreeding
5	c. Evolution	a. Adaptation b. Mutation d. Mimicry
6	c. Humans & monkeys evolved from a common ancestor	a. Humans evolved from monkeys b. Monkeys evolved from humans d. Humans & monkeys are not related
7	a. Fitness	b. Variation c. Selection d. Mutation
8	c. All of these animals have a common ancestor	a. All of these animals have fingers b. Since humans have them, everyone must d. This is a mistake

Table 23 Continued

#	Correct Answer(s)	Incorrect Answer(s)
9	Carbon Dating (Absolute) Layer of Rock it's found in (Relative)	Size or Hardness Looks Old Similarities to Other Organisms I don't know / No attempt
10	Green Bugs Survive Green Bugs Reproduce Get a large Population of Green Bugs	Green Bugs Die Off Green Bugs Get Eaten Green Bug Population gets Smaller I don't know / No attempt
11	Have a common ancestor Live in similar environments Eat similar foods	They are the same species They evolved from each other I don't know / No attempt
12	Mammals (Closest on Diagram)	Sharks / Ray-Finned Fishes / Coelacanth / Lungfish / Tiktaalik / Amphibians (Farther away on Diagram); I don't know / No attempt
13	Amphibians, Mammals, & Lizards (Evolved after Indicated on Diagram)	Sharks / Ray-Finned Fishes / Coelacanth / Lungfish / Tiktaalik (Evolved before Indicated on Diagram); I don't know / No attempt
14	No (Came from Common Ancestor or Not from Amphibian line)	Yes (Mammals came after Amphibians) / I don't know / No attempt
15	Similar DNA sequences or Proteins indicate common ancestry / The more similar = Closer Related	Similar DNA sequences among organisms mean that organisms came from each other I don't know / No attempt
16	Similar Body structures can indicate common ancestry	Similar Body structures mean that one organism came from another organism / I don't know / No attempt

Table 23 Continued

#	Correct Answer(s)	Incorrect Answer(s)
17	Similar anatomy over long periods of time show common ancestry	Fossils show how old the earth is / Comparing fossils shows how one organism came from another organism / I don't know / No attempt
18	Early stages of most organisms appear similar = Common Ancestry	Comparing Embryos shows how organisms are different / how they came from each other / I don't know / No attempt
19	No (If alleles stay the same, the population is not changing)	Yes (all populations evolve) I don't know / No attempt
20	Resistant / Mutant bacteria survive and reproduce, they pass on their resistance gene, population becomes resistant	Bacteria adapt because of the presence of the antibiotic I don't know / No attempt
21	The common ancestor had that structure and it continues to get passed down, whether or not it is still needed (Forelimbs, Fingers)	They came from each other so they have the same structures I don't know / No attempt
22	Having this structure is beneficial in their env. If they have it they are more likely to survive and reproduce and pass it on (Wings, Fins)	Species are related Species needed these structures so they evolved to get them I don't know / No attempt
23	Compare anatomies Compare DNA or Protein Sequences	Find fossils of the organisms Have the organisms mate I don't know / No attempt

APPENDIX D5

Website Project Rubric

Table 24: Website Project Rubric

	Excellent (5 points)	**Adequate (3 points)**	**Needs Work (1 point)**
Title & Group Member Names (5)	Descriptive Title / All Group Members Names Included	Non-Descriptive Title / Names Not Included	No Title / Names Missing
Introductory Paragraph about Organisms (5)	Informative and includes general info about organisms' taxonomy, traits, behaviors, etc.	Somewhat informative but is missing key info about assigned organisms	Not a complete paragraph / No relevant info
Summary Paragraph about Each Species (20)	4 summary paragraphs included / Each is informative about a specific species (Each paragraph is worth 5 pts)	Less than 4 paragraphs / Paragraphs are missing key info	Less than 2 paragraphs / No relevant info
Evidence for Evolution (15)	3 specific pieces of evidence that relate to your species (Each evidence is worth 5 pts)	3 pieces of evidence but not related well to species	Less than 3 pieces of evidence / Not related at all to species
Geologic Era (5)	Pictorial representation of when organisms came into existence	No pictorial representation, but indicates time period	Time period not indicated
Theory of Evolution Explanation (5)	Clearly explains the theory of evolution in the context of natural selection / Uses specific organisms as examples	Vaguely explains the theory of evolution / No examples given	Explains the theory of evolution in an unclear way / No examples given

Table 24 Continued

Misconceptions (10)	3 misconceptions & scientific rebuttals (Miscn. are worth 5 pts & so are rebuts.)	Less than 3 misconceptions / Less than 3 scientific rebuttals	Less than 2 misconceptions / Less than 2 scientific rebuttals
Common Questions (5)	2 common questions & answers	Less than 2 questions or answers	No questions or answers / Questions not relevant
Visual Appeal (5)	Relevant pictures or clipart included	Irrelevant pictures or clipart included	No pictures or clipart included
Bibliography (5)	3 sources (for info) / Picture sources	Less than 3 sources (for info) / No picture sources	Less than 2 sources (for info) / No picture sources

APPENDIX D6

Raw Data from Study (McNabnay)

Table 25: McNabnay Raw Data

Student	Pre-Survey	Post-Survey	Pre-Test	Post-Test
1	31%	38%	33%	96%
2	19%	38%	44%	96%
3	38%	75%	33%	100%
4	19%	88%	26%	96%
5	19%	63%	33%	93%
6	25%	88%	37%	81%
7	44%	75%	22%	96%
8	31%	69%	11%	89%
9	56%	94%	52%	74%
10	38%	69%	26%	63%
11	13%	81%	19%	100%
12	38%	94%	41%	96%
13	44%	88%	41%	96%
14	38%	69%	26%	96%
15	38%	75%	44%	81%
16	19%	88%	41%	89%
17	19%	38%	33%	100%
18	19%	25%	59%	93%
19	25%	81%	30%	93%
20	25%	88%	30%	96%
21	19%	63%	26%	96%
22	38%	88%	33%	93%
23	38%	81%	26%	93%
24	13%	88%	33%	100%
25	50%	94%	44%	100%
26	6%	63%	44%	96%
27	25%	69%	33%	89%
28	25%	81%	15%	96%
29	31%	81%	67%	100%
30	44%	75%	41%	85%
31	44%	88%	33%	96%

Table 25 Continued

32	31%	81%	33%	93%
33	25%	38%	7%	96%
34	31%	69%	15%	89%
35	25%	75%	22%	93%
36	50%	94%	52%	100%
37	25%	63%	19%	81%
38	25%	50%	19%	89%
39	13%	63%	19%	93%
40	38%	81%	30%	96%

APPENDIX D7

Raw Data from Study (Smith)

Table 26: Smith Raw Data

Student	Pre-Survey	Post-Survey	Pre-Test	Post-Test
1	13%	44%	15%	93%
2	13%	31%	7%	56%
3	13%	81%	22%	93%
4	25%	75%	26%	93%
5	38%	38%	30%	74%
6	69%	94%	59%	81%
7	13%	31%	41%	67%

APPENDIX D8

Raw Data from Study (Hamilton)

Table 27: Hamilton Raw Data

Student	Pre-Survey	Post-Survey	Pre-Test	Post-Test
1	19%	69%	30%	93%
2	25%	69%	37%	78%
3	63%	81%	30%	89%
4	50%	75%	37%	100%
5	38%	63%	26%	74%
6	44%	63%	30%	74%
7	19%	56%	22%	78%
8	31%	63%	30%	96%
9	50%	69%	15%	85%
10	38%	75%	26%	78%
11	25%	56%	33%	81%
12	13%	56%	26%	93%
13	44%	63%	26%	89%
14	19%	56%	41%	81%
15	19%	81%	44%	85%
16	75%	75%	52%	93%
17	63%	88%	44%	93%
18	13%	88%	30%	85%
19	19%	56%	4%	81%
20	31%	69%	22%	52%
21	56%	75%	30%	67%
22	25%	38%	26%	59%
23	13%	31%	22%	89%
24	25%	81%	15%	70%
25	6%	44%	26%	81%
26	6%	50%	15%	78%
27	6%	25%	37%	89%
28	25%	44%	15%	56%
29	6%	50%	4%	67%
30	31%	50%	33%	56%
31	56%	63%	30%	100%

Table 27 Continued

32	63%	50%	19%	81%
33	25%	63%	7%	67%
34	25%	25%	19%	93%
35	38%	75%	26%	93%
36	50%	63%	22%	74%
37	25%	44%	30%	63%
38	69%	88%	41%	96%
39	38%	88%	48%	89%
40	6%	19%	26%	56%
41	13%	44%	33%	81%
42	56%	75%	44%	74%
43	19%	56%	30%	59%
44	25%	50%	15%	48%
45	19%	63%	4%	78%
46	19%	44%	11%	89%
47	25%	25%	26%	93%
48	63%	44%	22%	96%
49	25%	50%	30%	85%
50	25%	38%	11%	59%
51	56%	50%	11%	48%
52	44%	31%	7%	85%

APPENDIX D9

Raw Data from Study (Milletics)

Table 28: Milletics Raw Data

Student	Pre-Survey	Post-Survey	Pre-Test	Post-Test
1	25%	44%	26%	74%
2	38%	19%	22%	78%
3	19%	44%	19%	67%
4	25%	75%	7%	56%
5	19%	56%	11%	70%
6	38%	31%	33%	56%
7	56%	81%	22%	59%
8	31%	31%	15%	70%
9	13%	63%	4%	63%
10	13%	50%	11%	93%
11	38%	56%	41%	81%
12	38%	69%	26%	67%
13	44%	56%	33%	74%
14	31%	44%	56%	96%
15	31%	56%	33%	89%
16	38%	44%	15%	81%
17	31%	38%	22%	93%
18	25%	19%	7%	93%
19	50%	63%	37%	70%
20	50%	63%	30%	85%
21	13%	38%	11%	59%
22	56%	63%	67%	93%
23	25%	63%	41%	78%

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