How can the 5-E Learning Cycle Model of Instruction Be Used to Develop a Differentiated Science Unit on Evolution Based on Six Minnesota Evolution Standards?

Monica Christine Digre

Hamline University, mdigre01@hamline.edu

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HOW CAN THE 5-E LEARNING CYCLE MODEL OF INSTRUCTION BE USED TO DEVELOP A DIFFERENTIATED SCIENCE UNIT ON EVOLUTION BASED ON SIX MINNESOTA MIDDLE SCHOOL EVOLUTION STANDARDS?

by

Monica Christine Wimpee Digre

A capstone submitted in partial fulfillment of the requirements for the degree of Master of Arts in Teaching

Hamline University

Saint Paul, Minnesota

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Primary Advisor: Barbara Swanson
Secondary Advisor: Irina Makarevitch
Peer Reviewer: Shannon Lee
To Leif and Layla, who inspire me every day.  
You are the legacy of 14 billion years of cosmic evolution.  
You are precious.
ACKNOWLEDGMENTS

Thank you Jeff for endless love and support through this process. Thank you to my parents, Barb and Chuck, for instilling in me the love of science and exploration. Thank you to my Capstone Committee for your help and patience. And finally, thank you to J & S Bean Factory for the constant supply of caffeine and workspace.
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CHAPTER ONE

Introduction

When I was about five years old, I was given the book *Koko's Kitten* (1985) by Dr. Francine Patterson. I was compelled by the story of a gorilla that can speak sign language and by her love for her pet kitten. I have been fascinated by apes ever since.

Humans have a natural curiosity about where they come from and, as a result, an innate interest in evolution. With this capstone, I intended to develop a primatology and human evolution-based curriculum that responds to this question: How can the 5-E Learning Cycle Model of Instruction be used to develop a differentiated science unit on evolution based on six Minnesota middle-school evolution standards?

My Interest in the Topic

While majoring in biology at the University of Wisconsin-Madison, I focused my studies on primatology, evolution, and genetics. During college, I was fortunate to live only two blocks from the Henry Vilas Zoo. This was a free public zoo, and I spent countless hours in the primate house. There were four adult chimpanzees, several ring-tailed lemurs, and a family of orangutans, including a baby. I would sit in front of the chimpanzee and orangutan exhibits to observe their behavior and mannerisms.

Watching the baby orangutan and its parents was my favorite pastime. I was amazed at how familiar the interactions between the mother, father and baby felt. I had seen all of these interactions before in human families. I was especially amazed at the
reaction of human children when they saw the baby orangutan. They seemed to be able to empathize and connect with the young ape.

Next to the orangutans were the lemurs. Kids responded to their presence more as observers than as participants. Many kids confused the lemurs' grey coloring and striped tail with that of a house cat. The lemurs did not seem like much more than pets, so their appearance was not all that fascinating to the children. But when they saw the baby orangutan, which looked similar to them and was behaving similarly to them, the children were fascinated. Reciprocating the interest, the baby orangutan seemed to be just as curious in the children. When the little ape was not running around and playing, he spent a lot of time near the glass, making eye contact with the kids and putting his hands on the window. The human children got a kick out of mirroring their hairy friend's actions; hands looking so similar, separated by nothing but glass and a few million years of evolution.

**Challenges of Teaching Human Evolution**

While teaching in an urban high school with at-risk teens, I struggled with teaching the evolution standards set by the state and national governments. I was a new science teacher and still trying to figure out how to engage my students in authentic learning experiences. When I first tried to teach a unit on evolution, I found it to be incredibly challenging. I was prepared for the conflict that I expected with some of my more religious students. I think every biology teacher has run into this conflict at one time or another. But what I found more of a struggle was many of my students lacked a tremendous amount of background knowledge required to fully grasp the concepts. Because the content was new and difficult for my students, they shut down and would not
I put any effort into learning it. I became frustrated that my students were so disinterested in a subject I was so incredibly passionate about.

One day, in a fit of desperation, I put in a DVD of a documentary about Koko the Gorilla, the same ape who captured my interest as a child. To my surprise, my students were completely taken by the story. After watching it they had tons of questions about Koko and her gorilla friends, Ndume and Michael. As a class, we ended up researching the three gorillas and where they are now. We discovered that Koko had a website and a blog, she even has a word-a-day to teach gorilla sign language. We also found out some sad news that Michael had recently died of a heart attack. One of my students even cried at this news. We began talking about emotions and wondering if apes were capable of feeling emotions surrounding mourning and loss. That was the hook I needed and it began a unit where my students learned about primates and human evolution.

Since that teaching experience, I have switched to teaching middle school and have encountered a similar disinterest with evolution. While the concepts are more simplistic at the middle-school level, the importance of mastering them are not to be overlooked. That experience with my students made me wonder about using apes as a means for teaching all of the evolution and genetics standards. Rather than approaching evolution in the traditional way by talking about the Speckled Moths in Industrial England and the different beaks on finches in the Galapagos Islands, maybe middle-school students could learn those same concepts by looking at our nearest relatives, the Great Apes.

Jane Goodall

Jane Goodall has been a hero of mine for twenty years, ever since I was in
elementary school. Her story of being a woman in a male dominated science field, proving herself, breaking barriers, making discoveries and getting to where she is today is incredibly inspiring to me. She started researching chimpanzees in 1960, at a time when women in science were not taken seriously. It was also a time when chimpanzees and their relatives were considered nothing more than wild, savage animals, incapable of thought, reasoning and emotion. As a young graduate student, Goodall traveled to Tanzania to observe chimpanzees in their natural habitat and to study their relationship to the evolutionary past of humans. She soon found there was much more to the apes than we ever knew. (www.janegoodall.org/wp-content/uploads/the-Jane-Goodall-Institute_JaneGoodall_LongBio.pdf).

The observation of chimpanzees making and using tools was groundbreaking and incredibly controversial. Before Jane Goodall's discovery, it was widely believed that humans were the only animals that had the intelligence necessary for problem solving and critical thinking. “It is in making tools that man is unique” (Oakley, 1944, p. 155, italics in original). Humans had to be redefined from "man the tool maker," which was the common definition in science texts. “Chimpanzees possess cognitive abilities once thought unique to humans” (Goodall, 1990, p. 207). It took a long time for Goodall to convince the scientific community of her findings. She was not taken seriously, not only because she was a woman, but also because of her unconventional way of classifying her research subjects (www.janegoodall.org/wp-content/uploads/the-Jane-Goodall-Institute_JaneGoodall_LongBio.pdf). She gave the chimpanzees names like Flo and Frodo, while other behavioral scientists gave them numbers or letters. Giving them names anthropomorphized the chimpanzees in a way many people thought was
inappropriate.

I have studied Jane Goodall's research and career since high school. She has several books I have read about her studies in the Gombe forest in Tanzania. I have been intrigued by her advocacy work for chimpanzee and other apes' rights. Some of the most insightful pieces I have read by Goodall are what she has written about human society. She has seen so many parallels between humans and our closest relatives. This has only fueled my curiosity and amazement of these creatures. Jane Goodall has not only become an icon in the science community but she has become a spokesperson for the humane treatment of laboratory and other captive animals.

The Jane Goodall Institute, which has a branch at the University of Minnesota, has expanded Goodall's work in many directions. One of its spin-offs is the Roots and Shoots program (www.rootsandshoots.org). This is a youth focused education program involving school children in learning about chimpanzees and environmental conservation. Part of what I am interested in doing in my own teaching is taking what is done so well with younger students and adapting it for secondary students. While teaching an interdisciplinary unit at a Saint Paul middle school, students read Jane Goodall’s (1996) book, My Life with the Chimpanzees, in their English classes, while in my science class students learned about evolution and ecology. My students had more of a framework to learn the science concepts when they had a story to go with it.

In 2008, I met Jane Goodall when she came to speak at the University of Minnesota. It was an inspiration to meet her and shake her hand. For many years, I have viewed her as a mentor for how to approach my teaching and how to approach my life in general. Her gentle way of interacting with people and her patience to understand their
point of view is a model of the person I strive to be. I have tried to apply what I have learned from her in the way I approach my students and try to understand their own views on the world, while at the same time helping them to learn something new.

**Awakening to My Teaching Style**

Upon completion of this capstone curriculum, I will have been teaching science for nine years. It was not until the past four years or so that I truly feel like a “real teacher” with my own teaching style. I spent several years looking for a permanent teaching position working as a long-term substitute teacher or as a probationary teacher. As a result, I have been to several schools and districts that all have a different mission, philosophy and priority towards science education. It was not until I had my own classroom that I began to go beyond mimicking other teachers and using prefabricated curricula, to developing my own style and my own way of lesson planning. I often use standard curricula as a starting point to my lessons, but I rarely follow a lesson start to finish without putting my own spin on it.

In 2009, I attended a workshop on Science Inquiry and it had a major effect on my teaching style. As a general guide, Science Inquiry flips the traditional science lesson sequence from “lecture, read, lab,” and instead puts the hands-on experience first. As a result, I develop most of my lessons with a lab or activity to start with. After students have a hands-on experience, I then go into a follow-up reading, lecture, or class discussion. I have found that students are more engaged in the follow-up activities when they have an authentic experience to refer to. This has become the foundation of my own personal teaching style.

I am also a very artistic and musical person, so I like to incorporate art and music
into my lessons. I often start the lesson with an internet video of a science song, animation or picture that depicts the concept we are covering. I also like to assign projects to students that allow them to use their own talents in their learning. I often provide choice assignments where there are several options that will cover the same content, but can be achieved in several ways. These choices might include writing a song or poem, creating a comic book, writing a traditional report, building a model, making a presentation or making a video. This has allowed me to provide excitement to my classes and allow for students to feel they are valued and true participants in their education.

I know that my teaching style will continue to evolve as I learn and develop as a teacher. My fundamental mission of teaching will likely evolve as well. My teaching mission and philosophy is an ever-changing guide to my overall career as a teacher. I view my job as a guide who provides activities, materials and access to knowledge, but the ultimate role of learning falls on the student. I do not believe that teachers “teach” so much as students “learn.” Over the years, I have reflected on my own learning and have come to the conclusion that I did the work of learning. My teachers worked very hard at providing me with access to knowledge, but I was the one who did the work to learn the material and concepts. I use this realization in my own teaching and provide my middle-school students with the tools to become independent and life-long learners.

**Summary**

In this chapter, I have explained my interest in evolution, primatology and science education. I have discussed aspects of this subject and people that have inspires me. It has set the foundation for my capstone burning question. I have also explained my journey in education and how I have developed my own personal teaching style as a
result of my varied experience. In chapter two, I will propose my burning question and further explain why this question interests me. I will also review literature by experts in the field of science education, evolution and primatology.
CHAPTER TWO

Literature Review

“Nothing in biology makes sense except in the light of evolution.”

Theodore Dobzhansky, 1973 (Franklin, 2010, p. 144)

Introduction

In the first chapter, I discussed why the topics of evolution and primatology interest me and why it is important to my teaching career. I wrote about my own interest in inquiry-based science and how it applies to my own teaching philosophy. In this chapter, I discuss what the experts have to say regarding teaching human evolution. I will review how evolution is traditionally taught and the troubles I have encountered with a traditional approach.

Through my teaching I have come to a burning question that I believe needs to be addressed. How can the 5-E Learning Cycle Model of Instruction be integrated into a curriculum unit designed to teach the six Minnesota middle-school evolution standards? I set a foundation in this chapter as to what expert opinion and research show regarding teaching evolution in middle school. I first explain why evolution is such a critical piece of the life science curriculum. There are reasons that are tied to the standards and high stakes tests overseen by the Minnesota Department of Education.

In addition, there are reasons for teaching evolution that are tied to a foundational understanding of the nature of science. This is crucial in having a strong understanding
across the biology field. There are many misconceptions and reasons why teachers fail at this particular topic and I intend to make a case for why evolution is so important to the overall understanding of life. Theodore Dobzhansky famously said, “Nothing in biology makes sense except in the light of evolution” (Franklin, 2010, p. 144). This quote has been like a mantra to me about how important evolution is. It unifies all aspects of biology into a theory that provides clarification to the seemingly unrelated observations that muddy our collective understanding.

The first section outlines the Minnesota Department of Education Teaching Standards. This is followed by a section on the Minnesota Comprehensive Assessment tests and how evolution fits into it. The third section explains the curriculum used in Independent School District 196 and how evolution is taught within that context. An overview of why evolution needs to be taught in schools is followed by a discussion of the importance of evolution in the broader biology field. Next is an explanation the cognitive stage of development of middle-school students since this is the intended audience of this curriculum. In addition to this, I will then write about the best practice of science inquiry when teaching the middle-school level. Then I will outline the traditional approaches that are used in teaching evolution followed by the obstacles that the traditional approach presents and then leads into common misconceptions about evolution held by many students. I will finish this chapter by outlining how to design a better curriculum for teaching evolution.

**Minnesota Department of Education Evolution Standards**

In 2009, the Minnesota Department of Education adopted new standards for education. These standards are what I will use to design my curriculum. The seventh
grade “Evolution in Living Systems” standards are outlined and discussed below.

“Minnesota’s evolution-education standards are supported by the Minnesota Science Teachers Association, whose Board of Directors endorsed the position statement of the NABT and National Science Teachers Association” (Moore, 2007, p. 268). The standards are comprehensive in the concepts that should be taught about evolution. They are also open ended and for better or worse, can be interpreted and put into practice in very different ways. Teaching standards are developed by the Minnesota Department of Education and are organized into topics and concepts that students should know by the end of each grade level. Each standard is divided into benchmarks, which are more specific and phrased to say what a student should be able to do. Districts, schools and teachers use these standards and benchmarks to guide their curriculum planning. Ultimately these are the teaching standards by which every student will be assessed. See Appendix B for an excerpt from the Minnesota Teaching Standards, which outlines the standards and benchmarks for seventh grade life science.

There are two standards in substrand “Evolution in Living Systems.” The first expects students to understand that “reproduction is a characteristic of all organisms and is essential for the continuation of a species” (Minnesota Department of Education, 2009, p. 20). I stress this idea in my evolution curriculum. Evolution cannot happen unless hereditary information is passed to the next generation.

The second standard states that students should understand that “individual organisms with certain traits in particular environments are more likely than others to survive and have offspring” (Minnesota Department of Education, 2009, p. 20). This concept is what is commonly called “survival of the fittest.” Evolution happens as the
result of small individual changes that either help or hinder survival. This natural
selection of small changes provide continuous variation that amount to large changes
over many generations (Strickberger, 2000, p. 515).

There are three benchmarks in standard 1. The first benchmark explains how
genesis are in cells and are responsible for determining traits (Minnesota Department of
Education, 2009, p. 20). My students view this concept as “in your blood,” like you have
curly hair because it is “in your blood.” This is a misconception that I address when they
learn that genes are in the nucleus of body cells and that each cell contains all of the
hereditary information.

The second benchmark (Minnesota Department of Education, 2009, p. 20)
discusses the differences between asexual and sexual reproduction. I discuss these
differences in my curriculum as either having one parent or two. Sometimes my students
get asexual reproduction confused with the fact that some kids have a single parent. So, I
try to address this misunderstanding delicately by talking about how every human has a
biological father and a biological mother, but that one does not necessarily view those
people as parents. When discussing the differences between asexual and sexual
reproduction, I teach that asexual reproduction produces a genetically identical offspring
and sexual reproduction produces a genetically unique offspring.

The third benchmark (Minnesota Department of Education, 2009, p. 20) discusses
the differences between inherited and acquired traits. This becomes important when
understanding how evolution works. Inherited traits are the only ones that will be able to
be passed on to the next generation. Acquired traits are a result of the environment and
are acquired by an individual throughout its life. I often explain this to my students in
terms that they observe in their own lives. Your natural hair color, your eye color, and whether or not you have dimples are all inherited and coded in your DNA. Whereas dying your hair blue, getting a tattoo, or having a scar from falling off your bike are all acquired traits; they will not be passed on to the next generation. But acquired traits are not limited to cosmetic or superficial traits. Examples could be types of cancers as the result of exposure to toxins or radiation or heart disease as the result of a poor diet. This idea is part of what distinguishes Darwinian thinking from Lamarckian thinking.

Lamarck’s principle of *The Inheritance of Acquired Characters* states that acquired traits “are preserved by reproduction to the new individuals which arise” (Strickberger, 2000, p. 24). The classic Lamarck example is of giraffes developing longer necks as a result of trying to reach higher leaves. This would be an example of an acquired trait and would not pass to the next generation because it assumes the giraffes were not born that way and through practice were able to make their necks longer during their life. Darwin explained traits differently and would explain a giraffe’s long neck as a product of natural selection; genetic variation exists within the population of giraffes, the ones with the longer necks were able to reach food and more likely to survive to pass their longer neck trait to the next generation. Each generation would select for the longer trait, slowly causing the population to have longer necks overall. In order to pass on a trait it needs to already be present in the genetic material (Strickberger, 2000, p. 25).

The second standard (Minnesota Department of Education, 2009, pp. 20-21) is divided into four benchmarks. The first benchmark (Minnesota Department of Education, 2009, p. 20) requires students to learn to interpret the fossil record, or the complete catalog of fossils found in rock layers throughout the world. Within the fossil
record there is evidence of speciation or the appearance of new species, where the
species’ fossils are not present in older rock layers. There is also a record of
diversification, where a fossil type will become more diverse in their variations in
subsequent rock layers. And finally there is evidence of extinction, where a fossil type
will no longer be found in younger rock layers. These rock layers can also be dated
based on relative dating, the concept that older rocks are lower in the strata and younger
rocks are high up and therefore their age can be determined in relation to other fossils.
The age of fossils can also be determined through absolute dating, where radioactive
isotopes are measured to determine how much has decayed. Since isotopes decay at a
constant and predictable rate, the age of the fossil can be determined without comparing
it to other fossils. I often simplify these different types of dating by telling my students
that relative dating is like saying, “I am older than my sister or my sister is younger than
me.” Absolute dating would be like saying, “I am 13 years old and my sister is 8 years
old.”

The second benchmark (Minnesota Department of Education, 2009, p. 21) refers
to comparative anatomy. To cover this benchmark, students will look at anatomical
structures in different organisms and compare similar features. These structures are
called homologous structures, which means that they share a common ancestry. An
example of this is looking at the forelimb bones of a human, frog, whale, and bird. The
same bones exist in a similar arrangement, but their proportions are different because of
the particular function of that limb in the different species. Another type of comparative
anatomy would be to look at analogous structures, or anatomical structures that have a
similar function but do not have a common ancestry. They are the result of living in
similar environments or having similar selective pressures. An example of this would be looking at the wing of a bird and the wing of an insect. They both allow for the animal to fly, but they have very different structures that allow for flight.

The third benchmark (Minnesota Department of Education, 2009, p. 21) addresses the genetic variation that exists in all populations. This variation is crucial for natural selection to take place. Since not all individuals within the population are alike, there are some that might be able to outrun the predator faster, blend in to the environment more because of a slightly different coloring, or be able to hunt food more effectively because of slightly more sensitive eyesight. Therefore this variation is how a species as a whole can adapt to changing environments over time.

The fourth and final benchmark (Minnesota Department of Education, 2009, p. 21) refers to extinction and how it occurs. It also addresses that extinction has happened and is happening all throughout history. It should be noted that stating that extinction is “a common event” should not diminish the efforts for preserving endangered animals or revitalizing environments to increase chances of survival. Human impact is a recent effect on the environment and has caused extinction among countless species, whereas the extinctions that have happened in the past were caused by nonhuman sources. Extinction can happen on a massive scale as the result of catastrophic events. These catastrophic events can include climate change, volcanic activity, a change in ocean pH, or an extraterrestrial impact like an asteroid. Extinction can also happen as a result of smaller scale changes. These could be disease among a population, introduction of a new genetic mutation, or the removal of a keystone species from the ecosystem. See Appendix B to see how my curriculum matches up with these standards and benchmarks.
The Minnesota Comprehensive Assessment and Evolution

In Minnesota, eighth graders are required to take the Minnesota Comprehensive Assessment (MCA) for science. While the test varies from year to year, students should be prepared to be tested on the science content from sixth through eighth grades. The MCA test is based on the Minnesota Teaching Standards. The six standards that cover evolution are potential test questions on the MCA. The MCA is used as a yardstick for measuring the quality of schools. This is an example of one of the high stakes tests that is prevalent in our current school culture. The eighth-grade science MCA is also sometimes used as a student rubric for placement into high school science classes. In 2011, 45% of Minnesota eighth graders were considered proficient on the Science MCA (Minnesota Department of Education, 2011, p. 1). This number was a decline from the previous year. While these numbers are not specifically referring to the evolution portion of the test, they do show that there is room for growth in Minnesota’s science education as a whole.

Independent School District 196 Curriculum

In 2011, Independent School District 196 adopted a new middle-school science textbook. This textbook is called CPO Science: Life Science (Eddleman, Eldridge, Carabatsos, & McAllister, 2012) and was written with collaboration among different middle-school science teachers. There is also a workbook of activities and labs that go along with the text. It covers evolution in traditional way, focusing on the lines of evidence supporting the Theory of Evolution, the fossil record, genetic comparisons, and comparative anatomy.

There are some activities that engaging to students, but they do not necessarily
depict evolution in an accurate way. One activity focuses on natural selection and is called Crazy Traits (Eddleman, Carabatsos, Benton, Dolcimascolo, & Hsu, 2012, pp. 71-73). The students really enjoy this activity because they get to build a creature from a kit and then play a game against the other students. Cards are drawn that will demonstrate a selective pressure and creatures will either survive or die. For example a card might say, “A bird of prey really enjoys eating creatures with stars on their antennae,” wherein any creature with stars will be eliminated from the game. The final creature standing will be considered the best fit for that particular environment. This game is fun, competitive and exciting, but I have found that it fails to help the students really understand the process of natural selection. Following this game, students still struggle with relating what they experienced in the game to real life examples.

Franklin (2010) stated, “The importance of evolution as a unifying principle demands engaging activities based on real species and the exploration of real evolutionary questions” (p. 114). Middle school is the perfect time to introduce these concepts because students are excited about hands-on experiences and curious about the natural world. As with ISD 196’s curriculum, many times evolution is taught with fictional creatures that are intended to simplify the concepts and streamline the observations, but I find that this belittles what nature has done. The CPO Crazy Traits activity is no exception; while it is fun and engaging, it fails to teach the concepts necessary to understanding evolution. There are plenty of real-world examples that are interesting to study and teach the concepts just as well as the fictional depictions in many science textbooks.
The Importance of Evolution

According to The Academy of Sciences for the Developing World, teaching evolution is important “to foster understanding of the science of nature” (Morabito, Catley, & Novick, 2010, p. 166). The evolutionary biologist Theodoius Dobzhansky titled an essay in 1973, “Nothing in biology makes sense except in the light of evolution” (Franklin, 2010, p. 144). The theme of evolution unifies biology because it links genetics, ecology, microbiology, anatomy, and physiology and explains the connections between them. (Strickberger, 2000, p. xi). The reason predator and prey relationships exist in an ecosystem, the reason a pathogen can infect a cell, the reason animals have similar arrangements of facial features, and the reason DNA passes from one generation to the next can all be explained under the umbrella of the Theory of Evolution. This is a concept that is deeply important to understanding the nature of life, but is unfortunately lacking when it comes to teaching the concepts. It is often brushed aside as a footnote in the broader curriculum but if brought to the forefront, it could be used to enrich and deepen the understanding of all concepts. Morabito, Catley, and Novick (2010, p. 166) stated:

Understanding the history of life on Earth requires understanding both microevolution, which focuses on mechanisms occurring at the level of the individual or population, and macroevolution, which emphasizes changes in species and groups of species over vast time periods in relation to Earth’s history. Microevolution is something that can be observed in an individual or population, such as a shift in gene frequency of the color of feathers in a particular bird species. Whereas, macroevolution focuses on dramatic shifts in species, such as the development
of feathers in some dinosaurs or the rise of lungs to allow tetrapods onto land (Strickberger, p. 287). These are vastly different in the eyes of an evolutionary biologist, but to a middle-school student, it is hard to see the difference. Students often get them confused and propagate misconceptions that evolution happens quickly. A fish does not just one day choose to develop lungs and move on land; there are many tiny changes that happen across large expanses of time that will allow for land colonization. This is something I try to address with an analogy that if you start walking south from Minnesota, you will eventually reach the Gulf of Mexico, but it will take a really long time. Each step is like a genetic mutation and the Gulf of Mexico would be like the development of a new species.

The Middle-School Brain: Cognitive Development of a Middle-School Student

Adolescents are in a very unique point in their cognitive development. They are at a transition between concrete thinking and more abstract and universal thinking. This poses unique challenges when trying to develop effective lesson plans. Adolescence is a very egocentric time and students have a hard time connecting to curriculum that does not apply to them. Besterman and Baggott la Velle (2007) discuss the difficulty in teaching evolutionary theory because “the nature of the subject does not lend itself to practical work.” (p. 76). Middle-school students often ask, “Why do I need to know this?” They think about science education as it affects their daily lives and not as a deeper or universal understanding of the natural world or a means of developing critical thinking skills that could be applied across the spectrum of their lives. This is the main reason that I believe it is difficult to teach middle-school students about evolution. They do not feel invested in the finches, moths, and tortoises that are often mentioned in traditional
evolution curricula. I have had more success connecting with students when I focus my lessons on chimpanzees and gorillas, since those animals are more relatable in their similarities to humans. This is why I developed a curriculum that is centered on humans and their close relatives in order to teach the concepts of evolution.

**Best Practices - Science Inquiry**

A research-based best practice in middle-school science education is science inquiry. The basis of this approach is to have authentic hands-on experiences. “Students have a much higher investment in learning something in which they are actively engaged,” according to Reichert, Leander, and Lenhart (2011, p. 208). Instead of the traditional format of lecture-read-lab, the inquiry approach turns it around and puts the lab or activity first. This allows for students to have an experience to draw upon when doing further reading about a concept. Science inquiry has five essential features. In *The Teaching of Science: 21st Century Perspectives* (2010), Bybee outlines these features as follows:

1. Learner engages in scientifically oriented questions.
2. Learner gives priority to evidence in responding to questions.
3. Learner formulates explanations from evidence.
4. Learner connects explanations to scientific knowledge.
5. Learner communicates and justifies explanations. (p. 82)

These features are in line with the 5-E Instructional model that is described in chapter 3. This model includes this lesson sequence: “engage, explore, explain, elaborate, and evaluate.” (Bybee, p. 12) I usually start my lessons with a demonstration or video, then move into an activity, and end the lesson with reading about the concepts they just
experienced. Discussion plays an integral role in inquiry as it allows for students to process their thoughts about the experience. I have often witnessed students talking themselves into understanding. These “aha” moments are what make teaching exciting for me. The students can construct their own understanding by working through the activity, manipulate materials and discuss their results.

According to Bybee (2010), there are six fundamental abilities that are required by students to be able to do scientific inquiry at the high-school level:

1. Identify questions and concepts that guide scientific investigations.
2. Design and conduct scientific investigations.
3. Use technology and mathematics to improve investigations and communications.
4. Formulate and revise scientific explanations and models using logic and evidence.
5. Recognize and analyze alternative explanations and models.
6. Communicate and defend a scientific argument. (p. 18).

This is important because a “rigorous education in science can help prepare students for good jobs, even if they never become scientists or engineers” (Bybee, p. 129). Students need hands-on activities to develop the expert thinking and problem solving in situations where there are no rules-based solutions (Bybee, p. 129). As a middle-school science teacher it is imperative that I help develop these skills in my students so they are prepared to use scientific inquiry as they get older. My evolution curriculum has a hands-on experience in each of the lessons to provide a science inquiry piece to each concept being learned.

**Traditional Approach to Teaching Evolution**

“Evolutionary theory is a challenge to present in the classroom because of the
way in which it is traditionally taught and the fact that the nature of the subject does not lend itself to practical work” (Besterman & Baggott la Velle, 2007, p. 76). When reviewing several biology and life science textbooks, I saw a similar sequence and topics of lessons. This traditional approach does not get to the inherent curiosity of the average middle-school student because it is difficult for them to relate to the content. I have rarely seen mention of humans in the content of these chapters. Often the only mention of humans will be a point on a geologic timeline showing the appearance of modern humans in the fossil record.

The first topics to be covered tend to be historical in nature, sometimes discussing outdated theories by Jean Baptiste LaMarck about heritability of acquired characteristics, but mostly discussing Charles Darwin and his voyage on the HMS Beagle to the Galapagos Islands. Most of the focus is on Darwin’s development of his 1859 theory and has “rather cursory overviews of natural selection” (Catley, 2006, p. 767).

It then goes into Darwin’s observations of finches and their specialized beaks and giant tortoises and their unique island-specific shells. Learning about Darwin’s finches can be difficult and cumbersome for adolescents. Besterman and Baggott la Velle wrote, “Unfortunately, looking at different shaped beaks, different foods and different islands can potentially become a little tedious for teenage students, as it is so far removed from their own experience” (2007, p. 79).

Natural selection is then discussed and explained as the mechanism for evolution. Often the example of Peppered Moths is discussed to support natural selection: As trees were covered in soot from industrialization, the prevalence of light colored moths declined and the populations of dark colored moths increased. This is a classic example
of natural selection commonly used in evolution curricula, but which has a few problems upon further research. It makes a clean example of how natural selection works, but the article “Darwin’s Missing Evidence” (Kettlewell, 1959) from *Scientific American*, discusses flaws in the science behind this example. One issue with this example is that the Peppered Moth “does not usually rest on tree trunks, normally choosing to reside on the underside of small branches high up in the tree” (Besterman & Baggott la Velle, 2007, p. 77). Grant, Owen, and Clarke (1996, p. 352) explained that there was not a reliable correlation between antipollution legislation and an increase in the population of the light colored *typica* moths. This no longer supports the claim in many textbooks that the color of the tree trunks will directly affect the frequency of dark colored or light colored moths. And finally, the common predator of the Peppered Moth is a bird that is sensitive to UV light and, therefore, seeing the coloring of moths through human eyes draws a very different conclusion than through the eyes of the predator. Majerus, Brunton, and Stalker wrote, “In human visible light the speckled form *typica* appeared cryptic when seen against a background of foliose lichen, whereas the dark form *carbonaria* was conspicuous. Under UV light the situation was reversed” (2000, p. 155). Besterman and Baggott la Velle, (2007) referred to Rudge (2000), who discussed that teachers should not totally stop teaching about Peppered Moths, explaining that “The situation is not as simplistic as many teachers make it, this does not necessarily detract from its pedagogical value” (p. 78). The use of this classic example just needs to be modernized for and updated with scientific discoveries and could be used to discuss scientific skepticism.

After natural selection, the textbooks I reviewed move into homologous and
analogous structures. The textbooks present diagrams showing the forelimbs of different vertebrates and they will discuss the homologous bones in the human arm, a dog’s front leg, a whale flipper, and a bat wing, along with explanations of common ancestry. Then the texts show analogous structures like bird wings and dragonfly wings and discussions on convergent evolution by experiencing similar selective pressures and living in similar niches.

To finish evolution, cladograms and phylogenetic trees showing branching of species and showing relationships between them are used to explain connections between species. “Likewise, college level organismal and evolutionary biology classes often are not oriented towards such ‘tree thinking,’ as they do not center around teaching evolution using phylogenetic trees as representations of evolutionary relationships” (Morabito, Catley, & Novick, 2010, p. 173).

While the traditional approach to evolution is full of strong content and explanations of natural selection, fossil record, and genetics, there is little mention of humans or their close relatives. Rather, they are limited mostly to the end of a branch in a diagram or a picture of their arms showing homologous structures. There is very little that middle-school students can relate to and even less with which they have first-hand experience. I plan to develop a curriculum that will teach these same concepts while at the same time connecting with the middle-school student. Besterman and Baggott la Velle (2007) proposed the importance of an alternative approach at “a time when the subject needs to engage the interest of students so they may pursue and support its central role in science” (p. 78).

There are problems that develop while teaching evolution through a traditional
approach. My students gave me feedback that the topic is dry and uninteresting which I think could be remedied by a more engaging approach based around human evolution. Morabito, Catley, and Novick (2010) look at a shortcoming in the traditional approach that gets more to the heart of the scientific concepts within the theory of evolution. They discuss that there is a “need to address the relationships between evolution and the history of life on earth” (p. 173). Evolution tends to be taught as little disconnected historical anecdotes, stories about competition within an ecosystem and gene mutation. At the middle-school level, these concepts are not often discussed as connected to the history of life on earth. I have had comments from students that relate to this disconnected understanding, such as, “Why did evolution only happen on the Galapagos Islands?”

**Obstacles in Teaching Evolution**

One of the obstacles in teaching evolution is the perceived dry nature of the subject when approached in a traditional way. When discussing the traditional textbook, DeSilva states, “The typical, linear representations of our evolutionary history are not only incorrect, they are boring” (2004, p. 258). They also tend to be out of date and shy away from new discoveries in human evolution.

There is a tendency of biology teachers to avoid teaching evolution (Moore, 2007, p. 269) possibly because of the inevitable conflict that it will cause with some students and parents. This conflict can be an incredibly frustrating one for biology teachers and since many people do not like negative confrontation, they tend to gloss over the subject as quickly as possible. In my experience, former colleagues would teach a unit in evolution without ever using the word “evolution” instead always referred to it as “change over time.” Since evolution is a unifying concept in biology, it can cause
students to have a disjointed understanding of biology when a clear understanding of evolution is lacking.

Some teachers will also present a caveat when teaching evolution and reference religious explanations of Earth’s history as well. “Although virtually all biology teachers in Minnesota know that they are not required to give equal-time to creationism, many mistakenly believe that they can (italics in original) give equal time to creationism” (Moore, 2007, p. 270). The law does not allow for teachers to teach religion in a science classroom and so should not be mentioned by science teachers. I have had conflict with parents when teaching evolution and have been asked to give their children alternative assignments. I was shocked to find out that my own district supports the idea that a science teacher can give students an alternative assignment or exempt them from the required assignments even though evolution is covered on the Minnesota Comprehensive Assessment that assesses schools’ performance. I would need to investigate further to find out if my district is supporting teachers in assigning religious-based alternative assignments. Moore (2007) outlines a study of Minnesota biology teachers that found that one-fifth of the state’s biology teachers teach evolution and creationism and that “approximately 10% of the teachers voluntarily identified themselves as creationists,” (p. 269). Therefore, one might conclude that many of the very teachers who are responsible for teaching evolution have a philosophical conflict with it. In my student teaching, I shadowed a public high-school teacher who, at the beginning of the evolution unit, told his class that evolution is just a theory and that he believed that God intelligently designed the universe. This overtly religious statement surprised me, and I fear that this type of statement may be quite common in many American science classrooms.
Another obstacle in teaching evolution is that students lack the background necessary to fully understand the concepts. “Related research also demonstrates that students’ abilities to analyze and interpret evolutionary relationships using cladograms - macroevolutionary diagrams illustrating the history of life - are cursory, at best” (Morabito, Catley, & Novick, 2010, p. 173).

In addition to the other obstacles, teachers themselves may not understand evolution well and so cannot teach it clearly. Morabito, Catley, and Novick stated, “Improvements in teacher education with respect to evolution are therefore critical. Teachers can hardly be expected to cultivate an adequate understanding of these principles valued by evolutionary biologists in their students while they, themselves, lack such understanding” (2010, p. 174). When the teachers are not educated in the concept of evolution, their students are not going to learn the concepts as well. When looking at the understanding of evolutionary concepts, Morabito, Catley, and Novick, (2010) stated that the “apparent lack of understanding of these fundamental evolutionary concepts can likely be attributed to inadequate exposure in and/or retention from their K-12 educational experiences,” (p. 173).

**Common Misconceptions About Evolution**

There are many common misconceptions that students have about evolution before coming to my classroom. These misconceptions are common and often cited in literature about teaching evolution. Many are reinforced by popular culture, media and limitations in the English language (www.evolution.berkeley.edu/evosite/misconceps/index.shtml). Every year that I teach evolution, I get questions based in these misconceptions and, as a result, I have developed
strategies to address and correct these misconceptions. Below, I have outlined the most common misconceptions I have experienced with my students and proposed possible ways to address them.

**Misconception 1: “Evolution Is Just a Theory.”**

This is probably the most common misconception that I encounter when teaching evolution. The colloquial use of “theory” diminishes the importance of a scientific theory. I often wish that the scientific community could use a different word altogether to avoid this misunderstanding. When people are casually talking about “having a theory,” they usually mean they just came up with an idea or have a hunch, as in “I have a theory that my garden will grow bigger this year because it has been a rainy spring.” That person would really be stating a hypothesis and not a theory. A hypothesis is the prediction of an untested experiment and, as data is collected, it will either be supported or refuted (Moore, 1993, p. 135). A theory, on the other hand, is an explanation of evidence (Hillis, 2012, p. 289). I think of it as the end result of looking at all of the known data, rather than the starting point before data is collected, as with a hypothesis.

Sanders and Ngxola stated,

Contrary to the popular understanding of a theory as a hunch or tentative idea, in science it is only once proposed explanations have been thoroughly tested by many scientists and a convincing body of evidence has accumulated that an explanation acquires the status of a scientific theory. (2009, p. 121)

Therefore, a scientific theory is a sound explanation that is backed up by all of the available data. According to the National Academy of Sciences, “many scientific theories are so well established that no new evidence is likely to alter them substantially”
Every time a new fossil is discovered or new genes are sequenced, this data joins the body of evidence that supports the Theory of Evolution. Therefore, the scientific Theory of Evolution only gets stronger and stronger. Morabito, Catley, and Novick (2010) wrote, “The concept of common ancestry as articulated by Charles Darwin (1859) in *The Origin of Species* has become increasingly supported over time, particularly given today’s prolific DNA evidence supporting this hypothesis” (p. 172).

**Misconception 2: “Giraffes Have Long Necks Because They Wanted to Reach the Leaves at the Top of the Trees.”**

In my teaching experience, this is a common misconception among my students that there is some type of choice or will in how evolution goes. Jean Baptiste Lamarck developed this idea of soft inheritance or Inheritance of Acquired Characteristics where individuals have an “inner perfecting principal” that allows them to develop adaptations as needed. (Strickberger, 2000, p. 24). But in order for a trait to be passed on, it already has to be in the genetic information of that individual. My students get confused by this “chicken-or-egg” type of thinking. They ask questions such as, “How did the gene get there if it hadn’t been selected yet?” Through random mutation, traits can arise and they are then selected for as they are being “tested out” by nature. So, the traits appear through random mutation, but it is up to natural selection to determine if they trait will stay. Besterman and Baggott la Velle (2007) stated, “As Deadman and Kelly (1978) found, students come to the study of evolution with many preformed, Lamarckian ideas, such as adaptation being an individual’s inherited response to environmental change” (p. 76). Lamarck also described that through the *Principle of Use or Disuse*, a structure
frequency of use determines whether a trait stays in the population (Strickberger, p. 24). I have heard people use this type of explanation when discussing vestigial traits in humans. One example is that humans do not need their appendixes, which will slowly get smaller and eventually go away. Just because an individual does not use a structure does not mean that the genes will cease to exist.

**Misconception 3: “Humans Are the Most Evolved.”**

This hierarchical way of thinking is a throwback to the Great Chain of Being explanation of life with a progression from imperfect to perfect. This hierarchy started with perfection, or God, at the top (www.britannica.com/topic/Great-Chain-of-Being). It then regressed from perfection to man and continued to “lower” creatures like worms and insects, then with plants and ending with inanimate matter (Strickberger, p. 7). The thought that humans are special, better, and somehow separate from the rest of the natural world is an archaic thought when it comes to modern evolutionary thinking of a world that is comprehensible and rational (Strickberger, p. 17). For example, my students often ask why humans are not evolving anymore and whether dolphins will eventually have opposable thumbs. To address the first question, humans *are* still evolving (Strickberger, p. 225). We have evolved just as much as everything else that is alive today. There is no such thing as a species that is more highly evolved. Every living organism has an equal place at the end of their branch of the communal evolutionary tree (Kardong, 2005, p. 9). In response to the second question, human traits work well for humans, but other species have different selective pressure, different environments and different strategies for survival (Kardong, 2005, p. 5). What works for us will not necessarily work for them. Different species are not evolving to become more human, they are evolving as a result of
the selective pressures they have within their unique environment. I think cartoons and images that show fish crawling onto land and eventually becoming human also propagate this misconception. While there are certain aspects of these images that can be supported by the fossil record, it is flawed to assume that humans are the evolutionary goal of all living things.

A cartoon that can reinforce the misconception that animals are evolving to be more human. (funnytimes.com/19990203/)

**Misconception 4: “Humans Come from Chimps or Monkeys.”**

This misconception will elicit questions such as, “If humans came from chimps, then why are there still chimps?” Students with this misconception have a very skewed understanding of a common ancestor. Morabito, Catley, and Novick wrote, “The concept of *most recent* common ancestry serves as such a key reference point and is of great predictive value” (2010, p. 172, italics in original). I often explain a common ancestor using the analogy of cousins who share a grandfather. One cousin did not come from the other; instead both descended from the same grandfather. This is the same with chimpanzees and humans. Humans did not come from chimpanzees, but instead chimpanzees and humans are both derived from a common ancestor that existed in the
Having the reference point of a common ancestor allows for discussion of lineage and relationships between related species. At the middle- and high-school level, these evolutionary relationships between species are drawn using cladograms. “Cladograms organize taxa based on shared derived characters in ways that make clear the distinction between a common ancestor and the MRCA [most recent common ancestor]” (Morabito, Catley, & Novick, 2010, p. 167). A cladogram is similar to a family tree, but instead of showing relationships within a species, it shows the relationships between clades, which are groups of species that include “a most recent common ancestor and all its descendants” (Morabito, Catley, & Novick, 2010, p. 167). Seeing these relationships in a simple tree allows for a clearer understanding of how species are related to each other. Morabito, Catley, and Novick state, “One needs reference points that are more restricted in their distribution to tease apart nested hierarchical groups of taxa” (2010, p. 172). Once there is an understanding of how a cladogram is drawn, species’ relationships can be described as more or less deeply branching. The further back in time the common ancestor is, then the more deeply branching two species would be; for example a human and snake are more deeply branching than a human and a chimpanzee.

**Misconception 5: “Geologic Time Scale vs. Our Personal Experience with Time”**

In general, people have a hard time understanding long periods of time. In my experience, this is especially true for adolescents who think of 50 years as an extremely long period of time. This causes problems when we discuss an event that happened a thousand years ago versus an event that happened a million years ago; those lengths of time seem the same in their minds. Evolution requires long stretches of time in order to
see dramatic differences in physiology. I will often use words like “recent” when referring to something like the Ice Age or state, “That occurred only a million years ago.”

I often need to remind myself that most of my students do not have the maturity, math skills, or experience to grasp geologic time fully. They have been raised with movies, television shows, and comics that show dinosaurs living alongside wooly mammoths or humans. They think of dinosaurs as a group of extinct animals that all lived together at the same time, not realizing that they spanned hundreds of millions of years with many of the most famous species not living as contemporaries, such as the Tyrannosaurus Rex and the Stegosaurus.

I address this misconception by doing a scale timeline of the history of the earth, based on Carl Sagan’s Cosmic Calendar (Sagan, 1980) as a model for this activity. When viewed on a long strip of paper that stretches the length of the classroom, students see that humans are only in the final millimeter of the strip. Students can then see geologic time in a very concrete way and gives them a framework for understanding how much time is represented in a fossil layer.

I find another aspect of this misconception somewhat endearing and it shows the youth of the age group of my students. In reference to the names of each of the eons, eras, and periods of Earth’s history, students have asked how we know what those time periods were called. This shows the naiveté of middle-school students and can be used as a starting point to learn why the time is broken into the pieces it is and why they are not equally spaced the way years, decades, and centuries are. The sections of time are divided based on major events in Earth’s history, often catastrophic, such as mass extinctions or dramatic climate shifts. They are named by scientists and their names are
sometimes inspired by events, places or living things that lived during those times.

**Misconception 6: “Extinction Only Happened Once”**

My students usually have an understanding of extinction, but they misunderstand how and how often it happens. They often think that extinction only happened once on Earth and killed all of the dinosaurs. Part of the Minnesota state teaching standards states that students “recognize that extinction is a common event and it can occur when the environment changes and a population’s ability to adapt is insufficient to allow its survival” (Minnesota Department of Education, 2009, p. 21). Extinction has occurred and continues to occur throughout Earth’s history. Sometimes there is a catastrophic event, like the asteroid impact during the K-T extinction, which causes a massive amount of extinction at once. Other times, there are small extinctions that happen on a species by species basis and can be caused by many different reasons. The Earth is a dynamic place and no species is safe from the threats posed by climate change, geologic phenomena, and extraterrestrial impact events. Therefore extinction is a relatively common event and is seen all throughout the fossil record (Eddleman, Eldridge, Carabatsos, & McAllister, 2012, p. 274).

**Summary**

This chapter sets the groundwork for why it is so important to have a high-quality curriculum for teaching evolution to middle-school students. I have considered each topic that I have written about when designing this evolution curriculum. The first place to start when designing a curriculum was to find a curriculum model that matched my teaching goals as well as my teaching style. I started by looking at science inquiry and how experts in science education would recommend laying out a lesson sequence. I then
found a curriculum design model that matches the science inquiry lesson sequence. In chapter 3, the 5-E Learning Cycle Model of Instruction is explained in detail, as well as how the 5E model can be easily paired with science inquiry. I used this instructional model to connect my teaching goals and the Minnesota Science Teaching Standards.

I discussed the issues with teaching evolution traditionally, expert research on best teaching practices. I proposed a new way to teach evolution by using the 5E Learning Cycle Model of Instruction. I discussed the Minnesota Teaching Standards for science education and what is required for students to know about evolution. I will go on to write about the current educational climate on high stakes testing and how Minnesota students perform on these tests. Chapter three discusses the curriculum foundation and structure, reviews the process of curriculum development, and explains how the lessons for this evolution curriculum were developed.
CHAPTER THREE

Methodology

This chapter explains the methodology of research for the capstone question: How can the 5-E Learning Cycle Model of Instruction be integrated into a curriculum unit designed to teach the six Minnesota middle-school evolution standards?

Setting

This curriculum is designed for a seventh-grade middle-school science class. I teach at Black Hawk Middle School, a diverse suburban school in Independent School District 196, in Eagan, Minnesota. Over the years of working with this particular population, I have seen what works and does not work when teaching evolution. This has driven my curriculum to be the way that it is now. My students are overall at grade level in reading and math. Compared to the state, this is above average. Thus, I can make some assumptions. First, I can assume a certain level of math and reading understanding when teaching science. Second, I assume they read a level necessary to read out textbook and ancillary materials. Third, I assume that the majority of students can do basic arithmetic necessary for figuring out averages and percentages. Most students can do basic line and bar graphing on an x- and y-coordinate plane. This allows me to approach my science teaching at the level that is laid out by the Minnesota teaching standards. Occasionally, I do some pre-teaching. I differentiate my lessons for those students who need of more help. Since every student learns differently, I offer varied activities and
learning experiences. Each unit has opportunities for enrichment beyond the standard curriculum and remediation for students who struggle with the content and concepts.

**Context**

This unit is positioned in the middle of the seventh-grade school year. The unit that just precedes the evolution unit is genetics. Up to this point students will have learned cells, living vs. nonliving things, and matter.

The year begins with a unit on living versus nonliving things. Next is the Matter Unit where students learn that all matter is made of atoms. In the Cells Unit, the students learn that all living things are built out of cells and they are the basic unit of life. By the time students learn about Genetics Unit, they should already have a firm grasp on what a living thing is, what cells are and what atoms and molecules are. They then use this information to learn about heredity and how traits are passed from one generation to the next.

The knowledge the students gain from these four units set the stage for learning about evolution. The knowledge from genetics about how traits are passed on and DNA replicates to make new cells, leads into learning about gene mutation and how very small changes in DNA can cause adaptations that can be advantageous for survival. The knowledge they learned from the living things unit about how organisms respond to their environment flows into the ideas about natural selection and “survival of the fittest.” By this point in the year, students have a very clear understanding that physical and behavioral traits are inherited from the previous generation. When we begin to discuss natural selection, it can now be talked about in the framework of those individuals with more advantageous traits are more likely to survive to pass their genetic material to the
next generation and those individuals with less favorable traits will not as likely survive reproduce and therefore those traits can be lost over time.

**Differentiation**

In my classroom there is a need for differentiation within the curriculum. There is a wide range of need and ability within the student body. Every student is entitled to a fair and appropriate education as determined by the Individuals with Disabilities Education Act from 1975 (Public Law 108-466). “Fair and appropriate” education means something different for each student. There are students that fall well below grade level in reading and math as well as students who are taking advanced math classes at the college level. This is important to keep in mind when developing curriculum. I have built into my curriculum opportunities for remediation for those struggling students. I have also included opportunities for deeper exploration at a more advanced level for those students on the other end of the spectrum.

**Links to Other Units**

Previously I discussed how units that are taught before evolution help to give prior knowledge to understanding the concepts in the evolution unit. Since evolution is the unifying theory of biology, I will now discuss how evolution fits into the curriculum for the rest of the school year. During the second half of the school year, students will study these units: Classification, Human Body, Microbiology and Disease, and Ecology.

Upon completion of the evolution unit, students will learn about classification of living things. Since they have an understanding of genetics and evolution at this point, it is easy for the students to see why living things can be organized into groups based on genetic similarities and evolutionary branching. Having and understanding of
evolutionary relationships to other living things, students can see how we have similar traits to other mammals such as hair, four limbs, and being warm-blooded.

During the human body unit, students learn about how the human body is organized into four levels: cells, tissue, organs, and organ systems. The human body is the culmination of millions of years of evolution and is continuing to evolve. Vestigial structures can be seen throughout the human body. Looking at these structures, such as a small appendix and fused tail vertebrae bones, show us where our species came from.

During the microbiology and disease unit, students learn about pathogens and how the human body fights them off. Discussions about co-evolution are common when discussing how diseases have always been with us. Our human immune system has been adapting over millions of years to fight these pathogens. In my class, antibiotic resistance among bacteria is discussed as an example of natural selection; only the bacteria with adaptations to survive antibiotics will reproduce causing the species to become more resistant over time.

Evolution has many connections with the ecology unit. There is competition within an ecosystem, predator and prey populations affect each other, and populations of producers affect the consumers. These all show natural selection in action. Evolution is often called the unifying theory of biology and I see how this is evident in the all of the units that I teach.

**Curriculum Design Model**

There are many different schools of thought on how to design effective curriculum. My philosophy of teaching is all about being student centered and working with appropriate methods for cognitive developmental stages. I decided that backward
design, as outlined by Wiggins and McTigue (1998) in *Understanding by Design*, fits with my teaching style and curriculum writing.

The backward design approach keeps the outcomes of understanding as the main focus of each lesson. (Wiggins & McTighe, 1998) The lessons are designed to meet each outcome, where it starts with the question and works backwards to what the student will need to do to answer the question. The outcomes of my curriculum are determined by the Minnesota State Teaching Standards (Appendix A). The outcomes are evaluated based on evidence presented by the student in the form of a demonstrated skill, a concept or information.

The 5-E instructional model is well suited for teaching inquiry-based science lessons because both lesson formats mirror the structure of the other. The 5-E model is a guide to each lesson by following the sequence “engaging, exploring, explaining, elaborating, and evaluating” (Bass, Contant, & Carin, 2009, p. 2).

The “Engage” phase of this instructional model has a goal of getting the students interested in the activity. It is also used as a time for teachers to access prior knowledge and discover any misconceptions students may possess.

The second phase of the lesson is “Explore,” during which students are involved in a hands-on activity or lab. This allows them to gather evidence and make observations about the lesson topic. These activities could involve conducting an experiment and collecting data, organizing cards or objects into different classifications or manipulating a model. This a crucial step in the lesson sequence because it will be the experience that the students draw upon for the rest of the lesson.

The “Explain” phase is third in the lesson sequence. This is a time when students
are asked to describe their experience and what they learned. They are reflective during this time and working on explaining their observations.

The students then move into the fourth phase of this lesson sequence called “Elaborate.” During this time in the lesson, students are asked to apply what they learned to a new situation. This could include looking at a similar scenario to one they have already seen and predict the outcome. It could also be a time to design an experiment to test questions that they acquired during the previous phases.

Finally, the students complete the lesson sequence by doing the “Evaluate” phase. This is when students are asked to demonstrate their knowledge of the concepts. This could be in the form of a test or quiz, but could also be in the form of self-assessment where students reflect on what they have learned in the lesson. The goal of the assessments should be to encourage metacognition and student ownership of learning.

After deciding upon backward design and the 5-E Learning Cycle Model of Instruction, I set out to design a 12-lesson unit on evolution. The Minnesota Science Teaching Standards set the groundwork for what concepts needed to be in the curriculum. Chapter 4 provides more detail about the steps of the curriculum development process.

**Summary**

This chapter provides background on the setting, participants, and construct of the curriculum unit that is presented in chapter four. That curriculum development was focused on discovering how backward design and the 5-E Learning Cycle Model of Instruction be used to develop a science unit on evolution based on six Minnesota middle-school evolution standards.
CHAPTER FOUR

Curriculum Design for Evolution Unit

In this chapter provides an overview of the curriculum I have developed. I will discuss how this is supplemental to currently adopted curricula and how this enhances it.

Curriculum Development Process

Backward design and the 5-E Learning Cycle Model of Instruction set the format of how I would approach the curriculum development process. I then began to design a 12-lesson unit on evolution using the Minnesota Science Teaching Standards as the groundwork for the curriculum. This 12-lesson unit is outlined in Appendix B; five of the lessons are included in Appendix C. The standards outline the concepts needed to be in evolution curriculum. After this, I wrote student learning goals for the unit that where phrased in the “Students will be able to” format. Then I set about to outline activities and lessons that would achieve these goals. Once the activities and lessons were established, I worked through several different sequences before deciding upon the final sequence of lessons. I wanted the unit to have a coherent arc that allowed for the most effective order so knowledge continued to build upon what was learned. Finally, each lesson was written in detail using the 5-E Learning Cycle Model of Instruction. In the process of writing the lessons, I developed a lesson plan format template that is explained in detail in the next section and discuss extensively in chapter four. The final product is a 12-lesson unit that can be taught over the course of three weeks. It accomplishes the
students learning goals as well as covers the Minnesota Science Teaching Standards.

**Introduction to the Evolution Unit**

The goals of this unit are to give seventh-grade students a strong foundation of understanding about evolution. It is intended to provide a solid background that will allow for students to explore in more detail as they continue in their science education. The curriculum is designed with the high-school standards in mind to provide the prior knowledge that will allow for the high school standards to be understood. Another goal of this unit is to address misconceptions and clarify common confusion surrounding the topic of evolution.

All of the lessons in this curriculum are based on the Minnesota Science Teaching Standards (Minnesota Department of Education, 2009). They are discussed in detail in chapter two. Many lessons cover evolution more broadly than is required of the teaching standards, but are all designed to be appropriate to the seventh-grade level. There are notes throughout the lessons that offer suggestions for differentiation for exceptional students. I have also included teaching tips that are things I have learned from implementing this curriculum in my own classroom.

**Intended Audience**

This unit is designed for an average middle-school life science classroom. Adaptations can be made to accommodate English Language Learners, gifted students, struggling readers, and special education students. Where appropriate, these adaptations can be found and the end of each lesson plan in Appendix C. The intention of this unit is to be taught as a supplemental unit to a more traditional curriculum. It can also be taught as a stand-alone unit, but might require adjustments depending on the needs of the
specific audience.

**Prior Knowledge Necessary**

Some prior knowledge is required to teach this curriculum effectively. My intended placement of this unit is about at mid-year of seventh grade. This unit will be after the units with topics covering cells, living things, genetics, and chemistry. I went into detail about what is covered in these units during chapter three in the section entitled “Context.” There is an extensive amount of vocabulary in this unit. Some vocabulary words are covered in this supplementary unit, while it is assumed that others be taught during the regular district curriculum.

**Sequence of the Lessons**

The sequence of the lessons in this evolution curriculum is organized so that each builds on the previous lesson up to a culminating authentic project. The unit begins with two lessons on geologic timescale and the fossil record. These lessons give students context about the time that is required for macroevolutionary changes. The next two lessons are about comparative anatomy. The students will compare homologous structures to see how similar structures can be explained by common ancestry. The following two lessons focus on the mechanism of evolution through geologic isolation and natural selection. Then there is a lesson on the history of science about Charles Darwin and the voyage of the H.M.S. Beagle. Next are four lessons on using genetic technology as it relates to human evolution. The final lesson is an authentic project where students can explore their own ancient family history by testing their mitochondrial DNA. I put a lot of thought into the sequence of these lessons and believe that the culmination of the unit with students seeing evolution in their own DNA is an
exciting and age appropriate way to conclude.

Lesson Plan Format

I developed a template that combines Backward Design and the 5-E Learning Cycle Model of Instruction. Chapter four shows how this lesson format will look in action. In Appendix A, the lesson-plan format template is shown and provides the outline of each lesson plan. The format starts with the goal that the lesson is trying to achieve. Then the lesson plan lists the teaching standards that it is addressing. This template organizes each lesson by stating the Minnesota Teaching Standards and lesson objectives as I explained when discussing Backward Design. The template follows the 5-Es as a way to sequence the learning activities. I also incorporated an opportunity to differentiate each lesson to adapt to the individual learners. Included in the template are lists of materials needed for the lesson as well as other resources, which may include items such as video links and supplemental articles. After that, a list of materials and resources is noted. Then the lesson sequence is laid out. This lesson sequence is in the form of the 5-E instructional model. Some parts of the format I have adapted to work with my own lesson-planning style, which includes hands-on and experiential learning as well as student directed exploration. At the end of the lesson plan, I list suggestions for differentiation for high achieving students as well as struggling students. In Appendix C, there are complete lessons that show how this format is used to organize the arc of a lesson.

Examples of Backward Design and 5-Es

I chose samples of lessons that are examples of Backward Design and the 5-Es Learning Cycle Model of Instruction. I used backward design (Wiggins & McTigue,
1998) to organize the arc and sequence of lessons. This is outlined in more detail in the Curriculum Map in Appendix B. In Appendix C, I have included a portion of the curriculum as examples of how this curriculum development process worked. The first step is look at the Minnesota Teaching Standards. Then these standards are translated into Student Learning Goals stated as what students will be able to do. After the learning goals are set, the lesson objective is then set and the lessons are then designed to allow for students to meet these goals. In this step, I brainstormed different ways to sequence the lessons to be the most effective for reaching these goals. The steps this Backward Design is highlighted in the following sequence of steps. I used one teaching standard to show how this unfolds from start to finish.

1. State the Minnesota Teaching Standard

   7.4.3.2.2 Use internal and external anatomical structures to compare and infer relationships between living organisms as well as those in the fossil record.

2. Translate to Student Learning Goals

   Students will be able to compare homologous structures and explain that common ancestry is the reason for the similarities.

3. Lesson to Reach Student Learning Goals

   Lesson 5 Objective: Students will be able to measure and calculate volume and area of several anatomical features of hominid skulls and be able to compare these measurements to infer relationships about their evolutionary relationships.

4. Where is the lesson in the Curriculum Sequence?
This lesson is the fifth lesson and falls midway through the curriculum sequence.

Backward design (Wiggins & McTigue, 1998) is used for the overall flow and goal of the curriculum, but the 5-E Learning Cycle Model of Instruction is used to organize the structure of the lesson. I used the stages of backward design when broadly determining planning the topics to be covered and sequence of lessons of the entire evolution unit. The backward design stages are:

1. Identify desired results.
2. Determine acceptable evidence.
3. Plan experiences and instruction. (Wiggins & McTigue, p. 9)

The 5-E Learning Cycle Model of Instruction was then used to develop the details of each lesson. Using the same lesson as above, one can see the 5-Es being used to organize the lesson. The lesson is about comparing skulls of close human relatives and ancestors. The lesson can be viewed in more detail in Appendix C, Lesson 5.

1. Engage
   Show students short video on the discovery of “the hobbit” (*Homo floresiensis*).

2. Explore
   Students study, observe and measure each skull. They use many different hands on tools to be able to compare the measurements of the different species.

3. Explain
   Answer analysis questions and explain the findings from the skull investigation.
   Students will write reflection on what they learned.

4. Elaborate
Students will explain their findings to other students. As a class, have a
discussion about the findings of the different skulls. Topics of discussion could
include; cranial volume relating to intelligence; cranial volume relating to
thermoregulation, chewing muscles needed for different diets, etc.

5. Evaluate

Students will be able to measure and calculate volumes correctly. Students will
infer and explain the homologous structures of the skulls and infer the common
ancestry of the species.

**What Does This Look Like in Action?**

In a middle-school classroom, things often look different than they appear in
writing. In my classroom, I have a 55-minute class period and there are many things that
need to be done in that short time. Many rituals and routines are established in my
classroom to reduce time wasted and increase student learning. I am going to explain
how one lesson might look as the class period progresses. The lesson I am explaining is
outlined in Appendix E, Lesson 7: Natural Selection.

1. Engage

At the beginning of class, students enter the classroom and pick up their lab
notebooks from their class’s storage box. They go to their seats and open their lab
notebooks to the next empty page. On the board, there is a warm-up question that they
write in their notebooks. The question reads, “You are on a deserted tropical island, you
can only bring three things with you. What would you bring to help you survive?” They
write for a few minutes, and I then address the class and ask for some examples about
what they would bring. I then pose additional questions to them: What if the island were
in the arctic? Would you bring the same items or would you want to bring something different? Students then discuss with their neighbors and then a few students share their responses with the class.

2. Explore

Students are then divided into different teams of 5-7 members. Each team sits around a table and it is explained that the table represents a different island. Students are given a data table to keep population data throughout the activity. I give background about the simulation. They are all the same species of birds that have found themselves stranded on an island. Within their population they have genetic variation. I then pass out the different tools to each group member. In each group, there are a variety of tools including chopsticks, spoons, tweezers, and plastic knives. At this point, the volume and activity levels of the room increase as the students begin to play around with their tools. They are instructed to write the population numbers of the different varieties on their data table.

Then I place a tray on each table. Each tray is filled with the “food” for the birds. Depending on the table, there is a different type of food source including dry beans, large marshmallows and rubber bands. I tell the students that their job is to get as much of the food into their cup as possible in the time allotted. I usually hear a few groans and complaints about how it is not fair that some students have “better” tools than others. I address this complaint with the idea that in nature there are some organisms that are born with an advantage over others. Their fears are also eliminated when I tell them they will still be able to participate even if they “die.”

I set a timer and tell the students to try to get 10 food items into their cups. When
the time runs out, those students with less than 10 items are told they did not survive. I then explain that the next round of the game represents the next generation. Everyone turns in their tools and then gets tools that are from the varieties of birds that survived. They then write down the new population data. We repeat this process for several more rounds with the time getting shorter each time. The noise level and excitement of the students increases as we progress in this activity.

Eventually, each table will have a clear “winner.” The populations of the different varieties of birds will have changed throughout the activity. The tool that was the best for picking up the food will have the highest numbers. While every class is different, usually the results will show the spoon works best for dry beans, the tweezers work best for rubber bands and the knives work best for the marshmallows. Students will then clean up and return to their seats.

3. Explain

Students will then analyze their data by graphing the populations on a line graph. The class will compile their data with the data of other classes to increase the sample size. This is to increase the validity of the results and reduce outliers. They will analyze the graph to see how the populations changed over time. There are follow-up reflection questions where they will need to explain what the trends of the data are. They will also need to explain possible reasons why the populations changed. After then finish this, they will compare their data with a group who had a different food source. The success of different populations will be different on the different “islands.” Because the selective pressures were different with each group and different adaptation was favorable.

4. Elaborate
Once the students’ reflection and follow-up work is completed the class is brought back together to have a class discussion. On the screen, I will show them pictures of the Galapagos Islands and the finches that live on each island. We will discuss as a class what the selective pressures were on each island and why certain adaptations were favorable on those islands. This will be paralleled with the data they have from their activity and show a relationship to our simulation and the real world.

5. Evaluate

Students are then evaluated based on the quality of their graphs. This exercise of graphing will help to reinforce math concepts that are needed throughout the science curriculum. The ultimate goal of the lesson was to have a solid understanding of how natural selection works. Students will be evaluated on how well they were able to describe natural selection in this activity. The students’ ability to explain that the food sources on the island drive the favorability of traits and explaining that those traits will become the dominant adaptation within the population is my goal with this lesson.

Summary

In this chapter, I have explained the curriculum that I have written to more effectively teach the evolution standards. Samples of lessons where shown as well as a narrative explaining what a lesson looks like in action. In the next chapter I will discuss the capstone process and reflect on what I have learned about writing a curriculum. I will also propose future work to be done and anything I would have changed as I look back on my writing.
CHAPTER FIVE

Conclusion

In the last chapter explained the evolution curriculum I developed, its context in the broader science curriculum, and its intended audience. This chapter offers reflection on the capstone writing process, what I have learned as the result of developing a curriculum, and what I propose future work to be done to enhance or expand this evolution curriculum.

Readdressing the Capstone Question

When beginning this capstone process, I wondered how I could write a curriculum on evolution that uses primatology and human evolution as a theme. I always had a love of human evolution and wanted to use this deep interest as a way to inspire a better evolution curriculum. Over the time I spent researching and writing my curriculum, this question slowly evolved into its final form: “How can the 5-E Learning Cycle Model of Instruction be integrated into a curriculum unit designed to teach the six Minnesota middle-school evolution standards?” While human evolution and primatology are still the theme of the unit, the process of writing this curriculum and capstone leaned more towards curriculum design than to the actual content of the curriculum. I think this organic transition made for a more coherent and comprehensive design for the evolution curriculum. I learned more about how a curriculum is designed and therefore the final product was better overall.
Review of Curriculum

The curriculum that I designed addressed the six Minnesota evolution teaching standards. The theme of this unit is human evolution and primatology for two reasons. The first reason is my deep interest and love of human evolution. I have always been fascinated by the question of where we came from and through my studies I have developed an even deeper understanding and desire to learn more. This lifelong connection with evolution became a frustration when I began teaching science. Students did not share my interest and made for a challenging conflict when trying to teach the concepts. I set out on a quest to remedy this problem by writing new lessons that focused on hands-on, inquiry-based learning. This not only is more age appropriate and research shows that students learn better this way, but it is also more exciting and enjoyable to teach in this method.

The curriculum follows a sequence that starts with geologic time and the fossil record. This is followed by classification and comparative anatomy. It then flows into learning about natural selection and the historical significance of Charles Darwin and his infamous voyage of the H.M.S. Beagle. These lessons set the foundation to them move into DNA evidence supporting the Theory of Evolution. The curriculum culminates in an exciting research project that allows for students to test their own DNA and explore their own family lineage and ancient migration. Throughout the unit, humans and their close relatives are the subjects of much of the activities. Adolescents have a natural curiosity about where they come from and this unit allows them to explore and find answers to these questions.
Reflections on the Literature Review

Through the process of researching literature for this capstone, I was interested to find out what experts in the field of science education have to say about evolution. It was important to me to see statistics about how thoroughly evolution is being taught. It was surprising to me to find out how few biology teachers actually teach the required evolution concepts. This gave more motivation to me to make a high-quality evolution curriculum that could be used by other teachers.

Another aspect of my literature review was researching different curriculum models. After reading many different types of models, there were two that resonated with me. Backward Design (Wiggins & McTighe, 1998) made sense to me because it keeps the outcomes as a main focus. It keeps in mind the questions what do the students need to know and where am I going with this unit. The other curriculum model that I thought applied appropriately to science education is the 5-E Learning Cycle Model of Instruction. This fit well with inquiry-based science because puts the focus on the activity and experience. It is constructivist in nature and assists the student in building an understanding through experiencing the concepts.

These two curriculum models set the foundation of how I would write my curriculum. They allowed me to have a framework around which to build my activities and lessons.

Review of Methods

Chapter three discussed the methodology I used to develop this curriculum and to write this capstone. It discussed the setting and context of this curriculum and the importance of applying what is learned in this unit to future topics of study. The decision
to use the Backward Design model of curriculum writing was justified and explained. I used this model as a way to design the overall structure of my unit with the ultimate goals of learning the Minnesota evolution teaching standards as the framework. I also discussed the use of the 5-E Learning Cycle Model of Instruction when designing the lessons within the curriculum. This model of instruction was in line with inquiry-based science, which is the leading science teaching strategy that is backed up by research.

**Reflections on the Curriculum Writing Process**

Through the curriculum writing process, I learned many things about how to design an effective learning experience. I worked hard to have a coherent flow and arc to each lesson sequence. I enjoyed the process and was able to use my creativity to come up with new ways to cover the same material. Through the experience I was able to imagine my ideal classroom and think beyond what materials I have access to. Some materials used in the unit are not things I have on hand, but by designing these lessons I could use whatever materials I wanted. Overall, I learned a lot about what goes in to writing a curriculum and how to find an appropriate design model to fit the content.

**Professional and Personal Growth**

I have grown in my ability to be an effective teacher. When I first began this process, I was mostly using lessons that came straight from my classroom textbooks. Through this process I have moved more toward writing my own lessons and units. Overall I have moved further away from the textbook lessons to incorporate more creativity and hands-on experiences into my classroom. When I began writing this capstone, I was a new teacher who relied mostly on my colleagues and classroom materials to guide my teaching. Now I am a more senior teacher in my department. I
am viewed as a professional by my administration and coworkers.

I learned a lot about how my own learning style works. I was able to grow as a writer and have much more confidence in my ability to convey a message in my writing. I started brainstorming lessons and writing my first chapters when my career was still in its infancy. I have matured as a student, as a teacher, and most importantly as a scholar.

**Future Exploration**

This curriculum has not been tested in a scientific way in a classroom. I have been using pieces of this curriculum in my own teaching, but do not have data to back up how effective it is. I would like to do a more controlled study in the future. This would be possible in my own school because our seventh-grade student body is such that they are divided in half between me and another teacher. I propose that in the future, we do a controlled study in my school. In order to do this, each teacher would do a pretest prior to teaching the evolution unit. Then in my classes, I would teach the curriculum laid out in this capstone while my colleague would teach the traditional curriculum that our district has adopted. After the completion of the unit, each teacher would give a posttest to assess the effectiveness of the two curricula.

If I did this capstone curriculum process again, I would do several things differently. I did much of my curriculum writing in a vacuum. It would have been nice to collaborate more with other science teachers. I work well in a community setting, and I think my curriculum could have been enhanced by the feedback and collaboration of colleagues. This was difficult because of the limited time available to my colleagues and developing an evolution unit is not a priority in my school.

I would also have liked to do more exploration into the resources available in my
city that could be used as partners in teaching evolution. There are many resources available at the various universities, zoos and museums in the area and I would like to look into how they can help me in the future.

**Summary**

This capstone has been in the works for a long time. I started this process as a novice teacher and a young adult just figuring out how to navigate this world on my own. Over the years of working on this, I have matured personally and professionally. There were times when I thought I would never finish or I just needed to scrap this and start over. But I kept going, chipping away at this slowly and steadily. The lessons I have learned through this process are invaluable.

Professionally, this capstone process ends with me as an established teacher in a district where I can build the rest of my career. I now have a strong understanding of how to write a curriculum and can apply this skill to improving my own teaching.

My children were both born during this capstone-writing process. Their presence in my life has given new perspective, motivation to my writing and the final completion of my Master of Arts in Teaching. My two children saw me work hard to achieve a goal in a difficult challenge. I worked on this after bedtime, during naps, on sick days and school vacations. It was not easy, but I was determined to finish. I hope that one day my kids can look to my experience and feel inspired when obstacles seem too hard. Ultimately, I did all of this for them.
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Appendix A

Lesson Plan Format

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<td>Minnesota Teaching Standards</td>
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<td>Materials</td>
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<td>Resources</td>
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<td>Lesson Sequence:</td>
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</tr>
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<td>1. Engage</td>
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<td>2. Explore</td>
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<td>3. Explain</td>
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<td>4. Elaborate</td>
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<td>5. Evaluate</td>
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<tr>
<td>Differentiation for high achievers</td>
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<td>Misconception to address</td>
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Appendix B

Curriculum Map

**Minnesota Teaching Benchmarks**

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<th>Benchmark Code</th>
<th>Benchmark Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.4.3.1.1</td>
<td>Recognize that cells contain genes and that each gene carries a single unit of information that either alone, or with other genes, determines the inherited traits of an organism.</td>
</tr>
<tr>
<td>7.4.3.1.2</td>
<td>Recognize that in asexually reproducing organisms all the genes come from a single parent, and that in sexually reproducing organisms about half of the genes come from each parent.</td>
</tr>
<tr>
<td>7.4.3.1.3</td>
<td>Distinguish between characteristics of organisms that are inherited and those acquired through environmental influences.</td>
</tr>
<tr>
<td>7.4.3.2.1</td>
<td>Explain how the fossil record documents the appearance, diversification and extinction of many life forms.</td>
</tr>
<tr>
<td>7.4.3.2.2</td>
<td>Use internal and external anatomical structures to compare and infer relationships between living organisms as well as those in the fossil record.</td>
</tr>
<tr>
<td>7.4.3.2.3</td>
<td>Recognize that variation exists in every population and describe how a variation can help or hinder an organism’s ability to survive.</td>
</tr>
<tr>
<td>7.4.3.2.4</td>
<td>Recognize that extinction is a common event and it can occur when the environment changes and a population’s ability to adapt is insufficient to allow its survival.</td>
</tr>
<tr>
<td>7.4.4.1.1*</td>
<td>Describe examples where selective breeding has resulted in new varieties of cultivated plants and particular traits in domesticated animals.</td>
</tr>
</tbody>
</table>

*This standard is not from the Teaching Standard: Evolution in Living Systems. It is included here because one lesson from this curriculum covers this benchmark along with 7.4.3.1.3.*
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<th>Lesson Title</th>
<th>Objective/Student Learning Goals</th>
<th>Benchmarks</th>
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<tr>
<td>1. Geologic Timescale*</td>
<td>Students will be able to translate geologic time into a linear timeline that is to scale. Students will make a scale model timeline of the history of the Earth.</td>
<td>7.4.3.2.1 7.4.3.2.4</td>
</tr>
<tr>
<td>2. Fossil Record</td>
<td>Students will use a simulated fossil record to be able to observe the diversification and extinction of species as well as infer environmental changes.</td>
<td>7.4.3.2.1 7.4.3.2.2 7.4.3.2.4</td>
</tr>
<tr>
<td>3. Cladogram*</td>
<td>Students will be able to organize primates based on physical characteristics and draw a cladogram depicting their evolutionary relationships.</td>
<td>7.4.3.2.2</td>
</tr>
<tr>
<td>4. Homologous vs. Analogous Structures</td>
<td>Students will be able to identify the difference between homologous and analogous structures as well as describe what the evolutionary significance is of each type of structure and infer common ancestry.</td>
<td>7.4.3.2.2 7.4.3.2.3</td>
</tr>
<tr>
<td>5. Skull measurements*</td>
<td>Students will be able to measure and calculate volume and area of several anatomical features of hominid skulls and be able to compare these measurements to infer relationships about their evolutionary relationships.</td>
<td>7.4.3.2.2 7.4.3.2.3</td>
</tr>
<tr>
<td>6. Geographic Isolation*</td>
<td>Students will be able to show how speciation can occur when a population becomes split and geographically isolated.</td>
<td>7.4.3.2.3 7.4.3.2.4</td>
</tr>
<tr>
<td>7. Natural Selection (Bird Beaks)*</td>
<td>Students will demonstrate the process natural selection of different bird beaks by actively competing for resources.</td>
<td>7.4.3.2.3 7.4.3.2.4 7.4.3.1.3</td>
</tr>
<tr>
<td>8. Darwin reading/comic book</td>
<td>Students will be able to describe Darwin’s Theory of Natural Selection and how he came up with it. Research the voyage of the HMS Beagle, Galapagos Islands, finches, tortoises; write and draw a comic book showing how Darwin came up with the Theory of Natural Selection.</td>
<td>7.4.3.2.3 7.4.3.2.4</td>
</tr>
<tr>
<td>9. DNA sequence Comparison</td>
<td>Students will be able to identify locations of gene mutation and see how those mutations can change the sequence of amino acids that are coded.</td>
<td>7.4.3.1.1 7.4.3.1.2</td>
</tr>
<tr>
<td></td>
<td>Lesson</td>
<td>Description</td>
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<tr>
<td>10.</td>
<td>Karyotype comparison</td>
<td>Students will be able to infer common ancestry by comparing and contrasting karyotypes of humans and chimpanzees.</td>
</tr>
<tr>
<td>11.</td>
<td>Artificial selection (domestication of plants, dogs, etc. by humans)</td>
<td>Students will be able to demonstrate a hypothetical scenario of early human artificial selection of plants.</td>
</tr>
<tr>
<td>12.</td>
<td>Haploid Groups: Human migration across the world</td>
<td>Students will be able to put haplogroups onto a world map and discuss the migration of humans around the world.</td>
</tr>
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</table>

*These lessons are included in Appendix C as a sampling of the total curriculum.*
Appendix C

Lesson Examples

Human Evolution Curriculum

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<td>Lesson 7: Student Worksheet</td>
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Lesson 1
Geologic Timeline Activity

<table>
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<th>Objective</th>
<th>Students will be able to translate geologic time into a linear timeline that is to scale. Students will make a scale model timeline of the history of the Earth.</th>
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<tbody>
<tr>
<td>Minnesota Teaching Standards</td>
<td><strong>Benchmark 7.4.3.2.1</strong> Explain how the fossil record documents the appearance, diversification and extinction of many life forms. <strong>Benchmark 7.4.3.2.4</strong> Recognize that extinction is a common event and it can occur when the environment changes and a population’s ability to adapt is insufficient to allow its survival.</td>
</tr>
</tbody>
</table>
| Materials | meter stick  
tape  
colored pencils  
adding machine tape |
| Resources | Student Worksheet  
Youtube video about Carl Sagan’s Cosmic Calendar |
| Lesson Sequence: | 1. Engage | Show video about the Carl Sagan’s Cosmic Calendar  
www.youtube.com/watch?v=GzG9fHMr9L4 |
| | 2. Explore | Follow the procedure for creating a geologic timeline. |
| | 3. Explain | Students discuss in their groups the placement of each event on the timeline. They should discuss what surprised them about the timeline. Are any events in earth’s history in spots that were not where you predicted? |
| | 4. Elaborate | Pair/share class discussion on what students noticed. The teacher adds details |
| | 5. Evaluate | The timeline will be compared against the master timeline to see if the relative placement of each event is accurate.  
The chart will be checked for accuracy of math calculations. |
| Differentiation for high achievers | For more of a challenge, do not give students the scale. Ask them to figure out a scale that would work and allow for the strip of paper to fit along the classroom wall. Have students research events and look up the dates they appear in the geologic record. |
Differentiation for struggling students

Provide students with the measurements of the events.
Have students assist each other in measuring.
Reduce the number of events that they will need to put on the timeline.

Misconception to address

Geologic timescale is much larger than many middle school students understand. Geologic timescale is required for evolution to take place.

Instructions:

1. Figure out how long your piece of paper should be.

   **Scale of your timeline.**
   - 1 meter = 1 billion years
   - 1 centimeter = 10 million years
   - 1 millimeter = 1 million years

   The Earth is 4.6 billion years old. Make the paper slightly bigger (5 meters) than needed so there will be some extra room.

2. Cut a piece of adding paper to the length necessary.

3. Draw a horizontal line down the middle of the entire strip of paper.

4. Start the timeline on the right side of the strip of paper. Label it “Present Day”.

5. Students should figure out how many centimeters you need to measure for each of the events and put answers in the chart.

<table>
<thead>
<tr>
<th>Event</th>
<th>When did it appear in the geologic record?</th>
<th>Location on the timeline (USE METRIC MEASUREMENTS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Formed</td>
<td>4.6 billion years ago</td>
<td>4.6 meters</td>
</tr>
<tr>
<td>First Life (Prokaryotic Cells)</td>
<td>3.8 billion years ago</td>
<td>3.8 m</td>
</tr>
<tr>
<td>Oxygen in the atmosphere</td>
<td>2.4 billion years ago</td>
<td>2.4 m</td>
</tr>
<tr>
<td>First Eukaryotic Cells</td>
<td>2 billion years ago</td>
<td>2 m</td>
</tr>
<tr>
<td>First multicellular life</td>
<td>1 billion years ago</td>
<td>1 m</td>
</tr>
<tr>
<td>First animals</td>
<td>670 million years ago</td>
<td>67 cm</td>
</tr>
<tr>
<td>First fish</td>
<td>500 million years ago</td>
<td>50 cm</td>
</tr>
<tr>
<td>First land plants</td>
<td>450 million years ago</td>
<td>45 cm</td>
</tr>
<tr>
<td>First insects</td>
<td>400 million years ago</td>
<td>40 cm</td>
</tr>
<tr>
<td>Event</td>
<td>Year of Event</td>
<td>Measurement</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>First plants with seeds</td>
<td>400 million years ago</td>
<td>40 cm</td>
</tr>
<tr>
<td>First amphibians</td>
<td>360 million years ago</td>
<td>36 cm</td>
</tr>
<tr>
<td>First reptiles</td>
<td>300 million years ago</td>
<td>30 cm</td>
</tr>
<tr>
<td>First dinosaurs</td>
<td>248 million years ago</td>
<td>24.8 cm</td>
</tr>
<tr>
<td>First mammals</td>
<td>200 million years ago</td>
<td>20 cm</td>
</tr>
<tr>
<td>First flowers</td>
<td>130 million years ago</td>
<td>13 cm</td>
</tr>
<tr>
<td>K-T extinction (most dinosaurs die)</td>
<td>65 million years ago</td>
<td>6.5 cm</td>
</tr>
<tr>
<td>First primates</td>
<td>65 million years ago</td>
<td>6.5 cm</td>
</tr>
<tr>
<td>First apes</td>
<td>15 million years ago</td>
<td>1.5 cm</td>
</tr>
<tr>
<td>First hominids</td>
<td>12.3 million years ago</td>
<td>12.3 mm</td>
</tr>
<tr>
<td>First stone tools</td>
<td>2.5 million years ago</td>
<td>2.5 mm</td>
</tr>
<tr>
<td>First use of fire</td>
<td>400,000 years ago</td>
<td>.4 mm (NOTE: Students will not be able to measure this accurately.)</td>
</tr>
<tr>
<td>First modern humans</td>
<td>200,000 years ago</td>
<td>.2 mm (NOTE: Students will not be able to measure this accurately.)</td>
</tr>
</tbody>
</table>

*Dates are from Carl Sagan’s book “Cosmos.”

6. Carefully measure from “Present Day” going to the left and add each event to the timeline.
7. Draw a picture representing each event.
8. Using RED, color the horizontal line during the time of Earth’s history where there was no life.
9. Using ORANGE, color the horizontal line during the time of Earth’s history between when life began and when the first animals appeared.
10. Using GREEN, color the horizontal line between when the first animals appeared and the first primates appeared.
11. Using BLUE, color the horizontal line between when the first primates appeared and when modern human’s appeared.
12. Using PURPLE, color the horizontal line from when human’s appeared to present day.
13. Answer follow up questions.
Lesson 1: Geologic Timescale Activity  
Student Instructions and Worksheet

Objective: Students will be able to translate geologic time into a linear timeline that is to scale.

Materials:
- meter stick
- tape
- colored pencils

Instructions:

1. **Figure out how long your piece of paper should be.**
   
   Scale of your timeline:
   
   - 1 meter = 1 billion years
   - 1 centimeter = 10 million years
   - 1 millimeter = 1 million years

   The Earth is 4.6 billion years old. (NOTE: We will make the paper slightly bigger than you need.)

   How long will the strip of paper need to be to cover 5 billion years? __________

2. **Cut a piece of adding paper to the length necessary.**

3. **Draw a horizontal line down the middle of the entire strip of paper.**

4. **Start the timeline on the right side of the strip of paper. Label it “Present Day”.**

5. **Figure out how many centimeters you need to measure for each of the events. Put answers in the chart.**

<table>
<thead>
<tr>
<th>Event</th>
<th>When did it appear in the geologic record?</th>
<th>Location on the timeline (USE METRIC MEASUREMENTS)</th>
</tr>
</thead>
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<tr>
<td>Earth Formed</td>
<td>4.6 billion years ago</td>
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<td>First Life (Prokaryotic Cells)</td>
<td>3.8 billion years ago</td>
<td></td>
</tr>
<tr>
<td>Oxygen in the atmosphere</td>
<td>2.4 billion years ago</td>
<td></td>
</tr>
</tbody>
</table>
**First Eukaryotic Cells** | 2 billion years ago
---|---
**First multicellular life** | 1 billion years ago
**First animals** | 670 million years ago
**First fish** | 500 million years ago
**First land plants** | 450 million years ago
**First insects** | 400 million years ago
**First plants with seeds** | 400 million years ago
**First amphibians** | 360 million years ago
**First reptiles** | 300 million years ago
**First dinosaurs** | 248 million years ago
**First mammals** | 200 million years ago
**First flowers** | 130 million years ago
**K-T extinction (most dinosaurs die)** | 65 million years ago
**First primates** | 65 million years ago
**First apes** | 15 million years ago
**First hominids** | 12.3 million years ago
**First stone tools** | 2.5 million years ago
**First use of fire** | 400,000 years ago
**First modern humans** | 200,000 years ago

*Dates are from Carl Sagan’s book “Cosmos.”

6. **Carefully measure from “Present Day” going to the left and add each event to the timeline.**

7. **Draw a picture representing each event.**

8. **Using RED, color the horizontal line during the time of Earth’s history where there was no life.**
9. Using ORANGE, color the horizontal line during the time of Earth’s history between when life began and when the first animals appeared.

10. Using GREEN, color the horizontal line between when the first animals appeared and the first primates appeared.

11. Using BLUE, color the horizontal line between when the first primates appeared and when modern human’s appeared.

12. Using PURPLE, color the horizontal line from when human’s appeared to present day.

13. Answer follow-up questions.

Questions
1. What percentage of Earth’s history had life?

2. What percentage of Earth’s history have modern humans existed?

3. What did you find most challenging about this activity?

4. What surprised you about this activity?

5. Is there anything that appears on the timeline that changed your understanding of Earth’s history?
# Lesson 3
## Primate Cladogram

<table>
<thead>
<tr>
<th><strong>Objective</strong></th>
<th>Students will be able to organize primates based on physical characteristics and draw a cladogram depicting their evolutionary relationships.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Minnesota Teaching Standards</strong></td>
<td><strong>Benchmark 7.4.3.2.2</strong> Use internal and external anatomical structures to compare and infer relationships between living organisms as well as those in the fossil record.</td>
</tr>
</tbody>
</table>
| **Materials** | Vertebrate cards (Blue)  
- Vertebrate Cards: Deeply branching vertebrates: frog, snake, bird, wolf, human, fish  
Primate cards (Green)  
- Primate Cards: lemurs, prosimians, old world monkeys, new world monkeys, lesser apes, great apes, humans |
| **Resources** | Student Worksheet |

### Lesson Sequence:
1. **Engage**  
   Put three pictures on the board; one of a wolf, one of a fox and one of a hyena. Ask students to decide which two are most closely related. (Most students will say that the wolf and fox are closest.) Then they should discuss in groups why they chose the animals they did. What did they have in common? What was different about the one they decided wasn’t as closely related?

2. **Explore**  
   1. Divide students into groups of 3. They should each get a set of Vertebrate Cards (Blue) and a set of Primate Cards (Green).  
   2. Set aside Primate Cards and use the Vertebrate Cards for the first round. Students should fill in Chart 1 and write a description about each animal.  
   3. Students then organize the cards in order of how closely related they think the animals are. More closely related will be closer together. More distantly related, or deeply branching, will be further away from each other.  
   4. Draw a cladogram based on the order they organized their cards.  
   5. Take a few minutes to discuss with each group or as a class the cladogram they drew. This is a good time to address any misconceptions or confusion about common
ancestors. A common misconception is that the different animals will evolve into each other as time goes on. Make sure that students write the animals on their cladograms all along the top to show that they are all currently living species. The common ancestors are further back in time.

6. During this discussion time, students should label the common ancestors as “Common Ancestor #1”, “Common Ancestor #2”, etc. On the line between each common ancestor, students should write an adaptation that developed at that branch.

7. Students should then set aside the Vertebrate Cards and use the Primate cards for the next round of organizing.

8. Students will follow the same steps they did when they were organizing the vertebrates. This time the differences are more subtle than the more deeply branching vertebrates. Draw attention to features like presence of a tail, whether or not the tail is prehensile (grasping), body posture, presence of a snout, etc.

9. After organizing the Primate Cards, students should fill in Chart 2 and write a description about each animal.

10. Students then organize the cards in order of how closely related they think the primates are. More closely related will be closer together. More distantly related, or deeply branching, will be further away from each other.

11. Draw a cladogram based on the order they organized their cards.

12. Take a few minutes to discuss with each group or as a class the cladogram they drew.

13. During this discussion time, students should label the common ancestors as “Common Ancestor #1”, “Common Ancestor #2”, etc. On the line between each common ancestor, students should write an adaptation that developed at that branch.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Explain</td>
<td>Students should then write answers to the follow-up discussion questions.</td>
</tr>
<tr>
<td>4. Elaborate</td>
<td>Students can do research on several different animals and create a cladogram based on their research.</td>
</tr>
<tr>
<td>5. Evaluate</td>
<td>Compare student created cladograms against master cladograms. Look for misconceptions about common ancestors and confusion about how to draw the branching of a cladogram.</td>
</tr>
<tr>
<td>Differentiation for high achievers</td>
<td>Students can research hominid ancestors and draw a cladogram showing the evolutionary relationships of the hominids.</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Differentiation for struggling students</td>
<td>Give struggling students fewer cards that do not have as many subtle differences; for example, limit the primate cards to lemur, new world monkey, chimpanzee and human.</td>
</tr>
<tr>
<td>Misconception to address</td>
<td>Species that are alive today share common ancestors. They do not evolve into each other. For example humans did not evolve from chimpanzees, instead humans and chimpanzees evolved from a common ancestor that is now extinct.</td>
</tr>
</tbody>
</table>
Lesson 3: Primate Cladogram
Student Worksheet

Lesson Objective:
Students will be able to organize primates based on physical characteristics and draw a cladogram depicting their evolutionary relationships.

Materials:
Vertebrate cards (Blue)
Primate cards (Green)
- Primate Cards: lemurs, prosimians, old world monkeys, new world monkeys, lesser apes, great apes, humans

Instructions
14. Set aside Primate Cards and use the Vertebrate Cards for the first round.
15. Fill in Chart 1 and write a description about each animal.

Chart 1: Vertebrate Relationships

<table>
<thead>
<tr>
<th>Name of Animal</th>
<th>Description of Physical Characteristics (Cold blooded or warm blooded?, lays eggs?, eggs have shells or are soft?, have fur/hair? etc.)</th>
<th>Which Animal do you think it is most closely related to?</th>
<th>Which Animal do you think it is most distantly related to?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frog</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bird</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wolf</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
16. Draw a cladogram with the most distantly related species on each end. Label “Common Ancestor #1”, “Common Ancestor #2”, etc.

![Cladogram diagram]

17. Use the Primate cards for the next round of organizing.

18. Follow the same steps as when you were organizing the vertebrates. This time the differences are subtle than the more deeply branching vertebrates. (Pay attention to features like presence of a tail, whether or not the tail is prehensile (grasping), body posture, presence of a snout, etc.)

19. After organizing the Primate Cards, fill in Chart 2 and write a description about each animal.

<table>
<thead>
<tr>
<th>Name of Animal</th>
<th>Description of Physical Characteristics (Tail or no tail? Upright posture? Prehensile tail? Snout? etc.)</th>
<th>Which Animal do you think it is most closely related to?</th>
<th>Which Animal do you think it is most distantly related to?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great Ape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lemur</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
20. Organize the cards in order of how closely related they think the primates are. More closely related will be closer together. More distantly related, or deeply branching, will be further away from each other.

21. Draw a cladogram based on the order you organized your cards. (Label “Common Ancestor #1”, “Common Ancestor #2”, etc.)

<table>
<thead>
<tr>
<th>Common Ancestor #1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesser Ape</td>
</tr>
<tr>
<td>Prosimian</td>
</tr>
<tr>
<td>Old World Monkey</td>
</tr>
<tr>
<td>Human</td>
</tr>
<tr>
<td>New World Monkey</td>
</tr>
</tbody>
</table>
22. Answer follow-up questions

**Follow-Up Questions**
1. Describe the purpose of a cladogram. What does the picture tell you?

2. What adaptations arose between each of the common ancestors in the Vertebrate Cladogram?

3. What adaptations arose between each of the common ancestors in the Primate Cladogram?
Lesson 5
Hominid Skull Comparison

<table>
<thead>
<tr>
<th>Objective</th>
<th>Students will be able to measure and calculate volume and area of several anatomical features of hominid skulls and be able to compare these measurements to infer relationships about their evolutionary relationships.</th>
</tr>
</thead>
</table>
| Minnesota Teaching Standards | **Benchmark 7.4.3.2.2** Use internal and external anatomical structures to compare and infer relationships between living organisms as well as those in the fossil record.  
**Benchmark 7.4.3.2.3** Recognize that variation exists in every population and describe how a variation can help or hinder an organism’s ability to survive. |
| Materials | Models of hominid skulls  
Modeling clay  
Water  
Graduated cylinder  
Metric ruler  
Tailor’s metric measuring tape |
| Resources | Student Worksheet |
| Lesson Sequence: |  
1. Engage | Show students short video on the discovery of “the hobbit” (*Homo floresiensis*). |
| | 2. Explore | *Set up three learning stations throughout the classroom. Students will cycle between each station.*  
1. Station 1: Ocular and Nasal Cavity Comparison  
   a. Using a metric ruler, measure the diameter of each ocular cavity of each hominid skull. (If there are not enough skull models, a printed picture of each skull that is to scale could be used instead.)  
   b. Fill in Chart 1 with the diameter of each eye. Estimate the area of the opening, using the formula for a circle. Put this calculation in Chart 1.  
   c. Measure base and height of the nasal cavity opening of each hominid skull.  
   d. Fill in Chart 1 with the measurements of the nasal cavity. Using the formula for a right triangle, estimate the area of the opening. Put this calculation in Chart 1. |
2. Station 2: Cranial Volume Comparison
   a. Note: Prior to setting up this station, make sure that the skull models can hold water. Plug up any holes with modeling clay.
   b. Turn skull over so you can see the foramen magnum, the hole at the base of the skull. Pour water into the hole until it is filled to the top. Then pour water out of the skull into a graduated cylinder with a large funnel. Note the volume of water and write it on the Chart 2.
   c. Repeat this process with all of the skull samples.
   d. Using a flexible tailor’s measuring tape, measure the outside circumference of the cranium of each skull. Note the measurement on Chart 2. (Note: If a flexible measuring tape is not available, students can measure with a string and then measure the length of string on a meter stick.)

3. Station 3: Anatomical Comparisons
   a. Visually compare each skull model and note the presence of certain anatomical features on Chart 3 with a check mark.

3. Explain
   Answer analysis questions and explain the findings from the skull investigation. Students will write reflection on what they learned.

4. Elaborate
   As a class, have a discussion about the findings of the different skulls. Topics of discussion could include; cranial volume relating to intelligence; cranial volume relating to thermoregulation, chewing muscles needed for different diets, etc.

5. Evaluate
   Students will be able to measure and calculate volumes correctly. Students will infer and explain the homologous structures of the skulls and infer the common ancestry of the species.

**Differentiation for high achievers**
- Explore and do research on another hominid species.
- Compare the dimensions to the class set of skulls.
- Calculate ratios of two measurements and see how they compare between species.

**Differentiation for struggling students**
- Reduce the number of skulls required.
- Give measurement refresher lesson prior to this lesson.

**Misconception to address**
Brain size does not necessarily correlate to intelligence. For example, students may find that some species have a bigger brain volume than a human, but one cannot conclude that it is more intelligent just by volume alone. There is other evidence needed to determine intelligence.
### Chart 1: Ocular and Nasal Cavity Comparison

<table>
<thead>
<tr>
<th>Species</th>
<th>Right Eye Diameter</th>
<th>Right Eye Area $A = \pi \times \left( \frac{D}{2} \right)^2$</th>
<th>Left Eye Diameter</th>
<th>Left Eye Area $A = \pi \times \left( \frac{D}{2} \right)^2$</th>
<th>Nasal Cavity base length</th>
<th>Nasal Cavity height</th>
<th>Nasal Cavity opening Area $A = \frac{1}{2} \times \text{base} \times \text{height}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Australopithecus boisei</em></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td><em>Homo sapiens</em></td>
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<tr>
<td><em>Homo neanderthalensis</em></td>
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<tr>
<td><em>Australopithecus afarensis</em></td>
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<tr>
<td><em>Homo erectus</em></td>
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<tr>
<td>Gorilla</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chimpanzee</td>
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</tr>
</tbody>
</table>

### Chart 2: Cranial Volume Comparison

<table>
<thead>
<tr>
<th>Species</th>
<th>Cranial Volume (mL)</th>
<th>Circumference of cranium (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Australopithecus boisei</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Homo sapiens</em></td>
<td></td>
<td></td>
</tr>
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<td>Gorilla</td>
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<td></td>
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<tr>
<td>Chimpanzee</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Chart 3: Anatomical Comparisons

<table>
<thead>
<tr>
<th>Species</th>
<th>Large brow ridge</th>
<th>High forehead</th>
<th>Occipital bun</th>
<th>Rounded occipital</th>
<th>Chin</th>
<th>Gap behind molar</th>
<th>Large Canine Teeth</th>
<th>Face protrudes forward</th>
<th>Midsaggital Ridge</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Australopithecus boisei</em></td>
<td></td>
<td></td>
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<td><em>Homo neanderthalensis</em></td>
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<td>Chimpanzee</td>
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</tbody>
</table>


Lesson 5: Hominid Skull Comparison
Student Worksheet

**Lesson Objective:** Students will be able to measure and calculate volume and area of several anatomical features of hominid skulls and be able to compare these measurements to infer relationships about their evolutionary relationships.

**Minnesota Teaching Standard Addressed:**

**Benchmark 7.4.3.2.2** Use internal and external anatomical structures to compare and infer relationships between living organisms as well as those in the fossil record.

**Benchmark 7.4.3.2.3** Recognize that variation exists in every population and describe how a variation can help or hinder an organism’s ability to survive.

**Materials:**
Models of hominid skulls
Modeling clay
Water
Graduated cylinder
Metric ruler
Tailor’s metric measuring tape

**Worksheets:**
Student Worksheet

**Learning Sequence**
*Set up three learning stations throughout the classroom. Students will cycle between each station.*

http://www.southernbiological.com/models/anthropology/half-scale-series/kam-set-7-set-of-7-half-scale-primate-skulls/
1. Station 1: Ocular and Nasal Cavity Comparison
   a. Using a metric ruler, measure the diameter of each ocular cavity of each hominid skull. (If there are not enough skull models, a printed picture of each skull that is to scale could be used instead.)
   b. Fill in Chart 1 with the diameter of each eye. Estimate the area of the opening, using the formula for a circle. Put this calculation in Chart 1.
   c. Measure base and height of the nasal cavity opening of each hominid skull.
   d. Fill in Chart 1 with the measurements of the nasal cavity. Using the formula for a right triangle, estimate the area of the opening. Put this calculation in Chart 1.
   e. Answer analysis questions.

<table>
<thead>
<tr>
<th>Species</th>
<th>Right Eye Diameter</th>
<th>Right Eye Area $A=\pi \times (D/2)^2$</th>
<th>Left Eye Diameter</th>
<th>Left Eye Area $A=\pi \times (D/2)^2$</th>
<th>Nasal Cavity base length</th>
<th>Nasal Cavity height</th>
<th>Nasal Cavity opening Area $A=\frac{1}{2} \times \text{base} \times \text{height}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australopithecus boisei</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Homo sapiens</td>
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<tr>
<td>Homo Neanderthalensis</td>
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<tr>
<td>Australopithecus afarensis</td>
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<tr>
<td>Homo erectus</td>
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<td>Gorilla</td>
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<tr>
<td>Chimpanzee</td>
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</tbody>
</table>
2. Station 2: Cranial Volume Comparison
   a. Note: Prior to setting up this station, make sure that the skull models can
      hold water. Plug up any holes with modeling clay.
   b. Turn skull over so you can see the foramen magnum, the hole at the base
      of the skull. Pour water into the hole until it is filled to the top. Then pour
      water out of the skull into a graduated cylinder with a large funnel. Note
      the volume of water and write it on the Chart 2.
   c. Repeat this process with all of the skull samples.
   d. Using a flexible tailor’s measuring tape, measure the outside
      circumference of the cranium of each skull. Note the measurement on
      Chart 2. (Note: If a flexible measuring tape is not available, students can
      measure with a string and then measure the length of string on a meter
      stick.)
   e. Answer analysis questions.

<table>
<thead>
<tr>
<th>Species</th>
<th>Cranial Volume (mL)</th>
<th>Circumference of cranium (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australopithecus boisei</td>
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<td>Homo sapiens</td>
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<tr>
<td>Homo neanderthalensis</td>
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<tr>
<td>Australopithecus afarensis</td>
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<tr>
<td>Homo erectus</td>
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<td>Gorilla</td>
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<tr>
<td>Chimpanzee</td>
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</tbody>
</table>
3. Station 3: Anatomical Comparisons
   a. Visually compare each skull model and note the presence of certain anatomical features on Chart 3 with a check mark.
   b. Answer analysis questions.

Chart 3: Anatomical Comparisons

<table>
<thead>
<tr>
<th>Species</th>
<th>Large brow ridge</th>
<th>High forehead</th>
<th>Occipital bun</th>
<th>Rounded occipital</th>
<th>Chin</th>
<th>Gap behind molar</th>
<th>Large Canine Teeth</th>
<th>Face protrudes forward</th>
<th>Midsaggital Ridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australopithecus boisei</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td>Homo sapiens</td>
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<td>Chimpanzee</td>
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http://afarensis99.files.wordpress.com/2006/03/neanderthal_skulls_compare.gif
Lesson 6
Geographic Isolation

<table>
<thead>
<tr>
<th>Objective</th>
<th>Students will be able to show how speciation can occur when a population becomes split and geographically isolated.</th>
</tr>
</thead>
</table>
| Minnesota Teaching Standards | **Benchmark 7.4.3.2.3** Recognize that variation exists in every population and describe how a variation can help or hinder an organism’s ability to survive.  
**Benchmark 7.4.3.2.4** Recognize that extinction is a common event and it can occur when the environment changes and a population’s ability to adapt is insufficient to allow its survival. |
| Materials | Construction paper (blue, green, brown, yellow)  
Hole punch  
Tweezers (one per student)  
Cups (one per student)  
Tape |
| Resources | Student Worksheet |
| Lesson Sequence: |  |
| 1. Engage | “Trapped on an Island”- Students will imagine that they are trapped on an island. Brainstorm what they will need to survive (i.e. shelter, tools to get food, etc.) Ask them to think about how their list might change if they are on a tropical island vs. an arctic island. This will get them thinking about geographic isolation and how the environment will require different adaptations for survival. |
| 2. Explore | 1. Preparation:  
a. Ahead of time, prepare small circles of different colored paper (green, brown, yellow) Mix them together and put in an envelope. These will represent frogs of the same species with genetic variation between them.  
b. Tape pieces of construction paper together as shown in Figure 1. Make one for each group. Alternative: This lesson can also be done as a demonstration with student volunteers. In this version, only one paper setup is required. The brown and the green represent different colors of ground cover; green may represent a wetland or forest, brown may represent a dry grassland, rocky terrain, or desert.  
c. Make a strip of blue construction paper to represent a river as shown in Figure 2. (Do not tape down.)  
d. Have tweezers set up with a cup for collection, one |
for each student. (The tweezers represent a predator like a hawk or fox.)

e. Lay out papers without the river to start.

2. Activity 1:
   a. Students sprinkle hole punches (frogs) evenly across the paper. (Figure 3)
   b. Give students 15 seconds to collect as many circles as possible using the tweezers only.
   c. After 15 seconds, have students do a population count of “frogs” left on the paper. (This is representative of the frogs that survived predation and can live on to reproduce.) Fill in data to Data Table 1.
   d. Students should empty their collected circles back into the envelope; they will not be used until the second activity.
   e. The remaining circles that are left on the paper should be collected, shaken up in a cup to mix the colors, and then sprinkled evenly onto the paper again. (This represents the next generation of frogs. There is still genetic variation, but they are now the decedents of those frogs that survived.)
   f. Repeat steps c-e two more times.
   g. Complete analysis questions.

3. Activity 2:
   a. This activity is very similar to Activity 1, except that there will be a geographical barrier between the green and brown papers.
   b. Place the blue river in between the green and brown papers. Explain to students that this is a geographical barrier that will not allow the frogs to cross. Discuss reasons why a river might cut through a piece of land throw processes of erosion, flash flood, etc.
   c. Students sprinkle hole punches (“frogs”) evenly across the paper, except for the blue river. (Figure 4.)
   d. Give students 15 seconds to collect as many circles as possible using the tweezers only.
   e. After 15 seconds, have students do a population count of holes on the paper. Fill in data to Data Table 2.
   f. Students should empty their collected circles back into the envelope; they will not be used anymore.
   g. The remaining circles that are left on the green paper should be collected, shaken up in a cup to mix the colors, and then sprinkled evenly onto the green paper again.
   h. The remaining circles that are left on the brown
<p>| | |</p>
<table>
<thead>
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</thead>
<tbody>
<tr>
<td><strong>paper</strong> should be collected, shaken up in a cup to mix the colors, and then sprinkled evenly onto the <strong>brown paper</strong> again. (Since the populations on either side of the river are no longer able to interbreed, their offspring will only be from those that are on their side of the river.)</td>
<td></td>
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<tr>
<td>i. Repeat steps c-h two more times.</td>
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<tr>
<td>j. Answer analysis questions.</td>
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</tbody>
</table>

3. **Explain**

Students will answer the analysis questions and explain what happened to the different frog varieties in each environment.

4. **Elaborate**

Students draw a diagram explaining the effects of geographic isolation on the frog populations. Then they hypothesize what will happen as the result if several other scenarios happen (examples: drought, flood, introduction of a new predator)

5. **Evaluate**

Students will be assessed on their ability to explain how geographic isolation results in evolution of a species. This explanation should include the following:

1. Genetic variation is key in a species ability to adapt to geographic isolation.
2. These variations provide a higher chance of survival at the population level since some individuals will be more fit for the new selective pressure than others.
3. Since selective pressures will be different in different geographically isolated areas, the populations in each area being selected to adapt in different ways.

Differentiation for high achievers

Students will research real world examples of geographic isolation and how populations changed over time as a result. Present this information in the form of a poster or presentation.

Differentiation for struggling students

After each round, ask students to describe what happened. Use this to gauge how well they are understanding the simulation and provide more or less support and explanation in the following rounds.

Misconception to address

Evolution happens at the population level not the individual level. Individuals are either survivors or casualties to natural selection, but evolution of a species is the results of natural selection happening over many generations.
Figure 1.
Tape 4 green pieces and 4 brown pieces of construction paper together as shown.

Figure 2.
Using two pieces of blue construction paper, cut a strip in the shape of a river that can be placed over the barrier between the green and brown sides. Do not tape down.
Figure 3: Set Up of Activity 1

Figure 4: Set Up of Activity 2
Figure 5: Predicted result from Activity 1.

Figure 6: Predicted result from Activity 2.
### Data Table 1

<table>
<thead>
<tr>
<th>Frogs</th>
<th>Population after Round 1</th>
<th>Population after Round 2</th>
<th>Population after Round 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Brown</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Data Table 2

<table>
<thead>
<tr>
<th>Frogs</th>
<th>Green Side of the River</th>
<th>Brown Side of the River</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Population after Round 1</td>
<td>Population after Round 1</td>
</tr>
<tr>
<td>Green</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td></td>
<td></td>
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<tr>
<td>Brown</td>
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</tbody>
</table>
Lesson 6: Geographic Isolation  
Student Worksheet

**Lesson Objective:** Students will be able to show how speciation can occur when a population becomes split and geographically isolated.

**Materials:**  
Construction paper (blue, green, brown, yellow)  
Hole punch  
Tweezers (one per student)  
Cups (one per student)  
Tape

**Activity 1 Instructions**

4. Sprinkle hole punches (frogs) evenly across the paper.
5. You have 15 seconds to collect as many circles as possible using the tweezers only.
6. After 15 seconds, do a population count of “frogs” left on the paper. (This is representative of the frogs that survived predation and can live on to reproduce.) Fill in data to Data Table 1.
7. Empty your collected circles back into the envelope; they will not be used until the second activity.
8. The remaining circles that are left on the paper should be collected, shaken up in a cup to mix the colors, and then sprinkled evenly onto the paper again. (This represents the next generation of frogs. There is still genetic variation, but they are now the decedents of those frogs that survived.)
9. Repeat steps 2-5 two more times.
10. Complete analysis question

<table>
<thead>
<tr>
<th>Frogs</th>
<th>Population after Round 1</th>
<th>Population after Round 2</th>
<th>Population after Round 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
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<td></td>
<td></td>
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<tr>
<td>Brown</td>
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</tbody>
</table>
Activity 1 Analysis Questions

1. Explain what happened to each population of frogs after each round.

2. Which frog variety had the highest populations at the end of Round 3?

3. Why do you think this variety was most fit for this particular environment? If there is a tie between two varieties, explain possible reasons why they both were best fit.

4. Draw a diagram showing what happened in this activity from start to finish.
Activity 2 Instructions
1. This activity is very similar to Activity 1, except that there will be a geographical barrier between the green and brown papers.
2. Place the blue river in between the green and brown papers. This is a geographical barrier that will not allow the frogs to cross.
3. Students sprinkle hole punches ("frogs") evenly across the paper, except for the blue river.
4. You have 15 seconds to collect as many circles as possible using the tweezers only.
5. After 15 seconds, do a population count of holes on the paper. Fill in data to Data Table 2.
6. Empty your collected circles back into the envelope; they will not be used anymore.
7. The remaining circles that are left on the green paper should be collected, shaken up in a cup to mix the colors, and then sprinkled evenly onto the green paper again.
8. The remaining circles that are left on the brown paper should be collected, shaken up in a cup to mix the colors, and then sprinkled evenly onto the brown paper again. (Since the populations on either side of the river are no longer able to interbreed, their offspring will only be from those that are on their side of the river.)
9. Repeat steps 3-8 two more times.
10. Answer analysis questions.

Data Table 2

<table>
<thead>
<tr>
<th>Frogs</th>
<th>Green Side of the River</th>
<th>Brown Side of the River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td></td>
<td></td>
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<tr>
<td>Yellow</td>
<td></td>
<td></td>
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<tr>
<td>Brown</td>
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</tbody>
</table>
Activity 2 Analysis Questions
1. Propose reasons why a river will cut through an area of land.

2. What were some effects on the frog populations as a result of the river cutting through the land? What is this type of event called?

3. Explain what happened to each population of frogs after each round on the green side of the river.

4. Explain what happened to each population of frogs after each round on the brown side of the river.

5. Which frog variety had the highest populations at the end of Round 3? Where these results the same on both sides of the river?

6. Why do you think this variety was most fit for this particular environment?

7. What selective pressures were on each side of the river?

8. Draw a diagram showing what happened in this activity from start to finish.
### Lesson 7
**Natural Selection**

<table>
<thead>
<tr>
<th>Objective</th>
<th>Students will demonstrate the process natural selection of different bird beaks by actively competing for resources.</th>
</tr>
</thead>
</table>
| **Minnesota Teaching Standards** | **Benchmark 7.4.3.2.3** Recognize that variation exists in every population and describe how a variation can help or hinder an organism’s ability to survive.  
**Benchmark 7.4.3.2.4** Recognize that extinction is a common event and it can occur when the environment changes and a population’s ability to adapt is insufficient to allow its survival.  
**Benchmark 7.4.3.1.3** Distinguish between characteristics of organisms that are inherited and those acquired through environmental influences. |
| **Materials** | Tray of dry beans (1 per table)  
Tools: spoons, chopsticks, plastic knife, tweezers, plastic cups |
| **Resources** | “Natural Selection of Bird Beaks” Student Worksheet |
| **Lesson Sequence:** |  
1. **Engage**  
   - Warm-Up Question (5 minutes) |
| 2. **Explore** |  
| 1. “Natural Selection of Bird Beaks’’ Activity (20 minutes)  
a. Students send one member of their table to get supplies.  
b. Each group member will choose different bird species from their sheet and underline on their sheet. Then choose the tool that corresponds to that bird.  
c. Students record the population of each bird on their sheet.  
d. Students will be competing for food and for survival with the other birds. In order to survive in the next generation you need to collect at least 10 beans. The class will have 30 seconds to collect 10 beans.  
e. Those “birds” that survive will be able to produce offspring in the next generation; the student keeps their same tool.  
f. Those birds that don’t survive will put down their “beak” and play the role of the surviving birds’ offspring. They will choose the correct tool to be one of the successful offspring.  
g. With each round, the time gets shorter; 30 seconds, 20 seconds, 10 seconds, etc. |
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<table>
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<tbody>
<tr>
<td></td>
<td>h. Students fill in the population of each bird species in the chart as the activity progresses.</td>
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<tr>
<td></td>
<td>i. The class data will also be collected throughout the activity.</td>
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<tr>
<td>2.</td>
<td>Clean Up (3 minutes)</td>
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<tr>
<td>3.</td>
<td>Explain Graphing and Questions (30 minutes) a. Students will graph their data to show how the population of each species of birds changes through time.</td>
</tr>
<tr>
<td>4.</td>
<td>Elaborate Students will work on follow-up questions</td>
</tr>
<tr>
<td>5.</td>
<td>Evaluate Informal formative assessment of students by checking in verbally with them through the lesson. Formative assessment: Complete graph and discussion questions.</td>
</tr>
<tr>
<td>Differentiation for high achievers</td>
<td>These variations could provide a more challenging learning experience for students. 1. Provide a variety of food types like rubber bands, cotton balls or gummy bears. The different size, shape and texture of these will give a different advantage to the beak tools. The students will collect data for each food type and then compare the results. This simulates the different selective pressures on the various Galapagos Islands that resulted in a variety of beak shapes in finches. 2. Do the simulation student directed rather than as a whole group. This can allow for more student engagement and gives them the opportunity to work at their own pace. 3. Use colored beads (red, black, brown) instead of beans and use different colored backgrounds (red, black, brown) when doing the simulation. For example, red beads will blend in more with the red background and show a selective advantage of camouflage.</td>
</tr>
<tr>
<td>Differentiation for struggling students</td>
<td>Graph the results in small groups with teacher support or enter data into a spreadsheet and graph the results using a program like Microsoft Excel. The act of graphing could be a barrier for the students to see the results of population changes. The goal of the activity is to see the population changes resulting from natural selection and graphing the results is more for practice and therefore is not required to achieve the objective.</td>
</tr>
<tr>
<td>Misconception to address</td>
<td>Evolution happens at the population level not the individual level. Individuals are either survivors or casualties to natural</td>
</tr>
</tbody>
</table>
selection, but evolution of a species is the results of natural selection happening over many generations.
Lesson 7: Natural Selection
Student Worksheet

Objective: This activity will demonstrate the process natural selection of different bird beaks by students actively competing for resources.

Instructions:
1. Each member of your group will act as a different bird species. Underline your bird species.
2. You will be competing for food and for survival with the other birds. In order to survive in the next generation you need to collect at least 10 beans.
3. Those birds that survive will be able to produce offspring in the next generation.
4. Those birds that don’t survive will put down their “beak” and play the role of the surviving birds’ offspring.
5. Choose the correct tool to be one of the successful offspring.
6. Fill in the population of each bird species in the chart as the activity progresses.
7. Each generation will have less time to collect food. Follow directions of the teacher as you go.

<table>
<thead>
<tr>
<th>Bird Species</th>
<th>Generation 1</th>
<th>Generation 2</th>
<th>Generation 3</th>
<th>Generation 4</th>
<th>Generation 5</th>
<th>Generation 6</th>
<th>Generation 7</th>
<th>Generation 8</th>
<th>Generation 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knife-bill</td>
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<td>Spoon-bill</td>
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<td>Tweezer-bill</td>
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<tr>
<td>Stick-bill</td>
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</tbody>
</table>

Questions: (Answer in complete sentences.)

1. Which bird species had the biggest population in the end? Why do you think that is?

2. Did any bird species go extinct? Which ones? Why?

3. When a species did not have enough beans to eat, why did we replace them with a surviving species in the next generation?
Graph the populations of each species in each generation.

Title:______________________________

x-axis:____________________________

Key

☐ Knife-bill Population
☐ Spoon-bill Population
☐ **Bird Beak Activity Follow-up Questions**
☐ Tweezer-bill Population
☐ Stick-bill Population
1. Compare your group’s data with the whole class data graphs, what differences do you notice between the two graphs? Why the difference?

_____________________________________________________________________
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2. An organism’s ability to survive in a certain environment is called “fitness.” What changes could have been made to this simulated environment that would cause the fitness of each bird to change? Propose one change for each species. Why would those changes affect fitness?

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