

TEACHING EVOLUTION IN A CHRISTIAN SCHOOL

by

Alan W Kalf

A professional paper proposal submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Science Education

MONTANA STATE UNIVERSITY
Bozeman, Montana

July 2012

STATEMENT OF PERMISSION TO USE

In presenting this professional paper in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the MSSE Program shall make it available to borrowers under rules of the program.

Alan William Kalf

July 2012

DEDICATION

I would like to dedicate this paper to my students, and all people who persevere in the process of reflecting on their faith in light of scientific knowledge that may seem to threaten it. I also dedicate this to the teachers who have the courage to push this issue to the forefront of their science classes, even in the face of resistance and risk.

ACKNOWLEDGEMENTS

I would like to acknowledge Genevieve Chabot, John Graves, Peggy Taylor, and Louise Mead, my science advisor. Finally, and most of all, I would like to acknowledge my wife, who served as my proofreader and encourager and supporter through this project.

TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND	1
CONCEPTUAL FRAMEWORK	4
METHODOLOGY	15
DATA AND ANALYSIS	30
INTERPRETATION AND CONCLUSION	41
VALUE	52
REFERENCES CITED.....	56
APPENDICES	58
APPENDIX A: HLDYIG	59
APPENDIX B: EALS	62
APPENDIX C: Exemption Regarding Informed Consent.....	67
APPENDIX D: Assignments and Assessments.....	69
APPENDIX E: CP Unit Test	71
APPENDIX F: Honors Unit Test.....	78
APPENDIX G: Interview Questions	87

LIST OF TABLES

1. Unit Outline	18
2. Data Collection Matrix	30
3. Tally of Mid-Unit Student Concerns	40

LIST OF FIGURES

1. Interpretation of Genesis in a CP Biology Class	31
2. Interpretation of Genesis in an Honors Biology Class	32
3. Pre-Treatment Attitudes and Literacy of Evolution in a CP and Honors Biology Class	34
4. Pre- and Post-Treatment Attitudes and Literacy of Evolution in a CP Biology Class	37
5. Pre- and Post-Treatment Attitudes and Literacy of Evolution in an Honors Biology Class	39
6. Unit Test Results for a CP and Honors Class (n=19, 33)	41

INTRODUCTION AND BACKGROUND

Lexington Christian Academy is a non-denominational Christian college-preparatory 6th through 12th grade school in Lexington, Massachusetts, a suburb north of Boston. Its mission statement states, “Lexington Christian Academy is an independent college preparatory school that exists to educate young men and women in the arts and sciences in the context of a complete commitment to the historic Christian faith” (<http://www.lca.edu>). As such, both academics and religion play highly in the school’s identity.

The school recently went through a process of vision-casting. Two points relative to this study were brought up: LCA will strive to be the best Christian, college-preparatory school in the country, and the school will have a focus in the area of math, science, and technology (LCA Vision Plan, 2009). With these bold charges, there is great pressure on the science department to be current, relevant, and rigorous. At the same time, there is a continuing pressure to be sensitive to the Christian faith. According to the School Profile, “The integration of examined Christian faith and rigorous academics is an important distinctive at Lexington Christian Academy. The LCA Community includes faculty and students with diverse spiritual backgrounds. Together we cultivate an environment of stimulating ideas, hard questions, and respectful inquiry.”

As a college preparatory school, LCA prides itself on its academics. It has a student-to-teacher ratio of 10:1, with an average class size of 15. The average tenure for a teacher is 12 years, and more than 80% of teachers hold advanced degrees. The school offers 19 Honors and 8 AP courses, and 100% of LCA students are admitted to 4-year colleges (LCA Profile, 2011).

There are currently 302 students enrolled, which is down from a high of around 350 in 2007 but up from last year's enrollment of 285 (personal communication with administrators, 2012). The tuition is \$20,200 for middle school and \$22,500 for high school, but 48% of students receive scholarships or financial aid (LCA Profile, 2011). While the roots of the school are Evangelical, the largest single denomination represented in 2009 was Catholic, and a significant number of students come from Calvinist (Reformed, Presbyterian, or Episcopal) backgrounds (Personal communication with administrators, 2010).

There are two groups of students involved in this study. These include 21 11th-grade students in College Preparatory (CP) Biology, which is introductory-level, and 33 11th-grade students in Honors Biology. Leveling is done by self-selection, but is limited by grades in previous science classes. The Honors class takes a molecular approach to biology, while the CP class takes an ecological approach. The faith background of students is predominantly Christian, with students from various denominations. In the research population, there are 49 American students, 4 international students from China, and 1 from Korea.

The course sequence in the science department follows the "physics first" model. Chemistry is taught before biology, with the understanding that modern biology, which includes a heavy emphasis on DNA, metabolism, and other cellular processes, requires an understanding of chemistry. Physics is taught before chemistry, with the understanding that topics such as waves, energy, electromagnetic attraction, and momentum are needed to understand chemistry (Vazquez, 2005). This means that by the time students reach biology, they should have been exposed to background knowledge tangential, but

necessary, to understanding evolutionary biology. These include the hypothesized origins of the universe, age of the universe and the planet, the basics of nuclear decay and radiometric dating, and randomness, to name a few. However, these are not part of current course maps (internal documentation). In addition, there is no upper school geology or earth science option, which means that students also have no knowledge of geological cycles, continental drift, formation of sedimentary rocks, or many other topics necessary to understand fossils.

Focus Statement

Biology may be the last chance that LCA students have to be exposed to the accepted scientific understandings on the history of the universe, and especially the history of life on earth before graduation. It is a unique opportunity, because the biology teacher faces the burden of correcting misconceptions students may have picked up about this area of science from their religious background, within the context of a supportive Christian environment. I wanted students' first exposure to the scientific explanation to the history and diversity of life to happen now, so that in college they would not reach a crisis of faith when confronted.

My research question started with, "How does a college-preparatory education teach evolution, in the context of a complete commitment to the historic Christian faith?" The answer was with great *science*, great *faith*, and great *teaching*. This was developed into my focus statement: "How effective will a scientifically rigorous, religiously sensitive, inquiry-based evolution unit be in a Christian school?" The success of the unit will be measured in terms of student *understandings* of evolution and student *acceptance* of scientific understandings.

CONCEPTUAL FRAMEWORK

In 1994, a paper released in *American Biology Teacher* put forth the argument that the lack of treatment of punctuated equilibrium in textbooks was the major problem facing evolution education. This may have been true from a content perspective, but it was quickly rectified, while the broader struggle to get students to accept evolution continues 18 years later. Reaching students on this sensitive topic requires much more than just the latest scientific insights. Evolution is necessary to understanding biology, and as such, should be an ongoing theme in a biology course, yet many students bring misconceptions that make them resistant to studying it (Skeptical Inquirer, 1998). Three effective ways of dealing with misconceptions and resistant students are to be religiously sensitive, use inquiry-based lessons, and be scientifically rigorous (Alters, 1994; Verhey, 2005).

Religious Sensitivity

To effectively reach students, the unit should be religiously sensitive (Meadows, 2010; Verhey, 2005). While it is illegal to teach creationism in public schools (Beckwith, 2003), that does not mean that public-school students are nonreligious. In addition, private schools have no legal restriction against including religion in the science classroom, and if parents favor creationism, they may exert pressure on the teacher or administrators. In the Lutheran school community in the United States, biology teachers were asked if the parents of their students wanted their students to learn about evolution. Thirty-four percent thought parents would say yes, 44.7% did not know or were undecided, and 21% said no. In Lutheran schools, only half of biology teachers thought their principals supported the teaching of evolution, while 30% were undecided or did not

know (Schultheis, 2010). So, it is easier and safer for teachers to omit this topic from their curriculum.

While engaging students through discrepant events is a common way to engage students in inquiry-based learning, and causing cognitive dissonance is a technique practiced since Socrates, pushing students to reject their religious beliefs may easily cause alienation, closed minds, and backlash. Flammer (2006) cautions teachers specifically against using science to challenge creationism directly. Similarly, if a teacher has a worldview that includes only natural causes, Alters (2002) urges the teacher to be cautious. Instead, the teacher should refrain from statements that pit science against religion; many people, scientists or not, accept both as valid. It is only when religion seeks to be seen as science that problems arise (Alters, 2002; Flammer, 2006).

Another way of managing conflict is being prepared for the students who have been indoctrinated in anti-evolution thought. There is a multi-million-dollar industry based on promoting a body of thought that focuses on incorrect logic and rhetoric to “disprove” evolution. If a student is particularly well versed in these arguments and is intent on bringing them up, it is better to not dig into them. This kind of reaction does what the anti-evolution groups hope for—it creates tension in the classroom, and promotes the idea that there *is* a conflict between science and religion. Instead, if students are genuinely engaged and are seeking to reconcile the two, the teacher should recommend helpful outside sources specific to the situation. By extension, in the case of a school where most or all students might be facing this, it may be worth examining these resources in class (Flammer, 2006; Verhey, 2005; Wiles, 2006).

Finally, it may also be helpful to remind students that the scientific understanding can promote values, such as ecological stewardship, and humility, that are held by many religions (Catley, 2006).

Inquiry-Based Learning

In addition to being sensitive to student's religious beliefs, it is important to consider the pedagogy of the evolution unit. The first general recommendation is to use a student-centered constructivist approach. As mentioned previously, Meadows recommends using inquiry to engage students, help them form their own questions, then analyze the evidence that scientists have accumulated. Not only does this remove the teacher from the role of having to convince students of something contrary to their beliefs, it also engages the problem-solving skills of the students. Implementing inquiry learning may be effective in teaching a very resistant audience. Rather than *telling* students the *conclusions* of the scientific community, give students the data, and help them see where the conclusions come from. Advise the students that while they do not need to *believe* scientific consensus, they at least must *know* the evidence and the conclusions. However, through the process of the learning cycle, students can be guided through the data, and can make their own, newly informed, conclusions (Meadows, 2009).

An important part of constructivist learning is accessing and assessing student preconceptions. If a student does not carefully examine his or her incorrect preconceptions, he or she will filter new information against them. The result is that they can selectively accept data that fits their existing understanding and dismiss the rest. One measure of these preconceptions and misconceptions is the How Literally Do You

Interpret Genesis (HLDYIG) instrument (Appendix A), based on the work of Eugenie Scott of the National Center for Science Education (Scott, 2000). Another is the Evolutionary Attitudes and Literacy Survey, or EALS (Appendix B). As its title suggests, this assessment was originally designed to test attitudes and literacy of evolution, as well as faith and political backgrounds, of college students in Kansas. It was also used to measure the effectiveness of the evolution curriculum to which students were exposed. This instrument was modified for this study by removing questions about student's biographical information such as political and faith background. (Hawley et al, 2011).

In addition to accessing preconceptions, another aspect of constructivist curriculum that is important but not often done in science classes is to deliberately help students through Perry's stages of intellectual and ethical development. William Perry was an educational psychologist who specialized in learning in college-age students. The stages he described start with students following or accepting the word of authorities. They begin to doubt the authorities, and move to a point where they think everyone has his or her own valid opinion. Eventually they start realizing that some thoughts are more valid than others, and they make the first commitment to their own beliefs. Then they move to the point of believing their own values, being able to defend them, yet respecting the beliefs of others (Rapaport, 2010). Even in college, students usually start in the first stage, that of black-and-white, right-and-wrong thinking. Not many students *ever* make it to the final stages of commitment to and defending of their own ideas. Helping high-school students through these stages with strong guidance from the teacher may mean more students reaching this final stage. Interestingly, Verhey (2005) also reports on

other studies that show “steadfast creationist” students exhibited signs of being stuck at the early Perry stages, following authorities without question. Being antagonistic or confrontational about evolution seemed to accentuate the problem of students sticking at the early stages, which again supports the idea of being religiously sensitive when teaching evolution. Students may perceive the presentation of strong arguments as attacking the authority they believe in. Because the evidence for evolution is strong, and students have been presented with the false dichotomy of having to choose between faith and science, teachers may exacerbate the reluctance of students to engage evolution (Flammer, 2006; Verhey, 2005).

One way of overtly addressing misconceptions is to analyze non-scientific explanations of the history of life. However, this runs the risk of feeding the antagonism between the two. However, some (Alters, 2002; Verhey, 2005) did suggest looking at pseudoscientific arguments such as specific examples of alleged irreducible complexity to see if they meet the criteria of being science, or of being sound arguments. This analysis could make students aware of the shortcomings of the non-scientific understandings (creationist, ID, or other). It is suggested that these lessons might take place as student-student discussions, or in another manner that allows students to do their own comparison of the logic and strength between the scientific and alternative understandings. Another option is to have students examine creation stories from cultures other than their own, then come up with their own stories to explain the local landscape. This could be coupled with analyzing movies that deal with stories of creation (Alters, 2006; Verhey, 2005).

Another aspect of pedagogy is ensuring students have the appropriate background before taking the course. Ideally, students should have been exposed to “controversial,” difficult-to-grasp ideas in other science content area courses (Nehm, 2006). If this has not been accomplished, the teacher will need to decide which are imperative and which ones can be left for other courses. For example, while the Big Bang is part of the scientific understanding of the universe, it is not integral to understanding evolution. However, understanding deep time is crucial. While deep time might have been covered in a physics, astronomy, or geology class, often it is left for the biology teacher. Since creationist understandings of time are much easier to understand, this topic must be tackled deliberately, with enough time given for conceptual change to an evolutionary understanding. It is not known whether the difficulties that so many students and teachers have in understanding deep time is a reflection of the inherent difficulty of the idea, or a lack of exposure to it (Cotner, 2010).

In addition to having the proper context in the sequence of courses, an evolution unit must have proper placement within the course. The first step in the sequence Flammer suggests is a unit on the nature of science. In addition to discussing how the scientific enterprise works, this unit can be used to introduce the evidence for ideas such as deep time, continental drift, or radiometric dating, which are necessary for understanding evolution but may not have been covered in previous courses. The second unit is an overview of diversity and life, which will raise questions in the minds of students. The third unit is evolution, which he claims will provide testable answers to those questions. Finally, evolution should be used as a continuous theme through the rest of the course (Flammer, 2006).

The first proposed unit as the nature of science (NOS) is a common theme from many papers. This may be because it is common for those holding creationist beliefs to dismiss evolution based on the idea that it is uncertain because “evolution is only a theory.” Wiles (2006) notes the claim that evolution is just based on faith, and that since science is just provisional, alternate theories such as ID deserve equal attention (Verhey, 2006). This demonstrates a lack of understanding of what a theory is, let alone the evidence for evolution. And, as Verhey (2006) observes, textbook coverage of the NOS is simplistic and inadequate. McComas (1996) has created a helpful guide of some of the major myths, icons, or misunderstandings on the nature of science propagated in school, and Flammer (2006) has created an extensive Web site, called ENSIweb, complete with lesson plans, on getting students to think scientifically. One aspect mentioned by both McComas (1996) and Flammer (2006) is that it is important to acknowledge that science (just like religion) can become political, and should be approached with an open mind. Science can also be done poorly. Science uses the processes of peer review and repeated research to give credibility to good science and discredit bad science. Another important aspect about the nature of science that is misrepresented in textbooks and anti-evolution literature is the idea that science can only legitimately work, and prove facts, through experimentation. It is important to understand that observations and inferences are valid ways of discovering aspects of the universe (Catley, 2006; McComas, 1996).

The second unit Flammer (2006) suggests is one on the diversity of life. He suggests this as the second unit because it will provide the raw data for students to become familiar with the living world. As students become familiar with the complex array of organisms, the teacher can start introducing observations and questions about

patterns that exist. What similarities do organisms have, and how do we account for them? What differences and novelties exist, and how might they have come about? These patterns exist in cells all the way through whole organisms. Flammer (2006) also suggests including the history of life, including a timeline around the classroom where one centimeter represents one million years. However, this requires that students already understand deep time.

Evolution can and should be used as a theme for other units in the biology course, since “Nothing in biology makes sense except in the light of evolution” (Dobzhansky, 1973, p.125). A student may ask, “Why do we have an appendix?” when studying human anatomy, “Why can we test medicine on rats?” when learning about vertebrates, or “Why is the genetic code the same for all organisms?” when learning about DNA. The scientific response of common ancestry and evolution gives a robust explanation that even provides predictive power (Flammer, 2006).

One example of a unit that should be built around evolution is ecology. Several sources recommend either including the discussion of ecology in the evolution unit, or at least teaching an evolution-based ecology unit. If ecology teaches students only to identify the food chains that we see in the biomes that exist today, it creates a very limited, two-dimensional picture. Instead, ecology should be presented with the idea that food webs are the result of millions of years of evolution. There is no ideal organism, just organisms that are best suited for their environment. It is the small differences that allow populations to adapt to niches and, over billions of years, created the systems we see today. Rather than seeing the needs of an organism as arbitrary or fixed, students need to understand them as balances that have evolved over long periods of time. This

can help shatter the misconception that if an organism's food web is upset, it will feed on something else instead. In fact, the effects of such an upset might be surprising and affect many organisms. Instead, students will realize if people upset these complex webs that have been set up over eons of evolution, organisms and ecosystems will not be able to adapt (Catley, 2006; Flammer, 2006).

When developing the evolution unit, it is important to take into account the developmental stage of the students. This can be challenging, as different teachers have different understandings of what is appropriate for certain groups of students. For instance, only 66% of Lutheran biology teachers thought evolution could be understood by beginning biology students (Verheis, 2010). The literature is also inconclusive about how thoroughly students can be expected to grasp deep time, which is a precursor to understanding evolution (Cotner, 2010).

Another point to consider when designing a pedagogically sound evolution unit is to integrate a variety of lessons. Discuss the history of the theory, do several labs showing the principles in action, tell the history of organisms, and show relevant videos (Flammer, 2006). There are many sources for lesson ideas, recent discoveries, and support in the case of challenges from resistant populations. The National Academies of Science have many curriculum sources on evolution, and ENSIweb has a wide variety of lesson plans and curricula to use on both evolution and the nature of science. The National Center for Science Education (<http://www.nationalacademies.org/evolution/>) has a wealth of information on dealing with untruths from creationists, and Kenneth Miller's website goes into great depth explaining the shortcomings of ID (<http://www.millerandlevine.com/km/evol/>). And

Meadows' book contains guidance on how to use the 5E learning cycle and scientific inquiry to create compelling lessons (Meadows, 2009; Padian, 2011).

Finally, it is important to keep the content coverage reasonable. Students will not be able to absorb all of the details of all of the aspects of evolution and the history of life on the first exposure, so sketch in the framework that will allow students to fill in the gaps in future courses (Alters, 2002, 2006; Flammer, 2006).

Scientific Rigor

After religious sensitivity and pedagogy have been considered, it is important that the unit is scientifically accurate, up-to-date, and rigorous. Again, considering that a prior unit on the nature of science is recommended, it could be helpful to focus on the process of how evolutionary theory has developed through history (Flammer, www.indiana.edu/~ensiweb, April, 2011). What is the evidence that has lead scientists to these conclusions? This can save the teacher from being the “bad guy” who is forcing the students to question authority (Meadows, 2009). However, if students can be urged to question authority, this can signal the move from the first to the second of Perry's stages of moral and intellectual development. This stage includes active scientific reasoning. This is something that many college graduates are unable to do (Alters, 2002).

For the last 50 years, much of evolutionary teaching has been based on how evolution affects the individual, but it is time to think more about how evolution relates to the bigger picture such as macroevolution (Padian, 2011). The history behind the traditional approach and its basis in the “New Synthesis” view of biology from the early-mid part of the 20th century has had a significant effect on how evolution is taught.

While its focus on fruit fly and yeast genetics has yielded fantastic discoveries, ignoring the population-level aspects of evolution has led to a variety of frustrations, including teachers being unable to cite examples of speciation. Instead of this narrow approach, teachers should think about the whole range of evolution, from DNA to populations to species to ecology. If students think about evolution on all these different levels, they serve to inform and strengthen the cohesive picture of the interconnectedness of life on earth. These levels are genome, individual, populations, species, and clades (family trees) (Catley, 2006). Catley (2009) and Padian (2011) particularly suggests focusing on macroevolution. The case could be made to add even more levels, such as genetics at the microscopic end to ecology on the largest end (Flammer, 2006).

If students are to draw their own conclusions, required when thinking scientifically, it is important to teach students to use the tools and techniques that scientists themselves use. One of the major tools that evolutionary biologists use to map out the tree of life as Darwin first envisioned it in 1859 is cladograms. These are hypothetical family trees created from analysis of common traits in organisms, and as recently as 2006 very few teachers or textbooks were utilizing them (Catley, 2006). The beauty of these trees is that they allow scientists and students to make and test hypotheses, something that the antievolutionary faction accuses them of being unable to do. These cladograms also allow teachers to use the historically rich presentations that Alters recommends. Flammer also makes the case to give students these trees, along with current, documented examples of speciation. Padian also makes the recommendation of using evograms, a type of cladograms, to understand macroevolution (Alters, 2006; Catley, 2006; Flammer, 2006; Padian 2011).

Summary

The topic of evolution has often been ignored in American schools because it generates controversy and student resistance (Farrell, 2010; Fowler & Meisels, 2010; Moore, 2005; Schultheis, 2010). This is unacceptable because evolution is not just an isolated topic, rather, it is a major underlying theme that runs through all areas of biology (Dobzhansky, 1973; Skeptical Inquirer, 2008). Thus, it is imperative to teach it, even to resistant audiences. Teaching this unit using inquiry-based methodology is an excellent way to do this, because it avoids the teacher acting as the antagonist. It allows students to examine actual scientific evidence and arrive at their own conclusions (Meadows, 2009). Furthermore, the teacher can further minimize antagonism in the classroom by using some simple methods such as being respectful of student beliefs, avoiding or being prepared to address creationist talking points, and by presenting the data while leaving students to use logic to reach the scientific conclusions (Flammer, 2006; Meadows, 2009; Verhey, 2005).

METHODOLOGY

Pre-Treatment Analysis

Background research was started three months prior to starting the unit, which started at the beginning of February, 2012. This work included administering the “How Literally Do You Interpret Genesis?” (HLDYIG) instrument (Appendix A) on November 7, 2011 to determine student resistance to evolution. The modified Evolutionary Attitudes and Literacy Survey (EALS) instrument (Appendix B) was administered a month later to determine student attitudes toward and knowledge of evolution. This data

was used to measure initial levels of understanding, and to ensure the unit plan was constructed around issues relevant to students. These instruments are presented in the Data Collection Instruments section below. To limit the length of the unit, some important topics to evolution but beyond the scope of an introductory biology class were not included in the unit. These include the Big Bang, the formation of the solar system and the Earth, and major processes of geology such as continental drift. Some issues and iconic examples are, unfortunately, hot button issues of anti-evolution advocates. One major example is the book and accompanying website *Icons of Evolution* by Wells (www.iconsofevolution.com) that lists ten different textbook examples of evolution, and how students can argue against them. So some topics were unfortunately omitted (such as Darwin's personal life and details of his finches, and the Miller-Urey experiment on the origin of life), while in other cases, different examples had to be found (transitional fossils other than Archaeopteryx had to be found, as did a new example of microevolution other than the peppered moth in England). The topic of human origins was not chosen as an Enduring Understanding, but whenever it came up in a class, it was brought up as a wonderful example of inquiry. "We find these fossils of organisms that don't quite look like humans—but don't look like non-humans. How might they be related to us? Could they think? Could they communicate with us? Could they interbreed with us?" This way, it was made a topic of curiosity, not of opposition.

The initial intent of the study was to use student-centered inquiry learning based on the 5E learning cycle. However, attempts to practice some of these techniques, including group learning, project-based learning, and flipped classroom, early in the year were met with resistance by some parents. This in turn resulted in the direction from the

administration to minimize this type of pedagogy, and do more lecture and traditional assessments. Thus, while the 5E methodology was used for the framework of the unit, the day-to-day methodology included more teacher-centered learning than had been the original intent.

The research methodology for this project received an exemption from Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

Treatment

Inquiry-Based Lessons

The Big Idea, or overarching concept, of the unit was *evolution explains the unity and diversity of life*. This comes from the 2012-2013 AP Biology Curriculum Framework (tinyurl.com/apbiocurriculumframework). The 5E learning cycles were built around five Enduring Understandings (EUs):

- 1) If a trait is helpful, it will become more common over time
- 2) Changes in living things start with small changes in DNA, and randomly, but have a major effect on a physical level.
- 3) A new species is formed when a group splits off the main group.
- 4) The earth is very, very old.
- 5) Similarities in organisms support the idea of a common ancestor, and allow us to build a family tree of life.

The five stages of the 5E learning cycle were used for each of the five Enduring Understandings, as summarized in Unit Outline (Table 1).

Table 1
Unit Outline

	EU 1	EU 2	EU 3	EU 4	EU 5
	If a trait is helpful, it will become more common over time	Change starts with small random changes in DNA, and have major physical effects	A new species is formed when a group splits off the main group	The earth is very, very old	Similarities in organisms support the idea of a common ancestor, and allow us to build a family tree of life
Engage	Pictures of ancient crops: what these have been changed into through selective breeding?	Youtube videos on Sickle cell anemia	Pictures of dogs as a kick-off to discussion of what is a species?	Timeline activity part 1: pre-conceptions about sequence and age of organisms	Put up pictures of members of a family: which people are closest related, and which are more distant related?
Explore	Hairless Rabbit activity on Natural Selection	Sickle Cell anemia activity	Activity on Stebbins' Salamanders in California	Timeline activity part 2: comparing preconceptions to scientific understandings	Phylogenetic trees activity
Explain	Notes and reading on Natural Selection and Hardy Weinburg equilibrium	Notes, PBS and HHMI videos, reading on DNA mutation, homeobox genes, and embryology	Notes and reading on speciation; online speciation tutorial	Notes and reading on radiometric dating, history of earth	Notes and reading on phylogenetic trees, homologous structures
Elaborate	Hardy Weinberg worksheet	PBS video, worksheet on HIV mutation;	Canine family tree activity done in EU 5	Determining Age of Rocks and Fossils activity	Dog/Wolf/Canine family tree activity
Evaluate	Writing about potential causes for change in an imaginary population	Sickle Cell CAT, worksheet extension on pesticide resistance and GMO potatoes	Creative writing assignment: write about a speciation event in humans	Summary questions on timeline. Artistic representation of a historical period (optional, extra credit).	Reflection paper for dog/wolf/canine tree lab

The first 5E step of Engagement was accomplished by a variety of methods, including discussion of pets, online video clips, and guessing. The intent was to provide a “hook” to engage students, get them interested in the topic, and to provide a reference point that could be remembered later in the unit.

The intent for the second 5E step was to examine evidence—actual raw data. However, due to administrative restrictions, this ended up taking the format of a variety of more formal activities. One was to look at timelines of deep time, and while this was not actual evidence in the sense of actual fossils, it was nonetheless framed by asking the question, “Why would scientists think this?” Another was to look at the actual DNA sequence of normal and sickle-cell hemoglobin to see how a minor difference in DNA could have a major physical effect. The purpose of these activities was to provide students the opportunity to look at the evidence without the pressure of accepting it, which helped create the safe environment that is desired.

The third 5E step is formulating explanations to address scientific questions. The intent was to examine misconceptions that were identified in the pre-unit EALS, but because of the administrative mandate to include more traditional activities; this was changed to include more notes, lecture, and quizzes.

The fourth step of the 5E learning cycle, elaboration, was accomplished through more in-depth activities based on the notes and concepts presented earlier in the lessons. These included deeper work with the mathematical aspects of the Hardy-Weinberg model as well as with calculations of exponential decay as used in radiometric dating. These also included watching a video on HIV mutation and antiviral resistance, with a follow-up activity where students applied the principles to pesticide resistance resulting from

genetically modified crops. A final, overarching activity analyzing the canine family tree to reinforce the concepts of speciation and phylogeny was planned but had to be omitted due to time constraints. It may yet be used as an additional review activity before the final exam.

The final stage of the learning cycle, evaluation, was done doing a variety of assessments that focused on application of the concepts within the Enduring Understanding. They all involved significant amounts of writing. Two of them involved creative writing and imagination, three of them required defending their analysis of a case study, and one that had to be made optional due to time constraints involved visual art.

Religious Sensitivity

In addition to using the 5E learning cycle, a second aspect of the treatment was to establish an attitude of respect for religion, as well as respect for those who accept the scientific understanding of the history of the universe. The latter is important, as the human tendency to look down on others with different views runs both ways. In any case, the attitude of respect was accomplished through general and direct means.

The general means of establishing respect for religious beliefs included treating all students and their beliefs with seriousness and respect, and insisting that students also treat views different from their own with respect. Another ground rule used to establish a tone of respect was that people could not question others' faith, salvation, or intellectual ability, and it was repeated that there were many Christians who are scientists and who accept the scientific understanding on the history of the universe. As it was important to avoid direct arguments with students, student questions and statements that demonstrated

resistance were acknowledged and dealt with at a time deemed appropriate by the teacher. This kept the locus of control on the teacher, and ensured the teacher would have adequate time to research the question and respond with a thorough, accurate answer. This also prevented vague answers or “waffling” around issues that are contentious in the mind of the public but not in the mind of scientists.

The first of the direct means of addressing religious sensitivity was previously completed in the unit on the Nature of Science (NOS), where religion and science were overtly discussed, and described as two different lenses to look at the world. If they appear contradictory, it requires humility in analyzing both lenses to refocus them. Some parameters and limitations of the two lenses were established, as well. This led to the idea that science and religion are not opposed, but rather should be viewed as complementary. Some basic logical progressions were presented to help students feel comfortable enough to consider the current scientific model, with the deliberate awareness of avoiding delving too deeply into theology in a science class. These included that a creator would not create lies or intentionally deceive us, and that thorough investigation of the natural world brings more glory to God. Another direct strategy was to break down the many ideas under the “hot button” umbrella terms of *evolution* and *Darwinism* into smaller topics, and acknowledging that these have varying degrees of certainty and importance. As different aspects and implications of evolution were covered, it was acknowledged that some of these observations are well-established whereas others are more speculative (Alters, 2002). This allowed students to be more discrete in what they accept and what they struggle with. This encouraged students to think in shades of grey, rather than in black and white (religion versus science).

Additionally, the direct means suggested by Meadows was employed. Students were told that they do not need to *believe* what is taught in the science class, but they do have to *understand* it (Meadows, 2009). Finally, about half way through the unit students were presented with an exit card on which they were asked, “*Has anything we have covered in the evolution unit thus far seemed irreconcilable with your faith?*” The issues identified were raised in class discussion during the second half of the unit.

Scientific Rigor

In order to achieve the third goal of the unit, scientific rigor, it was important to acknowledge evolution as one of the foundational aspects of biology. Thus, this unit was consciously situated within the course. There was a prior NOS unit, an introduction to diversity at a cellular level, and evolution was used as a continued theme in subsequent units.

The first technique to encourage scientific rigor was to use variety of standard and novel activities and assessments to investigate not only the basic aspects of evolution, but some of the recent major advances in evolutionary science. These included genomics, genome mapping, homeobox genes, new discoveries of ancient species, cladograms, and macroevolution. This relates to the first point of employing sound pedagogy by engaging preconceptions; a standard anti-evolutionist tactic is to deny that this vast body of scientific knowledge exists (Padian, 2010). Also, many anti-evolutionist arguments are stalled on combating “Darwinism,” while science has continued to progress and amass evidence of evolution for more than 150 years since the publication of the *Origin of Species*. Being bold and introducing clear new evidence made it easier to overcome the

intentional obfuscation of creationists and ID proponents. Including new information also tied in well with the prior Nature of Science (NOS) unit, which included a section on how the body of scientific knowledge accepts theories and expands, and how to evaluate scientific articles.

Data Collection Instruments

Data was collected before, during, and after the treatment. The instruments used before and after the treatment were concept inventories or surveys designed to get a general, class-wide level assessment of attitudes towards and understandings of evolution. In contrast, the treatment contained very specific assessments that measured how well specific students understood specific concepts of evolution.

Pre-treatment Collection Instruments

The HLDYIG instrument, based on the Creationist Continuum (Scott, 2000) was administered before the unit to determine student attitudes toward evolution. This instrument also helped identify some of the misconceptions students were dealing with as a result of their religious background (which aspects of the scientific model they rejected). It was designed as a flowchart for students to follow, with the most literal interpretation of Genesis branching off first, and the atheistic option at the end.

Young Earth Creationism (YEC) was the most literal option, where the universe came into being, with species are exactly as they are now, six thousand years ago, and that the first pair of humans were a man and woman named Adam and Eve. Adherents may or may not accept that microevolution (change within populations) can occur. A major proponent of this view is Ken Ham of Answers in Genesis; his website

(<http://www.answersingenesis.org>) has a list of information on how he argues his position. Old Earth Creationism (OEC) is similar, but concedes that there might be much more time than 6000 years since the 6 day creation period. Gap Creationism is makes one more concession, that there could have been a gap between the first and second creation stories in Genesis, and this would account for the age of the earth. Day-Age creationism holds that the creation story is generally accurate in sequence of creation events and the role of Adam and Eve, but the term used for the six “days” could be interpreted as much longer periods of time. Progressive Creationism agrees with science that the earth is very old and that there is a certain sequence of organisms appearing in the fossil record that does not match with the Biblical account, but explains this with God spontaneously creating these organisms throughout time.

Intelligent Design (ID) makes the further accommodation that some evolution of populations and speciation is possible, and even that some novel structures or features can be accounted for by random (or, controlled by God) mutation. However, ID insists that some complex structures can only be useful with many pieces in place, and thus could not have evolved gradually over time. This condition is termed “irreducible complexity”, and the explanation of how this can be solved is by spontaneous creation.

ID is primarily the result of the work of the Discovery Institute

(<http://www.discovery.org>). Theistic evolution is the view that the scientific view of the age of the earth, micro and macro evolution, speciation, and mutation of DNA are sufficient to account for life on earth. The distinguishing features are that while the mutations appear random, they are also part of a divine plan, which may just be that God created the parameters of randomness. The difference between this and Deism, the idea

that God is the watchmaker who made the universe and then left it alone, may seem subtle. However, the key difference is that Theistic Evolutionists believe that God is still tending the universe, and in particular, paying attention to humans, taking care of them and communicating with them. The last option on the survey was atheistic evolution, in which God has no role in the process that has led to the current state of the universe.

On Monday November 7, 2011, I opened class by explaining my enrollment in the MSSE program, and some of the science-based courses I have taken. These included geology, astronomy, and paleontology, so I used examples from these classes to transition the conversation to evolution, and how closely related it is to other scientific subjects, and how central it is to biology. I then explained my research project and told students that they would be participants. I distributed the HLDYIG assessment, and gave a brief verbal explanation of each of the viewpoints. Students were then given up to ten minutes to complete the survey. There were two sections of 11th grade Honors Biology (15 and 16 students, respectively, as some students were absent) and one section of the lower-level College Preparatory (CP) Biology (21 students). Since the two levels meet at different times, have different syllabi, and different textbooks, their data was analyzed separately, but the two sections of Honors were analyzed as one group. I made it optional for students to include their church affiliation, as this might be used to identify students. Data was processed by totaling the number of students who identified with each interpretation of Genesis. If students checked more than one box, their vote was divided between all of the boxes they checked.

After this initial survey but prior to the start of the unit, an Exemption Regarding Informed Consent was signed by the school's Head of Studies (Appendix C). A modified

version of the EALS instrument was also administered beforehand to establish a baseline of evolutionary knowledge, and to more precisely identify student misconceptions (Appendix B). This instrument was pared down by removing questions relating to religious identity and activity, political ideology and activity, attitudes towards life, and demographics. It retained the sections specifically related to understandings of, and objections to, evolution. The instrument was administered afterward as well, and analysis used to determine if there was a difference in any of the twelve aspects of evolutionary understanding measured by the instrument: Intelligent Design fallacies, Young Earth Creationist beliefs, moral objections to evolution, social objections to evolution, distrust of the scientific enterprise, relevance of evolutionary theory, genetic literacy, evolutionary knowledge, evolutionary misconceptions, knowledge about the scientific enterprise, self-exposure to evolution, and youth exposure to evolution.

Mid-Treatment Collection Instruments

During the treatment, data on student understanding of evolution was collected at most of the five stages for each of the five enduring understandings. These Assignments and Assessments included labs, worksheets, homework assignments, writing assignments, and small independent research activities (Appendix D). Most of these came from *Understanding Evolution* (<http://evolution.berkeley.edu>), *Evolution and the Nature of Science* (<http://indiana.edu/~ensiweb>), *PBS Evolution Series* (www.pbs.org/wgbh/evolution), or from student textbooks.

On Friday March 2nd, the day before spring break and in the middle of the evolution unit, students watched a video on the evolution of mammals, including whales

and humans. This video was chosen to spark some cognitive dissonance and discomfort, and to get students to think about the more challenging implications of evolution that had not yet been covered, major changes and human origins. At the end of the class, students were given an exit card with two questions: *What questions do you have on the science that has been covered so far?* and *What, if any, irreconcilable differences between science and your faith have you come across thus far?* Data was summarized over spring break, and presented to class. This was used to launch discussion on problematic areas.

Three Concept inventories, Tree Thinking (Baum et al., 2005), the Concept Inventory of Natural Selection, CINS (Anderson, Fisher, & Norman, 2002), and the Measure of Understanding of Macroevolution, MUM (Nadelson & Southerland, 2010) were also considered but ultimately not used due to administrative limitations on the use of surveys in class.

Post-Treatment Collection Instruments

Following treatment, student attitudes towards evolution were assessed using the EALS instrument and formal evaluations for both classes, the CP Unit Test and the Honors Unit Test (Appendices E and F). There were also one-on-one interviews with students that were self-selected that used the Interview Questions (Appendix G). Interview responses were used as qualitative reinforcement of the trends. The HLDYIG instrument was not used after the treatment because this was not a unit that involved reading or interpreting Biblical texts.

Student understanding of evolution was collected through the modified EALS survey. Comparison of the pre- and post-treatment EALS survey was done by comparing

averages of Likert responses of questions within constructs as defined by the makers of the instruments. In addition, strong outliers indicating student resistance were noted, as were questions with the highest difference before and after the unit.

The pre-unit EALS was performed on December 12 or 13, 2012, depending on which day each section met. It was introduced as a survey that would be anonymous and thus not used for grades; in fact, participation was voluntary as per the disclaimer at the top. However, participation would be appreciated, as it would help me design the evolution unit that would be used in my graduate research. Students were instructed to put the date, their class section, and the birthday of a close relative as their name. This served as a random number that would preserve anonymity while allowing their pre-and post-unit surveys to be compared side-by-side if desired. The post-unit survey was done on April 14, 2012, with the same disclaimers and instructions. For the pretest in the CP class there were 17 participants, while in the post-unit survey there were 18. Both Honors classes were treated as one data set, and there were 33 and 28 participants for the pre- and post-unit assessments, respectively. These differences in sample size are because some students were absent on the day of the assessments. In order to maintain anonymity, and in order to comply with administrative direction to not draw attention to the research process, opportunities to make up the surveys were not offered. Data was only used from students who participated in both surveys. After taking the second survey, students were given note cards and asked two questions: (1) *“In which areas did you change the most?”* (2) *“Were you surprised at anything when you looked back at your pre-unit answers?”* Their answers were also included in the data analysis.

In addition to the EALS instrument, the effect of a scientifically robust unit on student scientific understanding was measured using the CP and Honors Unit Tests (Appendices E and F). These included multiple choice questions generated from the textbook test bank, multiple choice questions from a SAT II preparation book, short answers, and a timeline. As the CP unit was several weeks ahead of the Honors class, the test scheduling was slightly different. The result was that the CP class had part of the evolution material on a test before spring break and the rest afterwards, but the Honors only had one evolution test, after spring break. The two tests feature many of the same multiple choice questions, but the CP test had fewer of them, and they tended to be lower levels of Blooms taxonomy than the Honors test. The CP test also included a long essay question on the evolutionary implications of genetic diseases that students had presented before spring break; the Honors class did not do these presentations or this question.

Student interviews were the final post-treatment data source, and used the pre-determined Interview Questions (Appendix G). The opportunity to be interviewed was announced in class. Five CP students and four Honors students volunteered to take it. Interviews were conducted at sufficient distance from other students to ensure confidentiality.

The following diagram (Table 2) summarizes the data sources for this project.

Table 2
Data Collection Matrix

	Pre-treatment	During treatment	Post-treatment 1	Post-treatment 2
How does the treatment affect student knowledge of evolution?	EALS survey (to identify misconceptions)	Labs, worksheets, exit cards, Concept Inventories (Tree Thinking, Natural Selection, Macroevolution), log of resistant questions	EALS Survey	Unit test
How does the treatment affect student attitude towards evolution?	EALS survey, <i>“How Literally Do You Interpret Genesis”</i> (HLDYIG) survey (to identify current attitude)	Classroom Assessment Technique exit cards	EALS survey	One-on-one interview

DATA AND ANALYSIS

In this study, background data was collected to determine prior beliefs and misconceptions in the study population. This was used to design the evolution unit, and as a baseline for comparing post-treatment attitudes and understandings. Data was also collected mid-treatment in order to identify student concerns and confusions so that these could be addressed in the second half of the unit. After the treatment, student understanding was measured using a traditional unit test.

How Literally Do You Interpret Genesis?

This survey was chosen to provide insight on student’s religious background in order to determine misconceptions. Because some students indicated more than one

answer on their instrument, their vote had to be split between all the options they chose. In the CP class, the most popular choices were YEC and ID, with 4.5 students each. The second most popular choice was OEC, 3.5, followed by Gap Creationism and Agnostic/Atheistic Evolution, with two each (Figure 1).

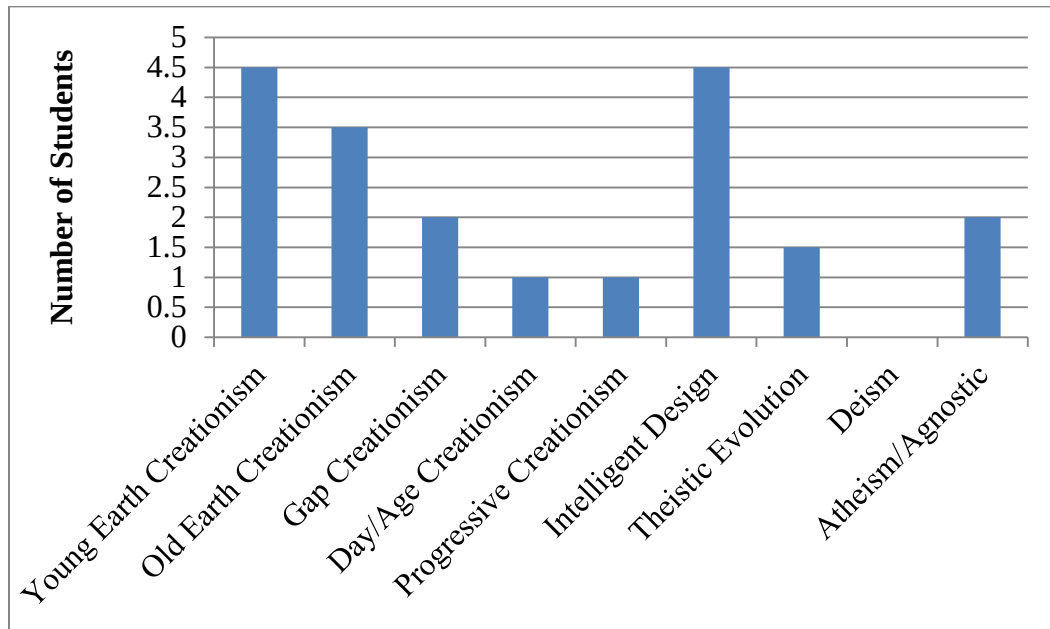


Figure 1. Interpretation of Genesis in a CP biology class, ($N=20$).

In the two Honors classes (combined into one data pool), Day/Age creationism was by far the leader with 14 students. 5.2 students identified as believing ID, 4.7 accepted Theistic Evolution, and 2.2 accepted YEC. There was only one student with an Atheistic/Agnostic Evolution interpretation (Figure 2).

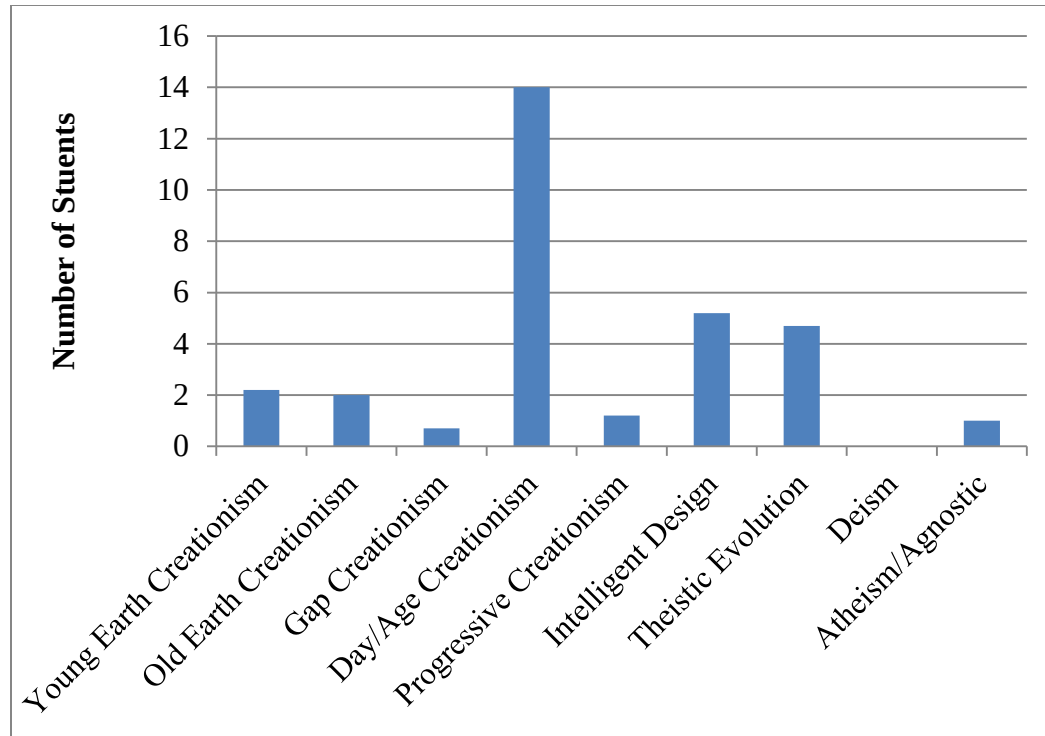


Figure 2. Interpretation of Genesis in an Honors biology class, (N=31).

The least popular choice in both classes was Deism, with no votes. In total, there were only three students who did not integrate the Bible at all into their understanding of the history of the universe (Atheistic/Agnostic Evolution). And although the students holding ID views in both class were fairly similar (22.5% ($n=4.5$) compared to 17% ($n=5.2$)), the Honors class had more students with beliefs that are attempts to reconcile Biblical literalism with science (Day/Age creationism, ID, and Theistic Evolution). Finally, only 17.5% ($n=3.5$) of students in the CP class and 18% ($n=5.7$) in the Honors class held beliefs that did not directly contradict science (Theistic Evolution, Agnostic, or Atheist).

Evolutionary Attitudes And Literacy Survey (EALS) and Interviews

As administered, the EALS instrument measured ten aspects of attitudes towards, and literacy of evolutionary theory. These are belief in ID, belief in YEC, objections to evolution based on moral implications, objections to evolution based on social implications, distrust of the scientific enterprise, perceived relevance of evolution in other areas of life, genetic literacy, evolutionary knowledge, misconceptions about evolution, and knowledge of the scientific enterprise.

The EALS instrument revealed two things. First, the pre-unit survey showed more objections to, ignorance of, and resistance to evolution in CP than in Honors. Second, both treatment groups demonstrated a major improvement in attitudes towards, knowledge of, and acceptance of evolution as a result of the treatment.

Before the unit, themes that showed misconceptions or reservations about evolution had higher levels of agreement in the CP class. These included ID (46% for CP ($n=7.8$) and 35% for Honors ($n=10.3$)), YEC (48% ($n=8.1$) and 35% ($n=10.1$)), moral objections to evolution (37% ($n=6.3$) and 21% ($n=6$)), distrust of science (30% ($n=5.1$) and 25% ($n=7.1$)). Themes that showed greater knowledge of science were more strongly represented in the Honors class. These included perception of relevance of evolution to other areas of study (51% for Honors ($n=14.9$) and 40% for CP ($n=6.8$)), genetic literacy (41% ($n=12$) and 33% ($n=5.8$)), and knowledge of how the scientific enterprise works (66% ($n=19$) and 62% ($n=10.6$)). The exceptions to these trends were that the Honors class had more objections to evolution based on social implications (29% for Honors ($n=8.5$) and 25% for CP ($n=4.3$)), while the number of misconceptions about evolution (39% for CP ($n=6.7$) and 36% for Honors ($n=10.6$)) and evolutionary

knowledge (53% for Honors ($n=15.3$) and 52% for CP ($n=8.8$)) were about the same for both classes (Figure 3).

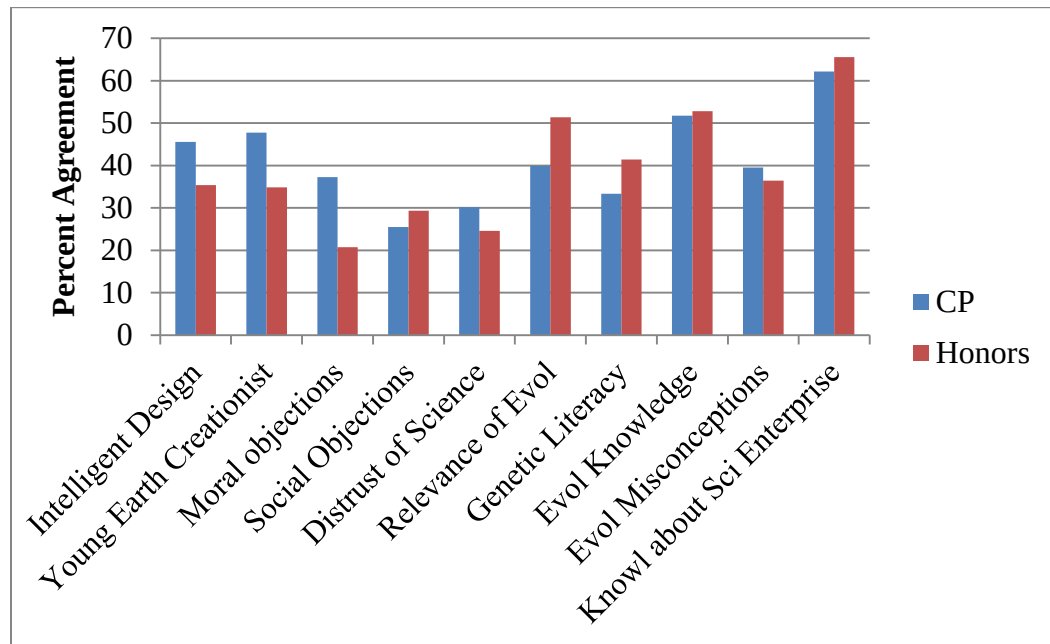


Figure 3. Pre-Treatment attitudes and literacy of evolution in a CP ($N=17$) and Honors Biology, ($N=28$).

In the interviews, students in the CP class associated the term “evolution” with half-humans, intermediate species, monkeys and Darwin. While Honors students thought of a wider variety of topics including speciation, very long periods of time, bacteria, the big bang, and organisms becoming more specialized, some students still initially thought of human origins. When asked about their prior influences by church and parents, only two of the CP students knew their church’s stance on evolution, but both of these were literal creationist congregations. One of the churches used to be led by the “Dino Pastor,” someone who later went on to open a creationist museum in Maine (<http://www.dinopastor.com/>). In the Honors class, two students reported coming from a conservative congregation; one of these had a former LCA parent come in to present his

anti-evolution book *Tornado in a Junkyard*, which builds the case that evolution is as unlikely as a tornado going through a junkyard and assembling a fully functioning Boeing 747. Two others reported that their churches had hosted debates or forums on the topic, presenting various points of view and leaving people to decide on their own. Three of the five CP students knew their parents' stand on evolution, and all were strongly against it. In the Honors class, two families were somewhat against it while two others allowed for some evolution. Only one CP student had learned about evolution before; they had learned about its shortcomings in a Christian middle school. Only one Honors student reported learning about evolution in school before; he had learned about it in public school, but his parents countered that with opposition to evolution.

Although the CP class showed more initial resistance to evolution, both classes made significant progress. In the CP class, nine of the ten indicators showed a change in the direction of increased acceptance of evolution or decreases in misconceptions (Figure 4). Agreement (both moderate and strong) with ID statements decreased from an average of 7.75 students to 5.75 students. YEC agreement decreased as well, from 8.11 to 5.8 students. Two students in the CP class wrote on their comment cards that when they compared their pre- and post-unit results, they were surprised how close-minded they had been to evolution at the beginning of the unit, and how much more accepting they were now.

Moral objections decreased from 6.33 to 4 students, and agreement with social objections to evolution decreased very slightly from 4.3 to 4.2, while 5.5 students were undecided. Lastly, student distrust of science also decreased, from 5.2 to 4.0, with 5.4 students undecided.

Some of the changes were increases in correct understandings. Student perceptions on the relevance of evolution to other areas of life increased from 6.8 to 8.1. One of the CP interviewees said that the most challenging and most rewarding part of the unit was putting all the facts together to see the big picture: everything we had done, from fossils to DNA and bacteria related to the evolution unit. Student knowledge of genetics increased, from 5.7 to 8.6. Student evolutionary knowledge increased as well, from 8.8 to 10.2. According to one student, “Before studying it I never fully understood what evolution was but now I do know. I also never knew what mutations and natural selections were so I never had an opinion about those questions, but now I do have opinions about them.” And knowledge about how the scientific enterprise functions increased slightly from 10.6 to 11.1.

Some student understandings, however, seemed resistant to treatment. Agreement with two common misconceptions about evolution increased slightly, from 6.7 to 7.7. The two misconceptions that increased the most were 62, “Species evolve to be perfectly adapted to their environment,” and 65, “Evolution is a linear progression from primitive to advanced species.” Agreement with both these statements increased by three students (from $n=7$ to $n=10$ for question 62, and $n=6$ to $n=9$ for question 65).

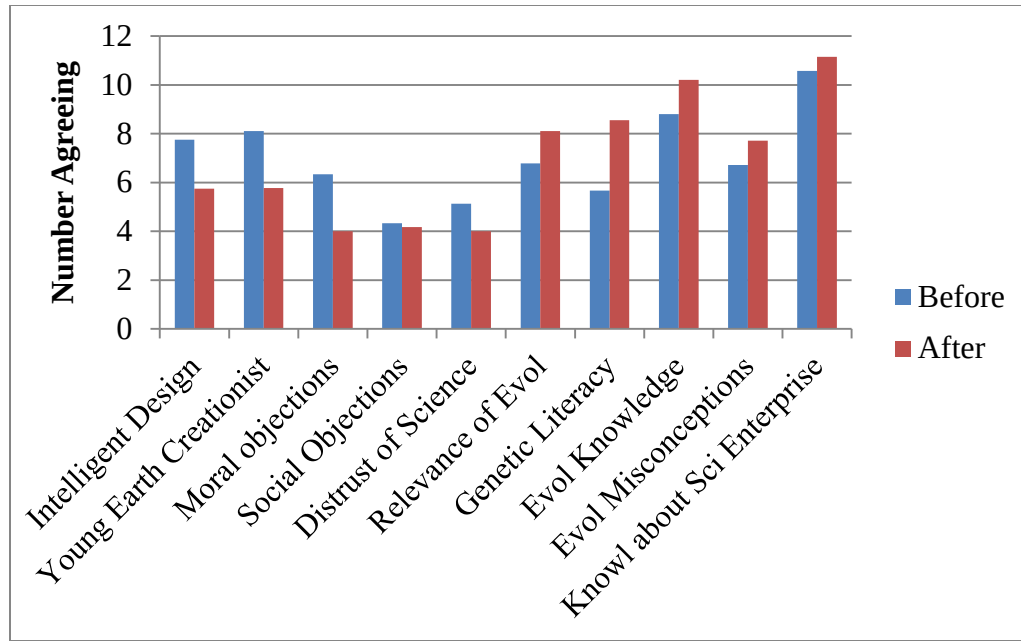


Figure 4. Pre- and Post-Treatment attitudes and literacy of evolution in a CP Biology Class, (N=17).

In the Honors class, the desired changes were observed in nine of the ten categories measured by the EALS (Figure 5). Some of these changes were decreases in misconceptions. Students agreeing with ID statements decreased from 10.25 to 7.3. Most of this change was an increase in strong disagreement ($n=3.9$). When comparing his or her pre- and post-treatment EALS, one Honors student reported that understanding more about homeobox genes made him more opposed to the idea of irreducible complexity, a hallmark of ID. Another said “I changed on my view of creation/ID. I was surprised that the growth [of my] knowledge of history [of life] corresponded with the certainty of some of the questions.” Similarly, with YEC, agreement decreased from 10.1 to 8.3. There was also a decrease in students who were undecided about YEC ($n=2.3$). Student agreement with common moral objections decreased from 6.0 to 4.2; the biggest change was that more students strongly disagreed with these objections after

the treatment ($n=3.0$). The number of students distrusting science decreased from 7.1 to 5.3; additionally, 3.1 students who were undecided beforehand became confident in science. Finally, student agreement with evolutionary misconceptions decreased from 10.6 to 7.0.

Some of the desired changes observed were increases in correct understandings. When asked if evolution was relevant to other areas of study, the number of students agreeing increased from 14.9 to 18.3. There was a marked increase in Honors students who strongly agreed with statements that indicated genetic literacy ($n=6.0$). Some of these students changed from being undecided, but since some only changed from somewhat agreeing to strongly agreeing, the net change is only from 12.0 to 14.1. However, at the same time there was a slight increase ($n=1.1$) in students who strongly disagreed with these statements. Another trait where strong improvement was seen was in evolutionary knowledge, where 7.2 more students strongly agreed after the treatment; this contributed in the net change from 15.3 to 20.7. Finally, there was an increase in knowledge about how the scientific enterprise functions, from 19.0 to 23.1 students agreeing.

There was one category where the anticipated change did not occur. This was agreement with social objections to evolution, which increased slightly from 8.5 to 9.7. The two questions with highest levels of agreement were 10, “The theory of evolution has contributed to genocide (the deliberate killing of a group based on nationality, race, politics, or culture)” ($n=17$) and 32, “The theory of evolution has contributed to racism” ($n=15$). Agreement with both of these increased ($n=1$ and 2, respectively). Students

agreeing with question 4, “The theory of evolution has contributed to an increase in abortion,” increased from 3 to 6.

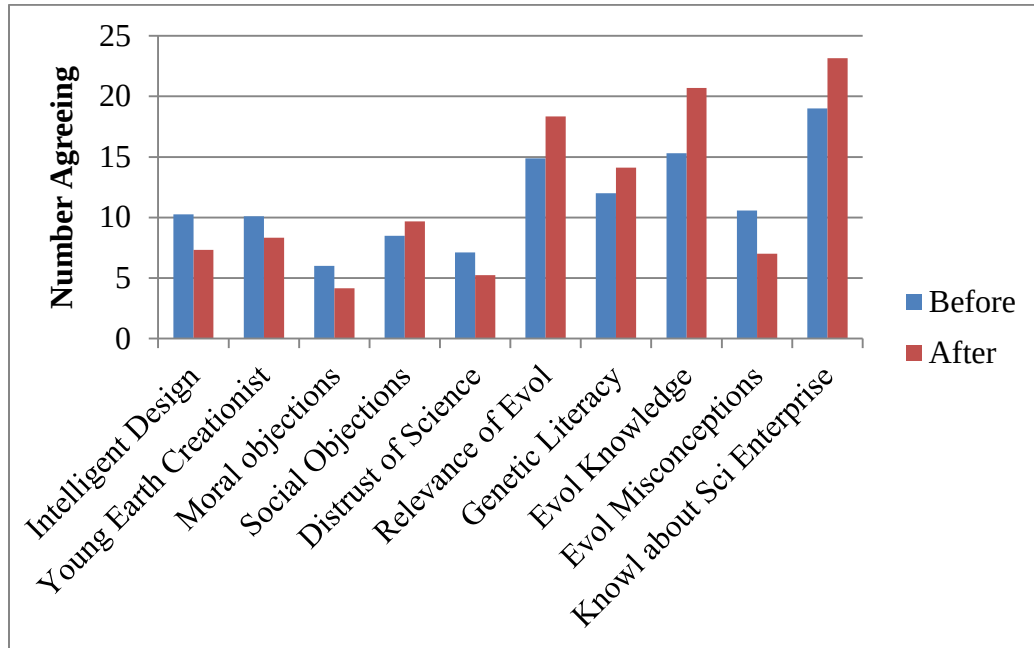


Figure 5. Pre- and Post-Treatment attitudes and literacy of evolution in an Honors biology class, (N=28).

Mid-Treatment Exit Cards

Over half ($n=10$) of the CP class reported no irreconcilable problems meshing the science we had covered thus far with their faith, and nearly a third of students ($n=10$) in the Honors class reported the same. The biggest concern in the CP class was that students had difficulty relating deep time to a seven day creation ($n=4$), and some were even more frank and were unsure how to accept evolution given that they were YEC ($n=2$). In the Honors class, the big concerns were seven students wondering how humans were related to other animals ($n=7$), and if God created species as we see them now, or if they had changed over time ($n=7$) (Table 3).

At the midpoint of the unit, the most common science questions were the five students who needed additional help with deep time, fossils, and radiometric dating. Four students in the honors class had the same concern, but the more common question dealt with how major changes—limbs, new structures, etc—evolve over time (Table 3).

Table 3
Tally of Mid-Unit Student Concerns

Faith Issues	CP (N=18)	Honors (N=27)
None	10	10
Relating deep time to Genesis/7 day creation	4	2
This has helped strengthen my faith	0	1
Did God create distinct species as we see them now, or do they change over time?	1	7
What is the role of God in the world?		5
How do humans relate to other species?	1	7
How can I believe in evolution if I'm a creationist?	2	0
Science Issues	0	0
Big Ideas	1	0
Homeobox genes	2	4
Big changes (major trends over time)	2	9
Fossils/dating	5	4
Natural selection	1	0
Human-caused mutation	1	1
None	2	3
Start of life	1	2

Unit Test

In the CP class the test average was 81% ($N=20$ as one student was absent), while the average was 86% in Honors ($N=33$). Grade distributions are shown in Figure 17.

The results from the timeline section were low in both classes because some students did not understand the formatting, so the CP students were given a re-test in class, and the Honors students were permitted to take it outside of class time. In both classes, the most frequent wrong answer in the Multiple Choice section was that Darwin did not rely on Mendelian genetics to form his theory. Performance on the questions selected from the SAT II preparation book was not noticeably different from the multiple choice questions from the textbook's test bank.

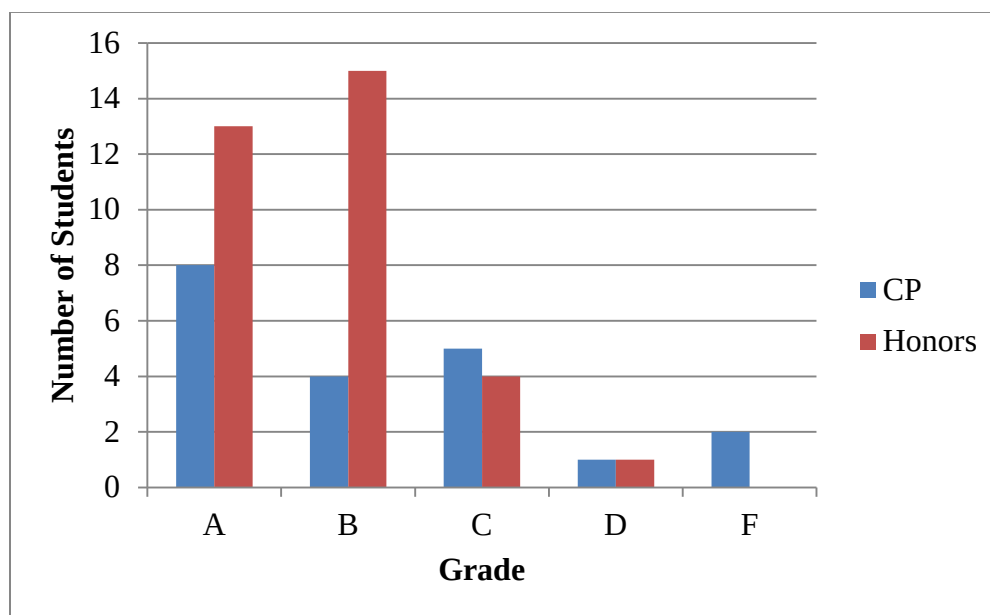


Figure 6. Unit test results for a CP ($N=20$) and Honors Biology ($N=33$).

INTERPRETATION AND CONCLUSION

Several trends were highlighted by this study. First, although the Honors students showed more effort in integrating science into their interpretation of Genesis in

HLDYIG, the prior misconceptions identified in the pre-unit EALS surveys were similar in both classes. These beliefs were then used as the basis for the five Enduring Understandings that were chosen. Second, the results of the unit test and the change noted in the post-unit EALS demonstrated that student understanding of the science occurred. Third, mid-unit reflections, discussions, and the post-unit EALS all demonstrated that many students had moved from simplistic integrations of faith and science to more complex ones.

The first pre-unit activity was the HLDYIG instrument. Because only three students out of the 51 respondents excluded God and Genesis from their understanding of the history of earth, the assumption on which the research project was based was accurate: The vast majority of students face reconciling their faith with science. And since 42 of those students held beliefs that directly contradict modern science, this unit was highly necessary. Several trends from the interviews backed this up as well: Many students came from families or churches that disagree with evolution, and only one student out of the eleven surveyed had had a significant evolution unit in school prior to this.

The fact that more students in the CP class claimed creationist views than the Honors class is consistent with results from HLDYIG, EALS and interviews. These students typically reported they came from conservative churches and families and had little prior exposure to evolution in school. The concentration of these students in the lower-level class could be because students had self-selected not to take an advanced class that would raise more conflicts with their faith, or it could indicate that CP students were less interested in thinking critically about the challenges of integrating a literal

interpretation of Genesis with science that contradicts it. Or perhaps students in the CP classes did not value science as much, and possibly they did not understand science as well as the students in the Honors class. Regardless, from the HLDYIG and EALS results, it was clear that this group was less versed in science and could be more resistant to learning it.

In the Honors class, there were also OEC and YEC students. What was unusual was the popularity of Day/Age creationism. This may be because the simplest way to integrate the fundamental scientific understanding of deep time with the basic stories of Genesis is by stretching the timeline while keeping the understanding of various stories (Adam and Eve, creation events, Noah and a worldwide flood) the same. This might allow students to accept ideas such as an old Earth, radiometric dating, dinosaurs, and the accuracy of the fossil record, but while Honors students might have been open to these ideas, only 42% of the class ($n=11$) rejected the ideas of a young earth. Thus, because many students in both classes held to OEC, YEC, or Day/Age creationism, the same five Enduring Understandings were chosen for both classes.

The first Enduring Understanding, that natural selection would tend to make helpful traits more common over time, was introduced first not only because it was a natural segue from genetics, but because it allowed the introduction of Charles Darwin's theories without focusing on Darwin himself. This was deliberate, as Darwin's name still carries negative connotations within some religious circles, but his science is sound and quite indisputable.

The second Enduring Understanding was chosen to fill in the data that Darwin never knew: that change starts with small changes in DNA, is unpredictable, and has

major physical effects. This was chosen to emphasize that science has progressed a great deal since Darwin, and advances in genetics and genomics have not only supported the idea the organisms change and are from a common ancestor, they have shown how this could happen. Although some students made mention of ID arguments such as irreducible complexity, not much time was spent discussing the implications and limitations of this philosophy, which focuses on creating a black box around unknown mechanisms of change. By focusing on genetic mechanisms of evolution, the class was able to move beyond the reasoning behind ID, without directly labeling it as pseudoscience. Rather than relying on mysterious mechanisms that nobody can understand, changes in organisms come from understandable mutations in DNA.

Enduring Understanding Three was included to challenge the commonly held beliefs in spontaneous creation (including young earth, old earth, and day/age). This EU showed how a species is formed when a group splits off from the main population, which was important because as indicated in the mid-unit reflection cards, students had difficulty accepting that species change and can come from other species. Again, by explaining the mechanisms of speciation, the mystical can be examined rationally.

Because various types of creationism have different explanations for the age of the Earth, significant time was needed to cover evidence that the world of life took a long time to reach its present form. This gave rise to Enduring Understanding Four: The Earth is very, very old. This included explorations of the age of the Earth (including radiometric dating) for the YEC, fossil formation (which also includes radiometric dating) and would have ideally included continental drift. The history of life, and how species unfolded through time, was briefly covered. The age of the Earth and the idea

that organisms appear over a long period of time should have been familiar concepts, but students showed significant struggle with the simple recall needed to complete the timeline on the test.

One main misconception unique to Day/Age creationists is that the sequence of events of creation as presented in Genesis is closely enough aligned to the scientific understanding of the sequence of evolution of organisms, and only the time scale is different. While differences between the Biblical account and the scientific account weren't highlighted, during the timeline activity students were asked to predict the order in which certain organisms appeared during the fossil record. The differences became apparent when they compared their predictions based on the Bible to the scientific account. All of this gave rise to the final Enduring Understanding: Similarities in organisms support the idea of a common ancestor and allow us to build a family tree of life. In order to connect the branches on the tree of life, a follow-up unit on diversity, phylogenetic trees and cladograms would be valuable.

The first main finding of this project was that while both levels of students had different ways of interpreting Genesis, they demonstrated similar general deficiencies in their understandings of science. The second main result was that students in both classes learned the science of evolution, and while the most easily quantifiable results that show this come from the unit test, other sources confirmed this.

With test averages of 81% for CP and 86% for Honors, students showed strong understanding of the questions chosen from the textbook test bank, as well as those from the SAT II sample test. Furthermore, the EALS results showed that both classes

demonstrated a marked increase in understanding of genetics, evolution, and the way science works.

On the topic of the unit test, many students missed the question about Darwin forming the theory of evolution without understanding anything about Mendelian genetics. This may be because relatively little time was spent on the biography and historical aspect of Darwin. This was partly done to sidestep students who have been steeped in the creationist movement, which typically vilifies the character and contributions of the scientist. Instead, his theory of Natural Selection was studied in the context of the Hardy Weinberg theory of genetic equilibrium, which seemed to evade the ire of creationists. Unfortunately, this means that students did not realize the predictive nature of evolutionary theory and the genius of Darwin, who demonstrated an understanding of the principles of genetics independently of Mendel.

Another unexpected result on the test was the poor performance on the timeline. This was included as a simple way for struggling students to get easy points through simple recall, but this proved to be a challenging section. The low performance may have been due to students spending inadequate time on the material, unclear formatting of the timeline on the test (it was vertical instead of the traditional horizontal presentation), or students not expecting a question that required so much recall.

Although the test results are most easily quantifiable, other sources show that learning occurred. Grades from labs, activities and assignments throughout the unit were all A and B work, with the exception of the CP class performance on the activity that dealt with the speciation of Stebbins' salamanders in California. Statements from the EALS exit cards and interviews were telling, as well.

On the EALS exit cards, the most common written response was that eight students noticed they had become more decisive about questions. This seems to reflect that they felt more informed on the topic. One student said, “My scientific views on evolution have become much stronger and more opinionated. I am surprised at some of my answers on evolution. Now I am more educated.” Another said, “I was surprised that I learned a lot since the last time. I changed the way I thought about animals being suitable for the environment and how important it is.” A third said “On the questions that were not opinion, I felt like I knew more. I also picked less "C"'s and had solid opinions.” Other comments more directly addressed areas of learning that had occurred. “It was surprising how ignorant I was towards evolution (and its causes) to natural selection.” Or, “My knowledge on what evolution was changed a lot. Before studying it I never fully understood what evolution was but now I do know. I also never knew what mutations and natural selections were so I never had an opinion about those question [sic], but now I do have opinions about them. Also [the questions about exposure to evolution] changed a lot because over the course of studying evolution I read and watched movie about evolution more than I ever had.”

During interviews, students pointed to a variety of activities that they enjoyed most or learned from the most; however, some of these were contradictory. Two students enjoyed learning about the millions of years of deep time, while another found it challenging to remember the order in which organisms appeared. And three students in the Honors class most liked the Hardy-Weinberg equilibrium section, because it was mathematical and clear-cut.

The final major result of this project was to have students think in more complex ways about relating science with their faith. This goal is the most difficult to quantify, but the trend is seen in several areas. First, consider the mid-unit exit card question asking if students had come across any major problems or irreconcilable differences between science and their faith. Ten of 18 CP students (typically the more conservative group) stated they had come across no such issues, and ten of the 27 Honors students stated the same. Of the remaining responses, only two students (both in the CP class) mentioned wholesale difficulty with evolution because they identify as [young earth] creationists. The remainder of the responses showed students engaging in the topic, struggling with particular issues, rather than outright rejection of evolution.

Second, the increased complexity of student thought on evolution was evidenced by the EALS results. Fewer people had moral or social objections to evolution, and more people trusted science. These trends show a willingness to engage the topic of evolution, rather than giving in to a kneejerk reaction to dismiss it. There were fewer people who identified as YEC or ID adherents as well, which indicates students were no longer content with a literal reading of Genesis, but were willing to include aspects of scientific understandings on the history of the earth such as deep time, change in populations, or speciation, none of which are part of the creation story.

Student responses when comparing their pre- and post-unit EALS responses also bore this out. “My answers on the probability of evolution changed by the greatest factor. What shocked me was that I wasn't exactly open minded when I took the test the first time. When I took it again, I had been able to ponder the questions that I had automatically answered unthinkingly.” Another student said, “Basically, all of mine are

different. I have a much more scientific view and read the Bible less literally.” A third student showed that his earlier, easier assumptions were no longer satisfying. “After [the unit I had] a better understanding of the mechanics of evolution, but less sure of how it should relate to Christianity (particularly Genesis). Before [I was] less opposed to irreducible complexity than after. Understanding Hox genes led to more disagreement with irreducible complexity.”

Third, student interviews showed that students were thoughtfully engaging the topic. Some students had trouble with major changes, but no students rejected evolution outright. Nobody indicated a crisis that caused them to lose their faith, and while some still identified specific scientific understandings they could not accept, most thought aspects of evolution were at least compatible with faith. One student said that before the unit, he never gave evolution a chance, but now he accepts parts of it as viable. Another said, “I feel like I can still be faithful, but at the same time believe that evolution is possible. Before, I didn’t think this was possible.” Another said this unit made him rethink his previous views on creation, and how to mix the two [faith and science] together.

Fourth, although the instruments did not directly measure Perry’s stages of moral and ethical development, there is significant evidence to suggest that students started out at earlier stages, such as following the word of authorities or starting to rebel against these authorities, and ended up at later stages, such as recognizing that some arguments are superior to others. Some statements from the exit cards and interviews showed initial close-mindedness to evolution but eventual open-mindedness to certain aspects, and even acceptance of aspects of evolution because it made logical sense. There was limited data

indicating if students reached the final stage, being able to defend one's own opinion while respecting others.

Finally, it is important to acknowledge that not all students were convinced that evolution was important or true, and not all aspects of understanding increased. Even after the unit, a third of the CP students identified with YEC statements and ID statements, and a quarter of Honors students did. A quarter of CP students had moral and social objections to evolution, and a third of Honors students had social objections to the theory. A quarter of both classes still distrusted the scientific enterprise. As one student said in his post-unit EALS, "I have shown a greater understanding of evolutionary processes discern it from religion. However, I believe that evolution is more of a belief currently due to lack of conclusive evidence. I do profess my faith in Christianity and that holds true in my answers compared to the beginning, when I was a bit unsure." And in the interviews, one CP student said that she was a day/age adherent before, and still was after, while an Honors student said that although she could accept some change in organisms, major changes like the start of each kingdom and the origin of humans must have been by special acts of creation.

One of the undesired changes was that more Honors students were concerned about the social implications of evolution after the treatment than before. This was specifically related to three questions, "The theory of evolution has contributed to an increase in abortion," "The theory of evolution has contributed to racism," and "The theory of evolution has contributed to genocide (the deliberate killing of a group based on nationality, race, politics, or culture)." The fact that more Honors students agreed with this after the treatment may be because some students are enrolled in the history course

on world wars, which covers genocide and the Nazi concentration camps. Depending on how the teacher approaches the topic, it may become linked in student's minds to natural selection or survival of the fittest.

Another of the undesired changes was the increase in evolutionary misconceptions in the CP class. This was the result of two misconceptions, "Species evolve to be perfectly adapted to their environment," and "Evolution is a linear progression from primitive to advanced species." Both of these misconceptions had been discussed in class and agreement was expected to decrease.

The focus question was to see how effective a scientifically rigorous, religiously sensitive, inquiry-based evolution unit could be in a Christian school. From traditional assessments such as homework, labs, and unit tests, the students demonstrated a good grasp of the material in the evolution unit. From the EALS, students demonstrated literacy of evolution improving in all categories. And from exit cards, interviews, and the EALS, students demonstrated attitudes toward evolution improving, and acceptance of non-scientific ideas decreasing.

The three key aspects of the unit—being scientifically rigorous, religiously sensitive, and using inquiry-based teaching—worked very well together. The result was a unit that was not dogmatic, but showed strong evidence to students in a non-threatening environment, allowing them to make their own conclusions. There were no anti-evolution flare-ups or parent complaints about the content, and while not all students accepted all aspects of the scientific understanding of the history of the universe, attitudes and literacy improved.

VALUE

There are several valuable concepts to be learned from the research population already at this stage of the study. First, almost all (94%) of students in the research population included Biblical understandings when they thought about the history of the universe. Second, students in the lower-level class were more likely to reject most or all scientific understanding of natural history, and even in the higher-level class where more students try to incorporate science, the majority (82%) held views contradictory to that of science. Third, a thorough, well-planned unit can help students understand and accept the findings of science, integrating it with their faith.

The action research process thus impacted me as a teacher from the first pre unit HLDYIG assessment. I became more aware of my students' beliefs, and was able to construct the unit to be respectful of them, while at the same time challenging them with current models, theories, and data. The process has also made me more aware of the many resources available on teaching evolution, and I am becoming more proficient as a teacher who uses inquiry-based lessons.

I believe there were several things about the way this unit was taught that lead to its success. First, I was intentionally non-confrontational with students and was sympathetic to their struggle to integrate what they had learned in church or at home with what they were learning in science. Rather than dogmatically marching through the textbook, telling them what to believe, I acknowledged what points were difficult to grapple with. I would say something like, "It's confusing to understand how the Bible says the Earth is 6000 years old, while science tells us it is billions of years old. Why would scientists think this? It's not just because they hate religion, it's because it's the

best explanation of what they see.” And I gave them the evidence that has lead scientists to their understandings, rather than the answers. Letting students analyze data is, after all, the key in constructivist learning.

Secondly, I didn’t present the unit as a package deal that they needed to trade in for their religion—“This is Science, and you must choose between all of this, or your faith.” Rather, I let them look at five key understandings about evolution with the idea that these would provide the foundation, or the roots of knowledge and curiosity that would allow them to dig deeper as they grow. If there was an area they could not accept, that is fine for now; it was more important for them to become open to the idea of evolution than it was to accept every detail.

Thirdly, when possible I avoided the areas of evolution where creationist advocates have created their arguments. These areas included Darwin and his personal life, the origin of humans (except when brought up by students), *Archaeopteryx*, Haeckel’s embryos, and the Miller-Urey experiment on the origins of life. Instead, I used different examples or approaches. For instance, *Archaeopteryx* has been used as an example of a transitional fossil for years, but it is not the only or even the best example, so I used whale species. I also relied more on current advances in evolutionary thinking that are harder to brush away—master control genes, molecular homologies, and current examples of speciation or appearance of new traits.

The value of this study goes beyond just this classroom. This project has shown that evolution can be taught in Christian schools with success, where success is measured both in student understandings of science, as well as in integration of faith and learning. This project showed how misconceptions and resistance in the target audience can be

identified and addressed, and how success can be measured. Not only could this process be directly applied in other Christian schools, it could be modified to be of significant value in public schools. Although public school teachers cannot address the specific religious areas of resistance that their students may bring, they will teach the concepts better with an acknowledgement that nearly half the American population shows some resistance to these ideas. And teaching science as a process of questioning, rather than a series of answers, is the ideal we strive for in creating the next generation of scientists.

Parent and student objections to the content of the evolution unit were expected, but none were demonstrated. However, during the months prior to the unit, there was significant institutional resistance to the student-centered and inquiry-based assignments that were tested. Experimenting with flipped classroom and self-guided activities resulted in student feedback that they “weren’t being taught,” and parent comments including, “Why not just pay the person who made the YouTube video [that was assigned for homework]?” One possible cause for these reactions is an institutional expectation—by students, administrators, and parents—of direct instruction and traditional assessments. Despite the body of research and the consensus of educational experts that lecture is a poor format for genuine learning, and that modes of education that make the student an active learner are far superior, these apparently cause discomfort. This may be because it takes time for students to learn the new format, or it may be because the teacher has to learn the new format. Building constructivist lessons is much more difficult than preparing a lecture, and being engaged and active through the process is more difficult than taking notes. And this might be the underlying reason for the student frustrations--students can no longer passively coast through class and cram the night

before the test; they are forced to regularly and actively participate. Educators looking to pilot these methods of teaching should be cautious, be sure to let students know what expectations are, and be sure they have the support of the school.

Finally, although the unit showed strong success, it is important to note that some students remain unconvinced. However, one may hope the unit was able to plant seeds that will continue to grow, seeds of knowledge that will prepare students to continue the process of learning science and of evaluating their faith.

REFERENCES CITED

- Alters, B. & McComas, W. (Sep 1994). Punctuated Equilibrium: The Missing Link in Evolution Education. *American Biology Teacher*, 56(6), 334-341.
- Alters, B. & Nelson, C. (Oct 2002). Perspective: Teaching Evolution in Higher Education. *Evolution*, 56(10), 1891-1902.
- Anderson, D, Fisher, K, and Norman, G. (2002). Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching*, 39, 952-978.
- Baum, D, Dewitt-Smith, S, and Donovan, S. (2005). Supporting Online Material for The Tree-Thinking Challenge. *Science*, 310, 979 (2005).
- Beckwith, F. (2003). Science And Religion Twenty Years After McLean v. Arkansas: Evolution, Public Education, And The New Challenge of Intelligent Design. *Harvard Journal of Law & Public Policy*, 26(2), 455-500.
- Catley, K. (Sep 2006). Darwin's Missing Link—a Novel Paradigm for Evolution. *Science Education*, 90(5), 767-783.
- Cotner, S., Brooks, D., & Moore, R. (Mar 2010). Is the Age of the Earth One of our “Sorest Troubles?” Students’ Perceptions About Deep Time Affect Their Acceptance of Evolutionary Theory. *Evolution*, 64(3), 858-864.
- Dobzhansky, T. (1973). Nothing in Biology Makes Sense Except in the Light of Evolution. *American Biology Teacher*, 35, 125-129.
- Farrel, J. (Nov 2010). Creationism still alive and kicking in US public schools. *New Scientist*, 208(2783), 01-01.
- Flammer, L. (Mar 2006). The Evolution Solution: Teaching Evolution Without Conflict. *NABT Journal*, 2006(3), Online Article.
- Fowler, S. & Meisels, G. (Feb 2010). Florida Teachers' Attitudes About Teaching Evolution. *The American Biology Teacher*, 72(2), 96+.
- Hawley, P. et al. (Mar 2011). What's the Matter with Kansas?: The Development and Confirmation of the Evolutionary Attitudes and Literacy Survey (EALS). *Evolution Education Outreach*, 4, 117-132.
- McComas, W. (Jan 1996). Ten Myths of Science: Reexamining What We Think we Know.... *School Science & Mathematics*, 96(1), 10.

- Meadows, L. (2009). *The Missing Link: An Inquiry Approach for Teaching All Students About Evolution*. Portsmouth NH: Heinemann.
- Moore, R. (July 2005). Why Many Biology Teachers Aren't Teaching Evolution. *The Chronicle of Higher Education*, 51(46).
- Nadelson, L. and Southerland, S (2010). Development and Preliminary Evaluation of the Measure of Understanding of Macroevolution: Introducing the MUM. *The Journal of Experimental Education*, 2010, 78, 151-190.
- Nehm, R. (Aug 2006). Faith-Based Evolution Education? *BioScience*, 56(8), 638.
- Padian, K. (Feb 2008). Improving Evolution Education. *Geotimes*, 53(2), 59-59.
- Padian, K. (Mar 2010). How to Win the Evolution War: Teach Macroevolution! *Evolution Education Outreach*, 2010, 3, 206-214.
- Rapaport, W. (Oct 2010). *William Perry's Scheme of Intellectual and Moral Development*. Retrieved February 21, 2003, from <http://www.cse.buffalo.edu/~rapaport/perry.positions.html>
- Rutledge, M. & Warden, M. (Jan 1999). The Development and Validation of the Measure of Acceptance of the Theory of Evolution Instrument. *School Science and Mathematics*, 99(1), 13.
- Schultheis, M. (Feb 2010). Education's Missing Link: How Private School Teachers Approach Evolution. *American Biology Teacher*, 72(2), 91-94.
- Scott, E. (Dec 2000). The Creation/Evolution Continuum. Retrieved Nov 18, 2011, from <http://ncse.com/creationism/general/creationevolution-continuum>
- Skeptical Inquirer. (Apr 1998). National Academy of Sciences: Evolution Must be Taught if Students are to Understand Modern Biology. *Skeptical Inquirer*, 22(4), 5+.
- Vazquez, Jose. (Spring 2006). High School Biology Today: What the Committee of Ten Did Not Anticipate. *Cell Biology Education—Life Science Education*, 5(1), 29-33
- Verhey, S. (Nov 2005). The Effect of Engaging Prior Learning on Student Attitudes Toward Creationism and Evolution. *BioScience*, 55(11), 996+.
- Wiles, J. (Mar 2003). A Threat to Geoscience Education: Creationist Anti-Evolution Activity in Canada. *Geoscience Canada*, 33(3), 135+.

APPENDICES

APPENDIX A

HLDYIG

Follow the questions below to see if you fit in with one of the common interpretations of the first chapters of Genesis. Do not put your name on this sheet, but please indicate which class you are in, and if you are willing, the church you attend. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

Class:

Church:

Data Collection:

1. The earth is about 6000 years old.
 - a. If YES, **Young Earth Creationism**. The Bible, including the story of Creation, and all the timelines and genealogies presented, are to be taken literally.
 - b. If NO, go to question 2.
2. The earth is more than 6000 years old, but took only 6 days to reach its present form.
 - a. If YES, **Old Earth Creationism**. The Creation story is to be taken literally, but the timelines and genealogies presented may not be sequential.
 - b. If NO, go to question 3.
3. The earth took more than 6 days to reach its present form; the extra time comes from a gap between Genesis 1 and 2.
 - a. If YES, **Gap Creationism**. The first creation story in Genesis 1 happened, but there was a period of time before the second creation story in Genesis 2, with Adam and Eve.
 - b. If NO, go to question 4.
4. The earth took a long time to reach its present form; the six "days" of creation represent longer eras of time.
 - a. If YES, **Day/age Creationism**. The sequence of events is correct, but the time periods ("days") involved may have been thousands or hundreds of thousands of years. Once created, species stayed the same. And once the six periods of time were over, no new species were created.
 - b. If NO, go to question 5.
5. New species appear throughout the long fossil record, but these came from special miracles or acts of creation.
 - a. If YES, **Progressive Creationism**. The creation story is rich in symbolism but not meant to be taken literally. The earth is very old and new organisms appeared over millions of years by special acts of creation.
 - b. If NO, go to question 6.

6. Most species are related by common ancestors, but some species or structures required special acts of creation.
 - a. If YES, **Intelligent Design**. The creation story is mostly symbolic, but it reveals some truths about God. The earth is approximately 4 billions of years old and species appear both by evolution, as well as special acts of creation. Similarly, there are structures that are “irreducibly complex” that couldn’t have evolved and were created by special acts.
 - b. If NO, go to question 7.
7. God set up the conditions for the start of the universe and lets it run by natural laws, but interacts with humans on a relational level.
 - a. If YES, **Theistic Evolution**. The creation story is purely symbolic; it gives credit to God but does not have a historical basis. God created the universe and allows natural laws--what appears to be random chance—to govern it. However, he has a special relationship with humans and interacts with them.
 - b. If NO, go to question 8.
8. God set up the conditions for the start of the universe and lets it run by natural laws, and does not interact with humans.
 - a. If YES, **Deism**. The creation story is a symbolic story. There is a God who created the universe, but he is not involved in how things unfold.
 - b. If NO, go to question 9.
9. God did not set up the conditions for the start of the universe; everything is the result of random motion of particles.
 - a. Scientific Naturalism. The creation story is a myth, like the creation myths of many other people-groups. All that exists is the physical universe, which came to being purely through the random motion of particles.

If your understanding of the origin of the universe do not fall within one of the categories above, please describe it here:

APPENDIX B

EALS

Please rate each of the following statements on the 7 point scale provided, where 1=Strongly Disagree and 7= Strongly agree. Participation in this research is voluntary and participation or non-participation will not affect a student's grades or class standing in any way.

1. People who accept evolution do not believe in God.
2. The earth isn't old enough for evolution to have taken place.
3. Intelligent Design should be taught in science classes.
4. The theory of evolution has contributed to an increase in abortion.
5. Evolutionary theorists believe that if something is natural then it is good or right.
6. People who accept evolution as fact are immoral.
7. There was a time when humans and dinosaurs lived on earth together.
8. There is scientific evidence that humans were created by a Supreme Being or intelligent designer.
9. Complex biological systems cannot come about by slight successive modifications (ie they are reducibly complex).
10. The theory of evolution has contributed to genocide (the deliberate killing of a group based on nationality, race, politics, or culture).
11. Evolutionary theorists believe that inevitable inequality is morally acceptable.
12. If you accept evolution, you really can't believe in God.
13. Present animal diversity can be explained by the Great Flood.
14. There is no evidence that humans evolved from other animals.
15. Evolution is a theory in crisis.
16. The theory of evolution has contributed to an increase of euthanasia (the act of killing someone painlessly or allowing to die to stop the suffering; also called mercy killing)
17. Evolutionary theorists believe that because the strongest survive, it's a mistake to help the weak.
18. Darwin strips meaning from our lives.
19. A majority of present-day geological features are the result of the Great Flood.
20. The theory of evolution is a matter and faith and belief, just like religion.
21. Evolution violates the 2nd law of thermodynamics (that systems move toward disorder, not order).
22. The theory of evolution is capable of being scientifically tested.
23. The available data are ambiguous as to whether evolution actually occurs.
24. If human beings are solely the product of chance, meaningless forces, then one can rightly question the value of man, the significance of life, and whether there is any basis for morality.
25. Adam and Eve of Genesis are our universal ancestors of the entire human race.
26. Humans were specially designed.

27. Natural selection cannot create complex structures; it is like a tornado blowing through a junkyard and creating a 747.
28. The vast majority of scientists accept evolution as a scientifically valid theory.
29. I read the bible literally.
30. All modern species of land vertebrates are descended from those original animals on the ark.
31. There are no transitional fossils (remains of life forms that illustrate an evolutionary transition).
32. The theory of evolution has contributed to racism.
33. Contemporary methods of determining the age of fossils and rocks are untrustworthy.
34. People can be moral and believe in evolution at the same time.
35. God created humans in their present form.
36. It is statistically impossible that life arose by chance.
37. Applying the theory of evolution to human affairs implies we are not fully in control of our behavior.
38. The data used to support evolution is untrustworthy.
39. Humans never could have been related to apes.
40. The theory of evolution does not explain similarities or differences between chimps and humans.
41. The theory of evolution has contributed to sexism.
42. The theory of evolution is capable of explaining the diversity of life.
43. Humans share a majority of their genes with chimpanzees.
44. Humans share more than half of their genes with mice.
45. Ordinary tomatoes do not have genes, whereas genetically modified tomatoes do.
46. Today it is not possible to transfer genes from one species of animal to another.
47. All plants and animals have DNA.
48. Humans have somewhat less than half of the DNA in common with Chimpanzees.
49. You can see traces of our evolutionary past in human embryos.
50. Humans developed from earlier life forms.
51. Mutations are never beneficial.
52. In most populations, more offspring are born than can survive.
53. Individuals better suited to the environment are more likely to survive and reproduce.
54. Individuals don't evolve, species do.
55. Individuals act for the good of the species.
56. Evolution is "survival of the fittest".
57. Natural selection is a random process.
58. Natural selection is synonymous with (means the same as) evolution.

59. Characteristics acquired during the lifetime of an organism are passed down to that individual's offspring.
60. Mutations can be passed down to the next generation.
61. Increased genetic variability makes a population more resistant to extinction.
62. Species evolve to be perfectly adapted to their environment.
63. Evolution means progress towards perfection.
64. The more recently species share a common ancestor, the more closely related they are.
65. Evolution is a linear progression from primitive to advanced species.
66. Natural selection is the only cause of evolution.
67. Natural selection causes mutations.
68. Mutations occur all of the time.
69. Good theories can be proven by a single experiment.
70. For scientific evidence to be deemed adequate, it must be reproducible by others.
71. Scientific ideas can be tested and supported by feelings and beliefs.
72. Scientific explanations can be supernatural.
73. Theories requiring more untested assumptions are generally better than theories with fewer assumptions.
74. Good theories give rise to testable predictions.
75. The theory of evolution helps us understand plants.
76. Evolutionary theory is highly relevant for biology.
77. The theory of evolution helps us understand animals.
78. The theory of evolution helps us understand human origins.
79. For explaining human behavior, evolutionary theory is irrelevant.
80. Evolutionary theory is highly relevant for social sciences (eg anthropology, psychology, sociology).
81. Evolutionary theory is highly relevant for the humanities (eg history, literature, philosophy).
82. Evolutionary theory is relevant to our everyday lives.
83. The theory of evolution helps explain the world as it is in the present.

For the following questions, please rate each of the following statements on the 5 point scale provided, where 1=Never, and 5=Frequently.

84. I've visited evolution related websites (eg Science Daily, Pharyngula, Edge.org)
85. I've watched evolution related videos on the web (eg Ted.com, YouTube)
86. I've read science magazines featuring evolution (eg Discover, National Geographic, Nature)
87. I've watched nature shows that discussed evolution (eg PBS/Nova, Discovery, National Geographic)

- 88. I have visited natural history museums on field trips or with family.
- 89. I've read evolution related books (eg by Richard Dawkins, EO Wilson, Steven Pinker)
- 90. As a child, I attended science and nature camps (eg Outdoor Ed Lab, local nature centers or zoos)

Thematic Breakdown of Questions:

Intelligent Design Beliefs: 8, 14, 20, 26, 31, 36, 40, 9, 15, 21, 27
 Young Earth Creationist Beliefs: 29, 35, 39, 2, 7, 13, 19, 25, 30
 Moral Objections: 1, 6, 12, 18, 34*
 Social Objections: 32, 37, 41, 4, 10, 16
 Distrust of the Scientific Enterprise: 33, 38, 42*, 5, 11, 17, 23
 Relevance of Evolutionary Theory: 75, 76, 77, 78, 79*, 80, 81, 82, 83
 Genetic Literacy: 43, 44, 45*, 46, 47, 48*, 49 50, 51*
 Evolutionary Knowledge: 52, 54, 60, 61, 64, 66*, 68
 Evolutionary Misconceptions: 57, 58, 59, 62, 63, 65, 67
 Knowledge about the Scientific Enterprise: 69*, 70, 71*, 72*, 73*, 74
 Self-Exposure to Evolution: 84, 85, 86, 87, 89
 Youth Exposure to Evolution: 88, 90

*These questions are reverse scored.

APPENDIX C

EXEMPTION REGARDING INFORMED CONSENT

I, Dr. Kim Winsor, Principal of Colin Powell Middle School, verify that the classroom research conducted by Alan Kalf is in accordance with established or commonly accepted educational settings involving normal educational practices. To maintain the established culture of our school and not cause disruption to our school climate, I have granted an exemption to Alan Kalf regarding informed consent.

__Kim Winsor_____

(Signed Name)

__Kim Winsor_____

(Printed Name)

(Date)

APPENDIX D

ASSIGNMENTS AND ASSESSMENTS

	Enduring Understanding 1: If a trait is helpful, it will become more common over time.	Enduring Understanding 2: Changes start with small changes in DNA, and randomly but have a major effect on a physical level.	Enduring Understanding 3: A new species is formed when a group splits off the main group.	Enduring Understanding 4: The earth is very, very old.	Enduring Understanding 5: Similarities in organisms support the idea of a common ancestor, and allow us to build a family tree of life
Engage	Look at these pictures of ancient crops: can you tell what these have been changed into through selective breeding?	Youtube videos on Sickle cell anemia	Pictures of dogs as a kick-off to discussion: what is a species?	Timeline activity part 1: preconceptions about sequence and age of organisms	Put up pictures of members of a family on board: which people are closest related, and which are more distant related?
Explore	PBS Hairless Rabbit activity on Natural Selection	Sickle Cell anemia activity	Activity on Stebbins' Salamanders in California (Berkeley)	Timeline activity part 2: comparing preconceptions to scientific understandings	Phylogenetic trees activity
Explain	Notes and reading on Natural Selection and Hardy Weinburg equilibrium	Notes, PBS video, HHMI video, and reading on DNA mutation, homeobox genes, and embryology	Notes and reading on speciation; online speciation tutorial (Berkeley)	Notes and reading on radiometric dating, history of earth	Notes and reading on phylogenetic trees, homologous structures (Berkeley)
Elaborate	Hardy Weinberg worksheet	PBS video and worksheet on HIV mutation	Canine family tree activity done in EU 5	Determining Age of Rocks and Fossils activity	Dog/Wolf/Canine family tree activity
Evaluate	Writing about potential causes for change in an imaginary population	Sickle Cell CAT, worksheet extension on pesticide resistance and GMO potatoes	Creative writing assignment: write about a speciation event in humans	Summary questions on timeline activity. Do an artistic representation of a historical period (optional, extra credit).	Reflection paper for dog/wolf/canine tree lab

APPENDIX E

CP UNIT TEST

Name: _____ Class: _____ Date: _____

ID: A

CP Evolution test**Multiple Choice***Identify the choice that best completes the statement or answers the question.*

- _____ 1. Mutation is critical to the process of evolution because changes in _____ increase variation in populations.
 - a. proteins
 - b. amino acids
 - c. alleles
 - d. phenotypes
- _____ 2. According to the Hardy-Weinberg model, one would predict
 - a. allele frequencies are stable over generations.
 - b. as allele frequencies increase, genotype frequencies decrease.
 - c. genotype frequencies are unstable over time.
 - d. allele frequencies are unstable over generations.
- _____ 3. The main factors that cause change in gene pools are
 - a. natural selection, genetic drift, mutation, and gene flow.
 - b. random assortment, genetic drift, microevolution, and gene flow.
 - c. natural selection, mutation, crossing over, and genetic drift.
 - d. gene flow, mutation, crossing over, and independent assortment.
- _____ 4. Genetic drift can have a substantial effect on small populations
 - a. but little effect on large populations.
 - b. but has more effects on large populations.
 - c. but has no effect on other populations.
 - d. but has large effects on large populations.
- _____ 5. Evolution would probably occur at a maximum rate in
 - a. two interacting populations that have low mutation rates.
 - b. a small population with a low mutation rate and a larger population.
 - c. two interacting populations that have high mutation rates.
 - d. a population with a high mutation rate and a smaller population.
- _____ 6. Biologists do not attempt to debate the origin of life by creation simply because
 - a. there are too many different creation accounts.
 - b. this is a religious matter.
 - c. it is not a testable hypothesis.
 - d. it has been disproved already.
- _____ 7. The oldest fossil remains that have been verified resemble modern
 - a. one-celled fungi.
 - b. one-celled algae.
 - c. bacteria.
 - d. viruses.
- _____ 8. The best current estimate is that Earth formed about
 - a. 4.6 billion years ago.
 - b. 3.0 billion years ago.
 - c. 4.0 billion years ago.
 - d. 3.6 billion years ago.
- _____ 9. Scientists have measured the rates at which various _____ decay for dating of rocks and fossils.
 - a. elements
 - b. minerals
 - c. radioactive isotopes
 - d. inert gases

Name: _____

ID: A

- ____ 10. Most rocks contain too _____ with carbon-14 dating techniques.
- little nitrogen-14 to date
 - little carbon and are too old to date
 - much nitrogen-14 to date
 - much carbon and are too young to date
- ____ 11. An important distinction in the definition of a species is that members of different species do not
- live in the same location.
 - produce offspring under any circumstances even when they are closely related.
 - breed and produce fertile offspring under natural conditions.
 - do not live in the same evolutionary time period.
- ____ 12. Collections of fossils
- provide clues about early ancestry.
 - are no longer useful for taxonomy.
 - cannot be dated for evolutionary study.
 - generally do not agree with evolutionary evidence from other sources.

Data Table**Title:** Traits of Plants

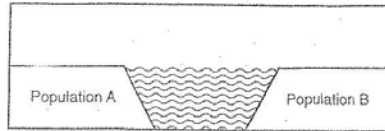
	tiger lily	rose	white pine	sensitive fern	polytrichum moss
Traits					
Flowers	✓	✓	X	X	X
Seeds	✓	✓	✓	X	X
Vascular tissue	✓	✓	✓	✓	X

Note: ✓ = present, X = absent.

Figure 18.02

- ____ 13. Refer to Figure 18.02. How many traits do the tiger lily and white pine have in common?
- 0
 - 1
 - 2
 - 3
- ____ 14. In general, the lower the rock layer,
- the younger the fossils.
 - the less preserved the organisms.
 - the more complex the organisms were.
 - the fewer the differences between species.
- ____ 15. In order to support his theory, Darwin did *not* use
- Mendelian genetics.
 - the fossil record.
 - results from breeding domestic animals.
 - comparative anatomy.

16. A population originally inhabiting the entire area shown on the accompanying diagram has become separated into two populations, A and B, by a barrier (water).



If the environment inhabited by population A undergoes severe changes and the environment of population B does not, which of the following will most likely be true about the rate of evolution of population A?

- (A) It will be consistently slower than that of population B.
 - (B) It will be consistently faster than that of population B.
 - (C) It will be the same as that of population B.
 - (D) It will be slower at first and then faster than that of population B.
 - (E) It will depend on the rate of evolution of population B.
17. Although the island of Madagascar is separated from Africa only by a narrow strait, many plants and animals common on the mainland are unknown on the island. What principle does this fact illustrate?
- (A) Incomplete dominance
 - (B) Independent assortment
 - (C) Evolutionary equilibrium
 - (D) Evolution in isolated populations
 - (E) Ecological succession
18. The most likely explanation for the presence of useless hipbones in the whale is that
- (A) the whale is descended from the coelocanth
 - (B) the whale is descended from an ancestor that used hipbones
 - (C) all vertebrates have hipbones
 - (D) the comparative anatomy of the whale is like that of any other water animal
 - (E) all vertebrates have four limbs

19. A popular supposition about the extinction of dinosaurs at the end of the Mesozoic Era postulates that an asteroid smashed into earth, causing such catastrophic environmental changes that the dinosaurs died off in a relatively short time, thus changing the course of evolution. This concept is an example of

- (A) the theory of gradualism
- (B) the theory of punctuated equilibrium
- (C) the heterotroph hypothesis
- (D) geographic isolation
- (E) the Hardy-Weinberg Principle

20. Different strata of rock in an undisturbed region are found to contain two different fossils: A and B. Fossil A is located in the layer of rock above the layer with fossil B. Which of the following statements is most likely true?

- (A) Fossil B is older than fossil A.
- (B) Fossil A is older than fossil B.
- (C) Fossil A is that of an organism that evolved from fossil B.
- (D) Fossil B is that of an organism that evolved from fossil A.
- (E) Fossils A and B are closely related and evolved from a common ancestor.

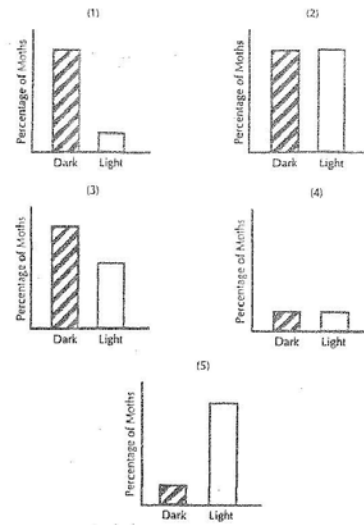
21. The oldest known dinosaur fossil, *Eoraptor*, was found in Argentina embedded in rocks near the Andes mountain. Paleontologists estimate that this early dinosaur lived about 225 million years ago. This fossil was probably formed in

- (A) igneous rock
- (B) a glacier
- (C) sedimentary rock
- (D) amber
- (E) molten lava that cooled

There are two forms of the peppered moth (*Biston betularia*), one dark in color and one light. Scientists observed that in the industrial area of Manchester, England, the originally prominent light form was replaced by the dark form between the years 1848 and 1895. At first, there were only light forms; later, the dark form comprised 98 percent of the total population.

A scientist explained this evolutionary change as follows: The moths rest on tree trunks during the day, and through their protective coloration avoid being seen and eaten by insectivorous birds. In the earlier years, before 1848, any dark forms were conspicuous on the light-colored tree trunks and were easily found by birds. With the coming of many factories after 1848, tree trunks became blackened by the soot given off in chimney smoke. Then the dark forms of moths resembled the background more closely, while the light forms stood out and were easily seen, and eaten, by the birds.

Use the graphs shown on the following page to answer questions 22-26



22. Which graph represents the original populations of the peppered moth?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

23. Which graph represents the moth population after the coming of the factories?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

24. The rural area of Dorset, England, has no factories, and the tree trunks are light in color. In a scientific study, equal numbers of the dark and light forms of the moth were released into the area. Which graph represents the percentages of the surviving moths?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5

25. Which of the following offers the best explanation for the change in moth color after 1848?

(A) Inheritance of acquired characteristics
(B) Gene mutations caused by the soot
(C) Natural selection of favorable variations
(D) Lamarck's theory of evolution
(E) Ingestion of the soot particles

26. What question would scientists need to answer in order to determine whether the two forms, light and dark, of the moth have become different species?

(A) Are the two forms the same size?
(B) Do the dark moths fly more frequently during the day than the light moths?
(C) Do light moths fly more frequently during the day than the dark ones?
(D) Can the two forms interbreed?
(E) Do the two forms feed on different food?

According to the theory of natural selection and the Hardy-Weinberg theory, undesirable traits should become less common over time.

- a) Explain why this is (3)
- b) Use THREE genetic diseases that were presented. For each, explain what they are, and why these diseases are still present in the human population, even though natural selection and Hardy-Weinberg theory suggest that they should be eliminated.

Use the time line below to explain what happened at each of these key dates (5). Then, describe what the biological communities were like (plants, animals, significant first events) in each of the intervening time periods (10).

Present time

65 MYA

245 MYA

543 MYA

3800 MYA

4600 MYA

APPENDIX F

HONORS UNIT TEST

Name: _____ Class: _____ Date: _____

ID: A

Honors Evolution test**Multiple Choice***Identify the choice that best completes the statement or answers the question.*

- _____ 1. What allows populations to adapt to new environmental conditions?
 - a. competition
 - b. variation
 - c. genotypes
 - d. genetics
- _____ 2. Mutation is critical to the process of evolution because changes in _____ increase variation in populations.
 - a. proteins
 - b. amino acids
 - c. alleles
 - d. phenotypes
- _____ 3. According to the Hardy-Weinberg model, one would predict
 - a. allele frequencies are stable over generations.
 - b. as allele frequencies increase, genotype frequencies decrease.
 - c. genotype frequencies are unstable over time.
 - d. allele frequencies are unstable over generations.
- _____ 4. People with sickle-cell anemia have a(n)
 - a. homozygous genotype.
 - b. heterozygous genotype.
 - c. physical characteristic.
 - d. environmental factor.
- _____ 5. A carrier of the sickle-cell trait has a(n)
 - a. homozygous genotype.
 - b. heterozygous genotype.
 - c. physical characteristic.
 - d. environmental factor.
- _____ 6. Malaria is the _____ involved in sickle-cell diseases.
 - a. homozygous genotype
 - b. heterozygous genotype
 - c. physical characteristic
 - d. environmental factor
- _____ 7. The main factors that cause change in gene pools are
 - a. natural selection, genetic drift, mutation, and gene flow.
 - b. random assortment, genetic drift, microevolution, and gene flow.
 - c. natural selection, mutation, crossing over, and genetic drift.
 - d. gene flow, mutation, crossing over, and independent assortment.
- _____ 8. Gene flow promotes evolution through
 - a. selective breeding.
 - b. inbreeding.
 - c. migration between gene pools.
 - d. mutations in species.
- _____ 9. Genetic drift can have a substantial effect on small populations
 - a. but little effect on large populations.
 - b. but has more effects on large populations.
 - c. but has no effect on other populations.
 - d. but has large effects on large populations.
- _____ 10. A small new population can have allele frequencies that are very different from its source population due to
 - a. natural selection.
 - b. artificial selection.
 - c. the founder effect.
 - d. gene flow.
- _____ 11. Evolution would probably occur at a maximum rate in
 - a. two interacting populations that have low mutation rates.
 - b. a small population with a low mutation rate and a larger population.
 - c. two interacting populations that have high mutation rates.
 - d. a population with a high mutation rate and a smaller population.

Name: _____

ID: A

- _____ 12. Biologists do not attempt to debate the origin of life by creation simply because
- there are too many different creation accounts.
 - this is a religious matter.
 - it is not a testable hypothesis.
 - it has been disproved already.
- _____ 13. The oldest fossil remains that have been verified resemble modern
- one-celled fungi.
 - one-celled algae.
 - bacteria.
 - viruses.
- _____ 14. Scientists have measured the rates at which various _____ decay for dating of rocks and fossils.
- elements
 - minerals
 - radioactive isotopes
 - inert gases
- _____ 15. Most rocks contain too _____ with carbon-14 dating techniques.
- little nitrogen-14 to date
 - little carbon and are too old to date
 - much nitrogen-14 to date
 - much carbon and are too young to date
- _____ 16. An important distinction in the definition of a species is that members of different species do not
- live in the same location.
 - produce offspring under any circumstances even when they are closely related.
 - breed and produce fertile offspring under natural conditions.
 - do not live in the same evolutionary time period.
- _____ 17. Collections of fossils
- provide clues about early ancestry.
 - are no longer useful for taxonomy.
 - cannot be dated for evolutionary study.
 - generally do not agree with evolutionary evidence from other sources.

Name: _____

ID: A

Data Table**Title:** Traits of Plants

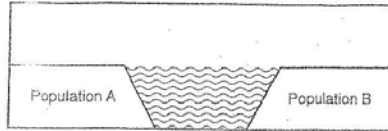
	tiger lily	rose	white pine	sensitive fern	polytrichum moss
Traits					
Flowers	✓	✓	X	X	X
Seeds	✓	✓	✓	X	X
Vascular tissue	✓	✓	✓	✓	X

Note: ✓ = present, X = absent.

Figure 18.02

- ____ 18. Refer to Figure 18.02. How many traits do the tiger lily and white pin have in common?
- 0
 - 1
 - 2
 - 3
- ____ 19. In general, the lower the rock layer,
- the younger the fossils.
 - the less preserved the organisms.
 - the more complex the organisms were.
 - the fewer the differences between species.
- ____ 20. In order to support his theory, Darwin did *not* use
- Mendelian genetics.
 - the fossil record.
 - results from breeding domestic animals.
 - comparative anatomy.
- ____ 21. As a result of continental drift, the sycamore trees of Europe and of North America have been geographically isolated for at least 20 million years. The strongest evidence for placing these two groups in separate species would be
- inability to produce fertile offspring.
 - different allele frequencies.
 - growth in similar habitats.
 - overlapping pollination times.
- ____ 22. New species are formed when two populations
- differ phenotypically.
 - are separated by a geographic barrier.
 - live under different climatic conditions.
 - can no longer interbreed.

16. A population originally inhabiting the entire area shown on the accompanying diagram has become separated into two populations, *A* and *B*, by a barrier (water).



If the environment inhabited by population *A* undergoes severe changes and the environment of population *B* does not, which of the following will most likely be true about the rate of evolution of population *A*?

- (A) It will be consistently slower than that of population *B*.
 - (B) It will be consistently faster than that of population *B*.
 - (C) It will be the same as that of population *B*.
 - (D) It will be slower at first and then faster than that of population *B*.
 - (E) It will depend on the rate of evolution of population *B*.
17. Although the island of Madagascar is separated from Africa only by a narrow strait, many plants and animals common on the mainland are unknown on the island. What principle does this fact illustrate?
- (A) Incomplete dominance
 - (B) Independent assortment
 - (C) Evolutionary equilibrium
 - (D) Evolution in isolated populations
 - (E) Ecological succession
18. The most likely explanation for the presence of useless hipbones in the whale is that
- (A) the whale is descended from the coelocanth
 - (B) the whale is descended from an ancestor that used hipbones
 - (C) all vertebrates have hipbones
 - (D) the comparative anatomy of the whale is like that of any other water animal
 - (E) all vertebrates have four limbs

29. A popular supposition about the extinction of dinosaurs at the end of the Mesozoic Era postulates that an asteroid smashed into earth, causing such catastrophic environmental changes that the dinosaurs died off in a relatively short time, thus changing the course of evolution. This concept is an example of

- (A) the theory of gradualism
- (B) the theory of punctuated equilibrium
- (C) the heterotroph hypothesis
- (D) geographic isolation
- (E) the Hardy-Weinberg Principle

30. Different strata of rock in an undisturbed region are found to contain two different fossils: *A* and *B*. Fossil *A* is located in the layer of rock above the layer with fossil *B*. Which of the following statements is most likely true?

- (A) Fossil *B* is older than fossil *A*.
- (B) Fossil *A* is older than fossil *B*.
- (C) Fossil *A* is that of an organism that evolved from fossil *B*.
- (D) Fossil *B* is that of an organism that evolved from fossil *A*.
- (E) Fossils *A* and *B* are closely related and evolved from a common ancestor.

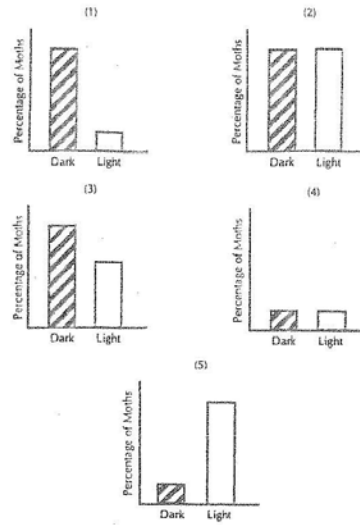
31. The oldest known dinosaur fossil, *Eoraptor*, was found in Argentina embedded in rocks near the Andes mountain. Paleontologists estimate that this early dinosaur lived about 225 million years ago. This fossil was probably formed in

- (A) igneous rock
- (B) a glacier
- (C) sedimentary rock
- (D) amber
- (E) molten lava that cooled

There are two forms of the peppered moth (*Biston betularia*), one dark in color and one light. Scientists observed that in the industrial area of Manchester, England, the originally prominent light form was replaced by the dark form between the years 1848 and 1895. At first, there were only light forms; later, the dark form comprised 98 percent of the total population.

A scientist explained this evolutionary change as follows: The moths rest on tree trunks during the day, and through their protective coloration avoid being seen and eaten by insectivorous birds. In the earlier years, before 1848, any dark forms were conspicuous on the light-colored tree trunks and were easily found by birds. With the coming of many factories after 1848, tree trunks became blackened by the soot given off in chimney smoke. Then the dark forms of moths resembled the background more closely, while the light forms stood out and were easily seen, and eaten, by the birds.

Use the graphs shown on the following page to answer questions 32-36



32. Which graph represents the original populations of the peppered moth?

- (A) 1
- (B) 2
- (C) 3
- (D) 4
- (E) 5

33. Which graph represents the moth population after the coming of the factories?

- (A) 1
- (B) 2
- (C) 3
- (D) 4
- (E) 5

34. The rural area of Dorset, England, has no factories, and the tree trunks are light in color. In a scientific study, equal numbers of the dark and light forms of the moth were released into the area. Which graph represents the percentages of the surviving moths?

- (A) 1
- (B) 2
- (C) 3
- (D) 4
- (E) 5

35. Which of the following offers the best explanation for the change in moth color after 1848?

- (A) Inheritance of acquired characteristics
- (B) Gene mutations caused by the soot
- (C) Natural selection of favorable variations
- (D) Lamarck's theory of evolution
- (E) Ingestion of the soot particles

36. What question would scientists need to answer in order to determine whether the two forms, light and dark, of the moth have become different species?

- (A) Are the two forms the same size?
- (B) Do the dark moths fly more frequently during the day than the light moths?
- (C) Do light moths fly more frequently during the day than the dark ones?
- (D) Can the two forms interbreed?
- (E) Do the two forms feed on different food?

1 What is a toolkit gene, and why do mutations in these genes cause such big effects?

2 What is a species? Why is it so difficult to give an absolute definition?

3 How does a new species form?

4 How did the lizard lab show how speciation might be occurring?

(continued on other side)

5 Use the time line below to explain what happened at each of these key dates (5). Then, describe what the biological communities were like (plants, animals, significant first events) in each of the intervening time periods (10).

Present time

65 MYA

245 MYA

543 MYA

3800 MYA

4600 MYA

APPENDIX G

INTERVIEW QUESTIONS

Date:

Define evolution:

What does the term “evolution” make you think of?

What is your church’s position on evolution? (how do you know—implicit/explicit?)

What is your parent’s view on evolution? (how do you know—implicit/explicit?)

Had you learned about evolution before this unit in school? (did you go to a Christian or public school?)

What’s your biggest remaining question about evolution (what would you most like to learn about)?

What was <your favorite, the most informational, the most challenging> part of the evolution unit?

How was your faith affected by the unit?

How has your attitude and opinion of evolution changed through this unit?

"Is there anything else you'd like me to know?"