AN ANALYSIS OF TEACHER STRATEGIES IMPLEMENTED WITHIN THE UNIT OF EVOLUTION AT THE SECONDARY LEVEL OF EDUCATION

by

PAMELA LAUREN CROWE

(Under the Direction of Norman Thomson)

ABSTRACT

At the high school level of education the unit of evolution can be one of great controversy. Although there is not a debate within the science community over the theory of evolution, there is a strong debate in the world of public education. This study attempts to discover how different teachers approach the content unit of evolution in a high school biology classroom. A semi-structured interview process was used to explore the different strategies that seven teachers used in their classrooms. Interviews are categorized and analyzed based on time spent, focus topics, and activities used to teach evolution with a strong emphasis on inquiry-based learning. The results of this study are used to describe that while some teachers are confident with teaching all aspects of evolution, others do not feel that certain concepts within the evolution theory are necessary to teach in high school.

INDEX WORDS: Strategies, Evolution, Controversy, Public Education, Theory, Inquiry-based Learning, Secondary Level

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CHAPTER 1: THE PROBLEM

Background of Study

During my experience as a high school biology teacher I have found that certain content units evoke quite different responses from students. The cell structure and function unit often leads to the explanation that they have already learned the material. The animal unit is always interesting to students. When I ask my students why they love the animal unit they tend to tell me it is because they know the animals already and appreciate learning about their world. When I introduce the evolution unit, however, several students become concerned. Each year a handful of students will ask me bluntly why we have to learn something that is "just" a theory. What they do not realize is that most of the concepts of biology, or science for that matter, are "just" theories.

Evolution is a scary word for a good majority of the general public. The reason behind this may simply be they do not understand the concept and wrongly assume we are teaching that humans evolved directly from monkeys. Research studies have been completed in the past to determine why students are apprehensive to learning evolution. Other studies have researched teacher acceptance and willingness to teach evolution as an accepted part of science in the classroom (Rutledge and Mitchell 2002). There is no question that evolution is a controversial topic in the public school setting. Yet one who understands the basic concept that populations change overtime must also wonder why this topic is still the center of controversy and misunderstood by the general public.

Before I started my own career as a biology teacher I spent several hours observing other teachers in their classrooms. During one of these observations a teacher was addressing the issue of a student who, along with both parental and administrative support, refused to be present in the classroom during the unit on evolution. Despite the teacher's actions, the administration backed the parents and the student was sent to the library daily during her biology period throughout the duration of the unit. The ironic aspect of the situation was that the alternative assignments included worksheets and computer labs teaching the concepts of evolution. It appeared to me that reading the concepts of the unit on the computer was more acceptable than hearing the information in the classroom. Whether or not a student wants to understand or "believe" the concepts of evolution, they are still required to take State mandated tests that will cover their understanding of evolution. If a teacher or administrator allows a student to "skip" evolution, they are actually doing a disservice to the student with respect to her/his academic achievement. It was during this observational experience that I realized that the controversy evolution education is, in fact, real. When I started my teaching career I was not sure what the big debate was. Personally my question was always how can evolution *not* be the reason for explaining diversity and change in our world. This experience helped demonstrate to me that there is a gap between the scientific world and the mainstream high school classroom.

Literature on the topic of evolution education is vast and full of hypotheses and opinions as to why evolution is such a controversial topic. This study is not questioning the controversy, but rather, describing and analyzing different teaching strategies that are currently being used in a selected group of secondary level biology classrooms. Perhaps teachers will soon focus not on "why" students are apprehensive to learn evolution, but on "how" they can use different strategies to help students learn and understand evolution as they do for every other unit.

The following is the Georgia Science Teacher Association's position statement on the teaching of evolution:

> Science is a method of explaining the natural world. It assumes the universe operates according to regularities and that through systematic investigation we can understand these regularities. Because the methodology of science is based on explanations that use empirical data, it cannot use supernatural causation in its explanations. Science has increased our knowledge because of this insistence on the search for data to explain natural processes.
>
> The most important scientific explanations are called "theories." In ordinary speech, "theory" is often used to mean "guess," or "hunch," whereas in scientific terminology, a theory is a set of

universal statements that explain the natural world. Theories are powerful tools. Scientists seek to develop theories that are internally consistent and compatible with the evidence, are firmly grounded in and based upon evidence, have been tested against a diverse range of phenomena, possess broad and demonstrable effectiveness in problem-solving, and explain a wide variety of phenomena. The body of scientific knowledge changes as new observations and discoveries are made. Throughout this process, theories are formulated and tested on the basis of evidence, internal consistency, and their explanatory power.

Evolution is a unifying concept for science and in the broadest sense can be defined as the idea that the universe has a history: that change through time has taken place. If we look today at the galaxies, stars, the planet Earth, and the life on Planet Earth, we see that things today are different from what they were in the past: galaxies, stars, planets, and life forms have evolved. Biological evolution refers to the scientific theory that living things share ancestors from which they have diverged: Darwin called it "descent with modification." There is abundant and consistent evidence from astronomy, physics, biochemistry, geochronology, geology, biology, anthropology and other sciences that evolution has taken place. (*www.georgiascienceteacher.org*, *2010*)

The GSTA statement on the teaching of evolution was adapted from the National Science Teachers Association (NSTA, http://www.nsta.org/about/positions/natureofscience.aspx). The statement focuses on the fact that evolution is a valid scientific theory that is based on evidence from several fields of science. Because evolution is the unifying theme to life sciences, if this concept is not taught then students will not be given the opportunity to achieve the scientific literacy required by our educational standards (NSTA, 2010). According to NSTA, evolution is a concept that is not emphasized properly in classrooms. This is credited due to several factors including education policy, intimidation of teachers, the general public being misinformed or simply uneducated on the topic, and simply a century of controversy (2010).

There are several angles one can take to investigate how we as teachers can better approach the topic of evolution in the classroom. As stated previously, NSTA gives several reasons why evolution is not emphasized properly in the classroom. It is important that teachers do not see these factors as an excuse, but to embrace the ethical responsibilities they have in the classroom. Teachers must approach the unit of evolution as confidently as they approach any other unit. Perhaps teachers could use evolution as a recurring theme throughout the academic year. Instead of having one unit of evolution that lasts two to three weeks, a thematic approach would allow the students to learn and continuously build on the concept of evolution.

At the high school where I teach biology for the full academic year, evolution is not addressed until midway through the second semester. Several students, though, usually begin showing their fears and concerns about learning evolution much earlier than second semester. For example, during the fall semester of 2009 students in my first period biology class started asking questions very early in November. While going through notes on Mitosis and Meiosis and discussing how mutations may occur, one student raised his hand. The student quietly asked, "Do you believe in evolution?" At first I considered telling him not to worry about it, and that we would talk about it next semester. Before I gave an answer that would, in sum, tell this student that his question was not important I realized his question might be important, not only for himself, but for others in the classroom. Evolution is the basis of biology, thus until a child understands the concept of evolution his/her approach to fully learn biology is handicapped (Shotwell, 1965). Perhaps this student was connecting the dots.   I stopped my presentation and addressed the student's question. I explained to the class that the topic of evolution is not something to "believe" in, but rather is a fundamental concept to understand. I went on to tell them that if you look at everything we learn in the biology classroom, it is all made possible through the mechanisms explained within the theory of evolution. Even units such as mitosis and meiosis are linked to evolution.   If you look at life on earth it is easy to see the diversity between and among the organisms of each species. No one seems to question the flu shot they are told to get once a year, so "why then do people become such skeptics toward a theory that explains quite simply why we are told to get a flu shot in the first place?"

Evolution can be a "scary" topic for not only high school biology students, but also teachers and community members. Every year when approaching the evolution unit there is one student, or perhaps a group of students, who ask if they have to learn the information covered in the unit. Before entering the high school biology classroom students have been exposed to a multitude of preconceptions and ideas about evolution. Perhaps they have grown up in a world or environment that supports scientific thought and processes, and thus do not show adversity toward the subject. Other students have preconceptions that lead them to believe that evolution is atheistic, so they come into the science classroom full of doubt and concern, and most of all fear. They may fear that what I teach them goes against everything they have been taught by their parents or church members, or both. Regardless of the different types or groups of students, it is always my goal to create a safe learning environment for all students; regardless of their preconceptions.

Even when students have become comfortable at the high school level biology class, evolution remains a sensitive issue. Students learn several theories during their high school science experience. Yet among the cell theory and atomic theory (and several others), the theory of evolution remains the most sensitive. Blackwell, Powell, and Dukes (2003) state the reason for such sensitivity relates to a literal acceptance of the creation as told in the King James Version Bible's Old Testament book of Genesis. This literal view of creation tends to be the core of the "literalist" person's religious belief system. Should a person go against this belief, he or she may have greater fears for salvation than a person who does not share the literal perception of creation (2003). In a classroom the goal should not be to ignore a student's fear or continue to worry them, but to attempt to help the student understand the concepts found in evolution. Human evolution is only a piece of the vast information found in evolution. It is not the job of the teacher to make the students accept the theory of evolution. The goal of teaching evolution, along with all of the other units in Biology, should be to help the student understand the concepts of evolution, regardless of whether or not they agree with the concepts.

Goals of Research

This study aims to investigate and analyze different strategies and methods teachers are currently using in their classrooms during the unit of evolution. By analyzing different strategies perhaps there is a unifying factor that teachers can focus on to help them be more successful in the classroom. The following questions are asked in order to meet this goal:

1. What lesson strategies do high school teachers use in teaching a unit on evolution?
2. How much time do teachers spend on evolution?
3. What evolution concepts are teacher giving more attention to during this unit?
4. What are the areas within the evolution unit that teachers find more difficult to teach?

The goal of this study is not to ask why students see the word "evolution" as an intimidation factor. In my experience, the words "mitosis" and "biochemistry" can be intimidating as well. I find it interesting though that the word "evolution" can create a wall in the science classroom dividing the resistant students against a concept that is all encompassing. If they cannot get past the word "evolution", then how will they learn to understand how the evolution theory unifies all biological concepts? Perhaps the answer to help bring this wall down is something teachers can do in the classroom. It is important that all students are provided with a safe and nonthreatening learning environment. There is a possibility that not all teachers are providing this type of environment during a unit that is personal to so many different types of students. It is also possible that teachers may simply ignore the fears and resistance of students and push through the unit regardless whether or not their students are really learning the concepts.

As a teacher, it is important to maintain the status of an objective educator in the classroom, regardless of the course title. It is unethical for a political science teacher to only convey his or her certain political party viewpoints rather than teaching the students aspects of all political systems. In the same regard, a biology teacher must remain objective in the science classroom; especially when controversial topics arise. Evolution is not the only controversial unit that is mentioned in a biology classroom. Subjects such as cloning, global warming, and alternative energy sources are all discussed at some point (GPS, 2009). It is the educator's professional responsibility to convey the facts without bias so that a student will be left to make his or her own choices regarding different subjects. When explaining evolution, teachers should approach the subject with the same objectivity and nonbiased lessons. Is it ethical or even constitutional to mention hypotheses or ideas that are not backed by sound science in a science classroom? Different people will answer this question in different ways, but science teachers should unite on at least this one concept. A science teacher is employed to teach the concepts of science and scientific theories. To teach anything else, does not match the job description or ethics of teaching science.

In this study, different strategies from teachers are described and analyzed in hopes of offering other teachers an opportunity to learn different strategies of teaching and approaching the topic of evolution in their own classroom. It is impossible to research the topic of evolution and analyze different teaching strategies without questioning oneself in regards to practices and successes in the classroom. Thus, along with presenting what other teachers are using in their classrooms, I will also present a self reflection that represents my own viewpoints and strategies used in regard to teaching the unit of evolution. As a consequence of this study, it is expected that biology teachers will have a better understanding of the different strategies used for teaching evolution objectively and successfully in their own classrooms.

CHAPTER 2: LITERATURE REVIEW

Teacher and Student Perspectives

Evolution has been one of the most volatile controversies in the United States public education classrooms over the last century. Studies by researchers such as Blackwell, Powell and Dukes (2003), Rutledge and Mitchell (2002), and Colburn and Henriques (2005), among others, attempt to explain why students have such a hard time accepting the ideas discussed in evolution. They have found that problems are often twofold. The first problem with acceptance of evolution has been the preconceptions students bring to the classroom, which are often religious based. The second problem with acceptance was that teachers may not approach the topic of evolution with an informed or dedicated approach (2003). In sum, the religious backgrounds and teacher inadequacies when teaching evolution may perpetuate the generations of students who do not understand the evolution theory, thus continuing the misconceptions and misunderstandings the general public has towards evolution. Teaching evolution using strategies that relate information students already understand may be a factor that allows the students to naturally incorporate some of the ideas of evolution in their own belief system, and thus the students can have a greater acceptance of the theory, instead of completely refusing any understanding of the topic (2003).

Among researching student acceptance of evolution, studies have also been completed that investigate student perceptions of evolution. Woods and Scharmann (2001) applied the four commonplaces by Joseph Schwab to investigate why students may have negative perceptions of evolutionary theory. Schawb's (1973) commonplaces for defensible education and curricula building include: the teacher, the subject matter, the milieu (community), and the learner. Not only must these four commonplaces exist, they must also be in equal rank. Woods and Scharmann found that in the unit of evolution, these four commonplaces do exist but are not in equal rank, thus perpetuating negative perceptions along with students being unable to accept ideas in the evolution theory. The study found that several of the commonplaces could become super-ordinate over the others and thus perceptions and acceptance will not change. When the cultural and political milieu of the general community becomes super-ordinate then it does not matter how well a teacher approaches the unit of evolution in the classroom, the students will still have a poor perception regarding evolution (Woods and Scharmann, 2001). The community is not always at fault though. A teacher may present the evolution theory using great methods but at the expense of the psychological needs of the student, making the teacher super-ordinate. Thus, no matter how well a teacher approaches evolution, she or he must account for the preconceptions and emotional needs of the student to ensure acceptance and positive perceptions of evolution (2001).

After interviewing several students for their study, Woods and Scharmann found the most frequently mentioned factor that shaped the attitudes of "Christian" students was theological (the Bible, God, religion, and church). The second most mentioned factor was personal relationships with parents, teachers, and friends (2001). This information can be very useful in the classroom. A teacher should always understand the students they are teaching. In the case of evolution, the teacher is not only trying to teach a new concept, he or she is also competing with factors such as religion, relationships, and even media that have importance in the students' lives. A teacher must account for these factors and approach evolution in a non-threatening way to students. If a teacher first accounts for these factors, and adjusts his or her teaching style for resistant students, then he or she may be more successful at helping the students not only form positive perceptions of evolution, but also accept the theory (2001).

While researchers such as Woods and Scharmann discussed factors affecting student perception, Rutledge and Mitchell (2002) investigated factors that affect teachers and their abilities to teach evolution in the classroom. Along with teacher perceptions, Rutledge and Mitchell also focused on teacher concepts and knowledge structure of evolutionary theory compared to teacher acceptance. Data was collected relating to three factors concerning the teachers: academic background, teaching of evolution (number of days, role in curriculum), and acceptance of evolution. A distinct pattern formed that showed the more a teacher accepted the theory of evolution, the better prepared that teacher was to approach evolution in the classroom (2002). Rutledge and Mitchell also found that 43% of the teachers they surveyed would choose to avoid or only briefly mention evolution in the biology classroom (2002). Overall it appears that the teacher may be the deciding factor in the classroom when it comes to student acceptance of evolution. If a teacher has a strong scientific background and accepts the evolution theory, then he or she is more likely to prepare to teach students the concept as well (2002). There are so many different strategies available to teachers to use in the classroom. A teacher must be careful to stay objective in the classroom, and pick the strategies that will best help the students learn the information.

<u>Inquiry-based Teaching Strategies</u>

In his book *The Missing Link*, Lee Meadows (2009) discusses in detail strategies to teach evolution using different features of inquiry instead of lecturing about concepts that some students may have already blocked out before the unit even begins. Meadows discusses how he was once a student that found great controversy between the religious world and scientific world when it came to the theory of evolution, until he saw Lucy (2009, p. xi). He describes that after seeing Lucy (*Australopithecus afarensis*) for the first time, evolution started to make sense, and he no longer feared the evidence, but became intrigued. In *The Missing Link* Meadows focuses on using different steps of inquiry to help resistant students learn the evidence of evolution, but not necessarily accept evolution. This is a key difference to other approaches of teaching evolution: Meadows' approach does not ask the teacher to resolve any conflicts between science and belief systems (2009, xvi). Through each step of his proposed teaching strategies he focuses on different levels of students, always making sure a safe and nonthreatening learning environment is offered. He does not focus on every small detail of the theory, rather the overall ideas that evolution has to offer. Students are not asked to memorize minute details throughout his plan; they are given the opportunity to understand the bigger picture.

As stated, Meadows's approach uses varying features of inquiry to help the students of varying belief systems understand the overall concept of evolution. Inquiry-based teaching is very important in science education, but can also be a broad concept and ranges greatly in teacher involvement. Meadows uses the Five Essential Features of Inquiry from the book *Inquiry and the National Science Education Standards* (National Research Council, 2000). These features define inquiry and help the teacher provide a framework for how to use inquiry in the classroom. The essential features are as follows:

1. Learners are engaged by scientifically oriented questions.
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
3. Learners formulate explanations from evidence to address scientifically oriented questions.
4. Learners evaluate their explanations in the light of alternative explanations particularly those reflecting scientific understanding.
5. Learners communicate and justify their proposed explanations.
   (Meadows, 2009, p. 8)

As one can see, these features allow the students to investigate the evidence and come up with their own explanations from a scientific view. They are not simply asked to read and accept facts that others have investigated, but come up with their own explanations and ideas that will most likely have a more lasting impact. In Meadows's approach to teaching evolution he stays with these features of inquiry, and thus the students are able to come to their own conclusions regarding the different concepts of the unit.

As stated in the five essential features of inquiry, the first step is to engage the students with scientific questions. In the evolution unit, this can be a difficult task as some students do not feel they need to learn about evolution, and they can find no meaning (Meadows, 2000, p. 29). With this being the case, engaging questions should be broad and safe for all students. If the question is based on specific science content, most students will not be engaged (2000, p. 29). In chapter two, Meadows lists several possible essential questions for beginning the unit of evolution that can also serve to engage all students regardless of resistance to learning evolution. A sample of the questions he proposes includes:

- Why is evolution so controversial?
- What is evolution and why should I care?
- Did evolution really happen?
- Why should we study evolution?
- Should we trust the evidence for evolution?
  (Page 23-24)

These questions are simple, broad, nonthreatening, and allow the students to become curious about the topic instead of choosing sides. They also open the door for students to start investigating evolution without fear of rejecting deep and personal beliefs. These questions are nonbiased in the sense that the student can answer them without previous knowledge; they simply set the stage for the students to start thinking about their own thoughts on a conflicting topic. Meadows is aware of resistant students and attempts to help the teacher overcome struggles that may arise. During the engagement segment of his approach he recommends letting the students know that his or her objection is heard, but to hold off discussing the issue until a later date (2009, p. 42). The teacher is in charge of determining the correct time to answer all objections and questions, but this early in the unit it is important to let the student learn more and possibly answer the question or resolve the objection on his or her own (2009).

Once the students are engaged, Meadows's approach allows the students to examine the evidence for evolution. He does not yet focus on the explanations, but lets the students examine and first come up with their own ideas and explanations. Throughout each section of his book, Meadows stays focused on the resistant student; perhaps this is because he was once resistant himself. Meadows offers a guide to help teachers productively facilitate the examination of the evidence. After evidence for evolution is examined, students are then asked to examine evolution itself, and again, Meadows offers focus questions and engagement activities to help the teacher accomplish this. He also stays focused on the five essential features of inquiry. At this point in his approach, examining for and of evidence falls between the second and third features of inquiry. Meadows suggested using a jigsaw approach where the students examine the natural selection of four different species selected by the teacher (p. 47). The students are looking at evidence and coming up with their own explanations, and with guidance, the students are focusing on the scientific side of the material.

Once students have examined the evidence for evolution, Meadows suggests deepening the understanding and addressing any remaining objections. Hopefully the objections students may have had in the beginning have been absolved though the students' own experiences. According to Meadows, the main objections that may remain at this point are based on three main areas: deep time, misunderstandings of evolution itself, and beliefs (2009, p. 41-42). For each of these types of objections Meadows offers focus questions to help the teacher make his or her own plan to tackle these objections. An example focus question is: "How does the fossil record support the idea of evolution of new classes of organisms?" (p. 84). Along with the three areas of misunderstandings, he also includes several other "miscellaneous" objections that may arise such as those about beauty and wonder, creationist objections, and complexity. For addressing these objections Meadows provides the scientific understanding behind each topic for the teacher to focus on, a focus question to allow the teacher to create a mini lesson, and the key message to reinforce the correct information. He also continues to encourage the teacher to not try and make the student accept evolution, yet to have the greatest opportunity to understand the concept and big picture of evolution.

At the end of the evolution unit, Meadows moves on to the fifth essential feature of inquiry by suggesting a project-based learning opportunity. This will allow the students to finalize their understandings in front of others just as an actual scientist would present his or her research at a conference or in a paper. Meadows's approach is different from the traditional sense because, instead of a simple lab report, project-based learning allows the students to be more hands on and accountable for their information since it will be presented to their peers. Meadows offers a table of project focus ideas for all students, from the accepting to resisting the evolutionary theory (2009, p. 97, Table 7.1). Students are usually required to work in groups simply to help the teacher manage and guide all projects going on in the classroom. One problem with the project-based learning is the time constraints many teachers feel in the classroom.   There are so many standards to cover and so little time to accomplish this. Meadows offers alternatives to the projects that also ensure the fifth feature is met, yet in a smaller amount of time. Alternatives include large-group discussion, journal entries discussed in smaller groups, or web-based research in which the students present their findings in smaller groups (2009, p. 106). Regardless of how the teacher decides to end the unit, all of these ideas allow the students to finalize understandings of evolution and have a sense of closure for the unit of evolution.

The high school biology teacher can also find resources for teaching evolution from the National Science Teachers Association. *NSTA Tool Kit for Teaching Evolution,* by Judy Elgin Jenson (2008) takes the teacher through several topics such as the history of evolution, active instruction, social challenges of promoting evolution instruction, and what we can do as community members to educate and make the public aware of the facts behind evolution. During the introduction, Jenson offers a table to remind teachers that evolution is a concept that students should be learning starting in the fifth grade and continuing through life sciences courses that extends through the 12th grade.   Table 2.1 was taken from the *Tool Kit for Teaching Evolution (pages X-XI)* although it was originally taken from the National Research Council (2000).

Table 2.1 outlines the different National Science Education Standards (NSES) for teaching evolution through the different grade levels. Depending on the state and school system students may start learning Life Science as early as fifth grade (2000). In this grade, according to the National Science Education Standards (NSES, 2000), students should start becoming familiar with several aspects of evolution, starting with the history of evolution. During this time, students should also become familiar with biological adaptations, diversity among and between species, and the levels of organization of life. Once students reach high school they should be able to expand on these ideas and apply concepts such as genetic recombination and mutation along with interactions with other organisms and the environment to help explain the processes of evolution.

Table 2.1 National Science Education Standards Pertaining to the Teaching of Evolution

Grades 5-8 Life Science

Topic: Regulation and Behavior (157)

- How a species moves, obtains food, reproduces, and responds to danger is based on the species evolutionary history
- All organisms must be able to obtain and use resources, grow, reproduce, and maintain stable internal conditions while living in a constantly changing external environment.
- And organism's behavior evolves through adaptation to its environment.

Topic: Diversity and adaptations of organisms (158)

- Biological evolution accounts for the diversity of species developed through gradual processes over many generations.
- Species acquire many of their unique characteristics through biological adaptation, which involves the selection of naturally occurring variations in populations.
- Biological adaptations include changes in structures, behaviors, or physiology that enhance survival and reproductive success in a particular environment.

Topic: Structure and function in living systems (156)

- Living systems at all levels of organization demonstrate the complementary nature of structure and function.

Topic: Reproduction and heredity (157)

- The characteristics of an organism can be described in terms of a combination of traits. Some traits are inherited and other result from interactions with the environment.

Grades 9-12 Earth Science

Topic: The origin and evolution of the earth system (190)

- The evolution of life caused dramatic changes in the composition of the earth's atmosphere, which did not originally contain oxygen.

Grades 9-12 Life Science

Topic: Biological Evolution (185)

- Evolution is the consequence of the interactions of the potential for a species to increase its numbers
- Evolution is the consequence of the interactions of the genetic variability of offspring due to the mutation and recombination of genes.
- Evolution is the consequence of the interactions of a finite supply of the resources required for life.
- Evolution is the consequence of the interactions of the ensuing selections by the environment of those offspring better able to survive and leave offspring.
- The great diversity of organisms is the result of more than 3.5 billion years of evolution that has filled every available niche with life-forms.
- Natural selection and its evolution consequences provide a scientific explanation for the fossil record of ancient life-forms, as well as for the striking molecular similarities observed among the diverse species of living organisms.
- Organisms are classified into a hierarchy of groups and subgroups based on similarities, which reflect their evolutionary relationships.

Topic: The behavior of organisms (187)

- Behaviors often have an adaptive logic when viewed in terms of evolutionary principles.

Original Source: National Research Council. 2000. *National Science Education Standards.* Washington DC: National Academy Press.

Although the NSES standards are suggested and school systems should not stray too far from these standards, many school systems across the country have adopted their own evolution education standards. The following two tables reflect the standards found in Georgia (Georgia Professional Standards, GPS), and, more specifically to this study, the Gwinnett County Standards (Academic Knowledge and Skills, AKS). Because this study is based in Gwinnett County Public Schools at the high school level, the remainder of this study will focus on the GPS and AKS standards for grades 9-12.

Table 2.2 Georgia Performance Standards: Science standards for the state of Georgia regarding evolution

Grade 9-12: Biology
- SB2. Students will analyze how biological traits are passed on to successive generations.
  • (d)Describe the relationships between changes in DNA and potential appearance of new traits including:
    a. Alterations during replication: Insertions, Deletions, Substitutions
    b. Mutagenic factors that can alter DNA: High energy radiation (x-rays and ultraviolet), Chemical.
- SB3. Students will derive the relationship between single-celled and multi-celled organisms and the increasing complexity of systems.
  • (c) Examine the evolutionary basis of modern classification systems.
  • (e) Relate plant adaptations, including tropisms, to the ability to survive stressful environmental conditions.
  • (f) Relate animal adaptations, including behaviors, to the ability to survive stressful environmental conditions.
- SB5. Students will evaluate the role of natural selection in the development of the theory of evolution.
  • (a) Trace the history of the theory.
  • (b) Explain the history of life in terms of biodiversity, ancestry, and the rates of evolution.
  • (c) Explain how fossil and biochemical evidence support the theory.
  • (d) Relate natural selection to changes in organisms.
  • (e) Recognize the role of evolution to biological resistance (pesticide and antibiotic resistance).

Grade 9-12: Earth Systems
- SES4. Students will understand how rock relationships and fossils are used to reconstruct the Earth's past.
  • (c) Apply the principle of uniformitarianism to relate sedimentary rock associations and their fossils to the environments in which the rocks were deposited.
- SES6. Students will explain how life on Earth responds to and shapes Earth systems.
  • (d) Describe how fossils provide a record of shared ancestry, evolution, and extinction that is best explained by the mechanism of natural selection.
  • (e) Identify the evolutionary innovations that most profoundly shaped Earth systems: photosynthetic prokaryotes and the atmosphere; multicellular animals and marine environments; land plants and terrestrial environments.
 	
Source: https://www.georgiastandards.org/Standards/Pages/BrowseStandards/BrowseGPS.aspx

Table 2.3 9-12 biology standards focused on evolution based on the Academic Knowledge and Skills (AKS) for Gwinnett County Public Schools
SCBI_B2005-9: analyze how biological traits are passed on to successive generations(GPS, HSGT) - 9b - explain the role of DNA in storing and transmitting cellular information including replication, transcription, translation, and gene expression (central dogma of biology) (GPS) - 9d - describe the relationship between changes in DNA and potential appearance of new traits including alterations during replication, insertions, deletions, and substitutions and mutagenic factors that can alter DNA (high energy radiation and chemical) (GPS)
SCBI_B2005-10: examine the relationship between unicellular and multicellular organisms and the increasing complexity of systems (GPS, HSGT) - 10b - examine the evolutionary basis of modern classification systems (six-kingdom system) (GPS)
SCBI_B2005-11: evaluate the dependence of all organisms on one another and the flow of energy and matter within their ecosystems (GPS, HSGT, CE) - 11e - relate plant adaptations, including tropisms, to the ability to survive stressful environmental conditions (GPS) - 11f - relate animal adaptations, including behaviors, to the ability to survive stressful environmental conditions (GPS)
SCBI_B2005-12: evaluate the role of natural selection in the development of the theory of evolution (GPS, HSGT) - 12a - trace the history of the theory (GPS) - 12b - explain the history in terms of biodiversity, ancestry, and the rates of evolution (GPS) - 12c - explain how fossil and biochemical evidence support the theory (GPS) - 12d - relate natural selection to changes in species populations over time (GPS) - 12e - examine modern evidence of micro-evolution as exhibited in biological resistance (pesticide and antibiotic resistance) (GPS) *Source: gwinnettk12online.net*

When comparing the AKS used by Gwinnett County and the GPS used by most school systems in the state of Georgia one can see that the AKS is taken directly from the GPS. The difference between the two sets of standards is found in other topic areas. AKS includes everything the GPS requires, but goes into more depth for certain topics. This depth can be found in the AKS standard for teaching Natural Selection. AKS requires students to investigate natural selection in greater detail (SCBI_B2005-12).

In *The NSTA Tool Kit for Teaching Evolution*, Jensen (2008) may focus on the National Standards, but the practices discussed can be used regardless of which specific set of standards a teacher is using. After addressing common teacher concerns in chapter one, the second chapter is devoted to specific lesson plan ideas. Each lesson plan is separated into the categories of Engage, Explore, Explain, Elaborate, and Evaluate. The first lesson plan example focuses on showing evolutionary relationships through cladograms (Jenson, 2008, p.19). Just as Lee Meadows focuses on inquiry-based teaching and learning, Jensen also provides an approach that is based on teaching with different features of inquiry.

The first section of every lesson idea starts with engaging the students, which can be defined by engaging the students and getting them interested in the topic. After they are engaged students are then asked to explore the topic on their own or by the guidance of the teacher. Once the students have been given the opportunity to gather their own thoughts and ideas, Jensen then encourages the teacher to explain to the students what they should have learned. This allows the teacher to stop and ensure that all students are on the same level of understanding. The teacher should then elaborate the topic, such as adding a different variable, and create the "bigger picture" and perhaps relate it to other areas that students may be familiar with thus helping them to not only learn the concepts but understand it as well. Finally, at the end of the activity the teacher should evaluate what each student has gained from the lesson. Evaluations can be done in many ways, perhaps by turning in a project, taking a quiz or even giving a presentation (2008).

Jensen offers lesson plan ideas for cladograms, which show evolutionary relationships, natural selection, human evolution, and detailed sets of instructions for an inquiry lab called "It's Molecular Time"(p. 34-39) which was designed by Jarrod Diamond in 2006. This last lesson is more detailed because it actually provides the teacher with step-by-step instructions and student worksheets.

Although the lesson plan ideas found in chapter two of the *Tool Kit* comprise a good section of the book (pages 17-39 of 66), the rest of the book focuses on social challenges on the controversial topic that is key to life sciences. Chapter three (page 45) focuses on the questions teachers may have regarding teaching only evolution when there are other ideas that may be easy to teach and avoid conflict. The first question asks "Why not appease the anti-evolution folks and teach the controversy… and demonstrate that evolution is the most complete explanation…?" This may seem like an attractive solution but it was actually put forth by the leaders at the Discovery Institute's Center for Science and Culture - which is well known for being a major supporter for Intelligent Design (Jenson, 2008, p. 47). Although it does seem like an easy way out, it only spurs on the notion that there is in fact a controversy. Jensen acknowledges that there is a political controversy regarding evolution, but there is no controversy within the scientific community (2008, p. 47). The next question focuses on evolution as a belief and Jensen quickly reminds teachers that evolution is not a topic based on opinion, but empirical evidence (2008, p. 48). It is important for teachers to understand the difference between science and faith/belief. Several people such as Lee Meadows and interviewees of the Colburn and Henriques (2005) study have found that one can have both science and faith simultaneously because they are different subjects.

In my own experience, as student or teacher, I have never had a personal conflict with religion and evolution. I am able to see them as entirely different subjects that teach different concepts. The fact that science is limited to the natural world without allowing supernatural explanation creates a barrier between the two subjects that forces them to stay divided. Colburn and Henriques (2005) attempted to explain how both religious groups and scientists alike can agree on the concepts that shape the evolution theory. During their study in 2005 it was found that several clergy members accept the theory of evolution without reservations. It was the students, teachers, and community members who were dealing with the controversy instead of the scientists and the religious leaders. Though study after study has researched different aspects of the controversy between religion and evolution, it is still not entirely understood why teachers struggle with this unit and why students in general are more resistant to learning the information compared to other units of study. Perhaps the main problem is with teacher perceptions, as discussed previously by Rutledge and Mitchell (2002).

When a science teacher is approaching a unit he or she will have different methods of planning the unit. Different teachers have different strategies they use to teach their students. In science education it important to teach using different inquiry-based lessons in the classroom, thus many teachers use labs and hands on activities. According to David L. Haury in *Teaching Science Through Inquiry* (1993), inquiry-based teaching engages students in the investigative nature of science. As seen in Meadows' strategies, there are several different features of inquiry as suggested by the National Research Council (2000). These features can range in different levels of inquiry used from facilitated or guided, where the teacher helps the student with procedures and methods, to full discovery inquiry, where the teacher may simply give students materials and leave it up to the students to figure out everything about the lab themselves(NRC 2000). Inquiry-based teaching also allows the student to take responsibility in the learning process. The student is not simply required to write notes that he or she may remember, but to take part in hands on activities and actually figuring out a posed problem or question. If a student can figure out a problem for him- or her-self, then each is more likely to remember the information and lesson (Haury, 1993).

It is important to differentiate the lessons to ensure that all students are able to construct their knowledge base. Some students need more guidance, while others do not. There are many different types of learning styles, and while it may seem overwhelming at first to attempt to reach each students' individual learning style, it is entirely possible. In one classroom a teacher may use visual notes displayed on PowerPoint, and also read through the material for those learners who do not learn visually but through an auditory mode. Graphic Organizers are yet another way to help students organize the different concepts into a more visual friendly and organized manner. The KWL Graphic Organizer is a great way to assess previous knowledge students have at the beginning of the unit and compare this to the knowledge gained at the end of the unit (see Figure 2.1). Incorporating laboratory activities into the lesson plans allows students to work hands on with the materials and information, and hopefully better understand certain mechanisms and concepts of science.   There are so many different strategies to teach different concepts in the science classroom, and it can be simple to ensure that all units have teaching strategies that suit every type of learner.

Topic:____		
What I Know	What I want to know	What I learned

Figure 2. 1 Sample of a KWL Chart.   Source: http://www.eduplace.com/graphicorganizer/

At the end of the unit, whether it is biochemistry or evolution, it is important to assess what the student has learned. Student assessment can be done in several ways. Multiple choice tests are very popular, but it is important to remember that there are several ways to assess a student's knowledge besides a multiple choice test. The assessment strategy should be consistent with the teaching style that has been used. Different assessment strategies might include projects, discussions, and presentations. Just as it is important to differentiate lessons during the unit, it is also important to differentiate assessment style. As a teacher, I have come across several students who are very intelligent, yet have severe test anxiety and do poorly on traditional multiple choice tests. Some students may not be able to choose A, B, or C, but if you give them a chance they can write you an essay and explain everything you need to know about the given unit. Differentiating test strategies can be as easy as including a short answer section to your multiple choice test to give those students a chance to explain they understand the concepts. Some students are very creative and visual, and may enjoy unit projects and presentations. Just as some students may be able to write about what they learned, others are good at telling you and showing you what they learned.

These are just a few examples of how to differentiate lessons and assessments. Once a teacher gets in the habit of including differentiated lessons and assessments, it becomes easier to ensure that all units have the basic components of differentiated lessons for the numerous learning styles in each classroom.

Science versus Religion: The Controversy

The general public has, on several occasions, taken the controversy to the legal level of authority. Throughout the 20th century, and entering the 21st century, different groups such as the Discovery Institute (www.discovery.org) have attempted to dispute ideas represented in the theory of evolution, and demean the theory by demanding the alternative, though nonscientific, "theories" to be represented in the public classroom as well.

For the past century, as well as currently, evolution has been at the core of controversy in United States public education. Questions have been raised as to whether evolution should be included at the high school level biology classroom. Due to the fact that evolution is the central theme of the life sciences one can expect that this unit will not go away any time soon. Others have come to the same conclusion and are now looking for other ways to discredit evolution or demean the theory itself. Certain people, such as those at The Discovery Institute, are pushing to include creationism and intelligent design as alternative "theories" to evolution within the same unit. Though several trials have taken place the results are always the same. Evolution is included in the high school biology curriculum and creationism and intelligent design are not deemed scientific and thus should not be included in the public science classroom (*Edwards v. Augillard*, 1987).

Legally, a public school system cannot have a disclaimer that singles out evolution from other scientific theories (*Selman et al. v. Cobb County District et al.).* According to the news article, "Evolution Theory Stickers Taken Off textbooks: Georgia County Lost Lawsuit on Church vs. State Grounds", by *The Associated Press*, in 2005, the school district of Cobb County, Georgia attempted to appease the community's concerns with evolution by placing a sticker in the front of 34,452 biology textbook stating: "This textbook contains material on evolution. Evolution is a theory, not a fact, regarding the origin of living things. This material should be approached with an open mind, studied carefully, and critically considered". When taken to court over the matter, the judge ruled that the advisory sticker was unconstitutional according to the First Amendment, and was removed (2005).

The *Kitzmiller et al. v. Dover Area School District et al.* case in 2005 is the most recent court case concerning evolution in the public school system, and attempted to include intelligent design within the evolution unit. This policy was struck down by U.S. District Court Judge John E. Jones III (Jenson, 2008, p. 49). The controversy of teaching evolution in public schools will continue to be an issue until the majority of the general public understands the concepts of evolution. Education of the public starts in the public school system, thus teachers have a great responsibility in ending the controversy concerning the evolution theory. Though it may seem like a large responsibility, efforts will eventually pay off as the public becomes more educated. People once believed that the world was flat, hopefully someday we will all look back on the days when evolution was a controversy.

For most units, teachers have no fear or concern with how students or parents will react, but just as the word "evolution" may seem scary to some students, it is the same for some teachers. Studies have reported that some teachers have anxiety about teaching the unit of evolution for reasons that range between the fact that they do not accept the theory or because they do not understand the concepts well enough to teach confidently (Trani, 2004). Perhaps teachers need more training in evolution at the college level in order to successfully teach the concepts to their students (2004).

Colburn and Henriques (2005) completed a study in attempt to understand the source of the controversy. The goal of their study was to determine different viewpoints from clergy members in order to assess whether or not the religious leaders were the source of the conflict between religion and science. During this study they interviewed several different clergy members in regards to their thoughts and understandings of evolution. The interviews were then compared with surveys completed by teachers and community members regarding the same topic. This study is interesting because it shows the clergy members accept the concepts of evolution; however, the teachers and general public have reservations.

Clergy members interviewed during Colburn and Henriques study represent a large subgroup of Christian denominations. Denominations represented in the study include: Catholic, Methodist, Lutheran, Presbyterian, Episcopal, United Church of Christ, Christian Church, and Undeclared (2005, p. 424). In regards to the questions concerning science conflicting with faith it was found that clergy felt more strongly than teachers that evolution and God were compatible, and clergy agreed more strongly than teachers that religion should not be introduced in the public school (2005). One clergy member interviewed states, "The Bible and science go hand in hand… The Church has often changed its mind or position on things through time (i.e., the role of women, views on slavery, and the role of homosexuals). In many cases it is science that has shed light on the issue." (2005, p. 435).

Despite different teachers' reasons for their concern of teaching the controversial unit of evolution, educators must objectively present the subject matter to the students. As previously stated, all students deserve a fair and bias-free education. It has been deemed unconstitutional to include any other "theories" of how life has changed and developed over time even on the teachers own time (*Webster v. New Lenox School District*). It is also very important to distinguish the difference of the scientific theory and everyday theory to students in the classroom. Just as conviction in the church is much different than a conviction in the courtroom, a scientific theory and everyday theory have severely different meanings. Hopefully, through learning the nature of science throughout a year in biology class, students will learn that a scientific theory is in fact a valid explanation for how life changes over time.

According to the textbook *Prentice Hall, Biology* (Miller and Levine, 2008), used by Gwinnett County high schools, evolution is a "change over time, a process by which modern organisms have descended from ancient organisms" (p. 369). The same textbook goes on to define a theory as a "well-supported testable explanation of phenomena that have occurred in the natural world" (p. 369). Although the students can simply look up the definition for a theory, several students are still convinced that a theory is just an educated guess (researcher's observations). Although the unit of evolution may not begin until late in the year, depending on the curriculum calendar, it is important to start teaching students what a scientific theory is. If students have grasped the concept of what a theory is, perhaps they will not have the excuse that evolution is *just* a theory when approaching this unit.

It is important to understand the history of the controversy of such an important scientific theory, but it is more important to understand how to teach our students the unifying concept of biology successfully. Several studies have researched the reasons for student adversity and teachers' struggles as discussed in this section. Perhaps it is time to go on and look at what teaching strategies may be explored to successfully teach our students. Jensen and Meadows both give detailed lesson plan ideas for teachers to use and make their own. Yet even with resources such as *The Missing Link* and *Tool Kit for Teaching Biology*, it is found that teachers still struggle with teaching the evolution unit. Because evolution is such an important topic in the biology curriculum, it is necessary to look at the different strategies teachers are currently using to teach the subject of evolution.

CHAPTER 3: METHODS AND METHODOLGY

Methodology

This qualitative research study focused on both ethnographic inquiry as well as autoethnographic inquiry. According to Michael Crotty (1998), ethnographic inquiry seeks to uncover meanings and perceptions on the part of people participating in the research (p.7). A semi structured interview was the primary mechanism for determining how teachers approach evolution in the high school biology class. Autoethnographic inquiry was also used in order to include a self reflection at the end of this study, which includes analyzing oneself. Because I am also a high school biology teacher, it is important that my own ideas and strategies regarding evolution education were stated. Autoethnography asks the central question:"How does my own experience connect with and offer insights about this situation?" (Patton, 2002, p.132).

An interpretivist approach was used due to the fact that it sought "culturally derived and historically situated interpretations of the social-life world" (Crotty, 1998, p. 67). This theoretical perspective was used in an attempt to understand and explain human and social reality (p. 66-67). During the current study, I attempted to explain and understand how different teachers are approaching the evolution in the high school biology class. My goal wass to find out what strategies teachers are using, how long they spend on evolution, difficulties they have with the unit, and areas of focus teachers are giving more attention to.

Interview Development

Researchers such as Colburn and Henriques (2005) and Woods and Scharmann (2001) used different types of interview strategies to gather information to complete their respective studies. Colburn and Henriques used a semi-structured set of interview questions to gather their information, while Woods and Scharmann used a post interview to gather additional information and help explain results found by pre and post tests.

The current study was primarily composed of interviewing seven biology teachers and analyzing the strategies discussed within each interview. The interview process (both verbal and online chat formats) was chosen to gather information regarding different teachers' approaches to the evolution unit in the high school biology class. There were many types of interviews to examine when setting up the design of the study. The interview strategy chosen for this study used the "guided approach" (Fraenkel and Wallen, 2009, p. 447).

The interview guide approach allows the researcher to set specific topics and issues to be discussed in advance and later can choose the sequence and wording of the questions throughout the course of the interview (2009, p. 447). The interviews conducted during this study were semi-structured and conversational. Because this study used a guided approach style of questioning, the topics, issues, and sample questions were chosen prior to interviews taking place. Using this guided approach kept collecting data systematic and allowed the gaps in answers to be anticipated. Weaknesses of this interview strategy include inadvertently omitting important topics and different responses from participants based on different perspective (p. 447). Important topics may be omitted due to the situational manner of the interview.

In order to meet the goals of this study, and not inadvertently omit important topics during the interview, an interview protocol was formed to cover the following topics: time allotted for teaching evolution, difficulties within the unit, focus areas of the unit, and experiences with resistant students or evolution adversity. For a complete list of possible interview questions see Appendix A. Due to the informal nature of interview process used in this study, each interview had a different sequence of questions.

Research Design

The goal of this study was to investigate the strategies that are used by teachers in a selected group of classrooms to teach. A research proposal for conducting this study was submitted and approved through The University of Georgia Instructional Review Board (IRB # 2010-10504, 3/18/2010). Seven different teachers from three Gwinnett County public schools were interviewed regarding methods and strategies they use to teach the theory of evolution. The methods and strategies were analyzed based on how the teacher handles adverse situations regarding resistant students, whether or not the teacher perceives him or herself as successfully teaching evolution, and the levels of inquiry and strategies used (Table 3.1).

Table 3.1: Level s of inquiry adapted from the five essential features of inquiry used by Lea Meadows

Level	Description
1	Engagement: use scientifically oriented questions to engage students
2	Evidence: students use scientific evidence to develop explanations
3	Explanations: students form their own explanations to answer scientific questions
4	Evaluate: students compare their explanations with other scientific explanation
5	Communicate: students communicate their findings and justify explanations

Twenty-three teachers representing five high schools were asked to participate in this study, of which seven teachers from three high schools agreed to participate. The three schools are referred to using pseudonyms throughout the remainder of this thesis: Oak Grove High School, Chapel Hill High School, and Providence High School. The schools were chosen based on close proximity of each other and each had biology teachers willing to participate in this study. Teachers from different schools were chosen in an attempt the gather an array of different strategies and lessons used to teach evolution.

The Gwinnett County Public School system is divided in attendance zones which are set into "clusters" determined by geographical clusters within the county and each of these clusters has one high school (www.gwinnett.k12.ga.us). Oak Grove High School currently serves 1,342 students and has five biology teachers. Chapel Hill High School serves 2,802 students and has seven biology teachers. Finally, Providence High School serves 2,715 students and has eight biology teachers. Each school offers the following academic levels of biology: College Prep, Honors, Gifted, and Advanced Placement.

Participant Selection

Teachers were asked to participate based on the subject they taught regardless of years of experience. All teachers approached had between one and 25 years of teaching experience and all had experience teaching high school biology. Academic level taught (e.g. College Prep, Honors, Gifted) was not a variable considered in this study due to the fact that I aimed to collect as many strategies for as many levels of students as possible. The only requirement for participation was that the teacher currently taught a biology class. Twenty-three teachers were asked to participate in an interview either in person or online. Seven of the approached teachers (30%) chose to participate in the interview. For the sake of keeping teachers interviewed anonymous, each teacher is assigned a letter of the alphabet (A-G) and will be referred to in the masculine manner. Transcripts of interviews can be found in Appendix B.

Interview Implementation

The seven voluntary participants all took part in a semi structured interview process that lasted between 30 to 60 minutes, depending on the interviewee. Participants were asked questions regarding basic strategies, inquiry lessons used, time commitments, focus topics and difficulties with teaching the evolution unit (Appendix A). Interviews were either tape recorded or printed as online chat format. All participants were made aware of the tape recorder, when used, and acknowledged consent. Notes were also taken during each interview for data gathering purposes.

Interview questions were formed in order to stay focused on the evolution unit. It was important to establish the background of the teacher by first finding out how long each participant had been teaching biology at the high school level. Even though this was not a major factor during this study, experience may later be an implication for further studies. Time spent on evolution was another very important factor to evaluate during this study. Participants were asked in general how much time they spend as well as how much time they need to teach evolution. Along with the length of time needed to teach evolution, participants were asked if they agree with the placement of evolution on the academic calendar set by Gwinnett County. As of 2010, the evolution unit is taught second semester after genetics and before classification.

Finally, interviews assessed difficulties teachers have with the unit of evolution. These difficulties include both teaching strategies as well as how teachers deal with student resistance in the classroom. It is important to assess how a teacher handles resistant students as this may be correlated to the types of strategies a teacher uses in the classroom. Questions regarding student adversity were asked to get a glimpse as to what is currently going on in the classroom in regards to this issue.

The format used for interviews was used to allow freedom in the order and number of questions asked during the interviews. Certain participants were asked to explain and elaborate on different answers, while other participants may have elaborated without additional questioning needed. Further questioning depended on how much information each participant gave on his or her own.

Finally, a self reflection was completed in order to include my own strategies and discuss how I might incorporate other strategies or change my own unit for greater student achievement in the future. I feel it is impossible to research a topic I am so passionate about without also analyzing my own strategies. The self reflection consisted of analyzing my past three years of teaching experience and applying what I have learned during this study to better teach evolution in the future. The self reflection involved looking back at each year of lesson plans and discussing which strategies I found to be most helpful, and why others are no longer used. Implications of this entire study, including interviews and self-study, were considered and discussed.

CHAPTER 4: RESULTS

Time Spent on Evolution

During this study fourteen activities were collected and analyzed. Activities provided include those that teachers were willing to share with this study based on the helpfulness of the activity in regards to teaching the evolution concepts. Activities can be found in Appendix C. Interviews were transcribed and then categorized based on time spent on evolution in the classroom, focus within the unit, difficulties, and different activities used. The first topic analyzed is how much time teachers spend on evolution in the classroom as seen Figure 4.1 below.

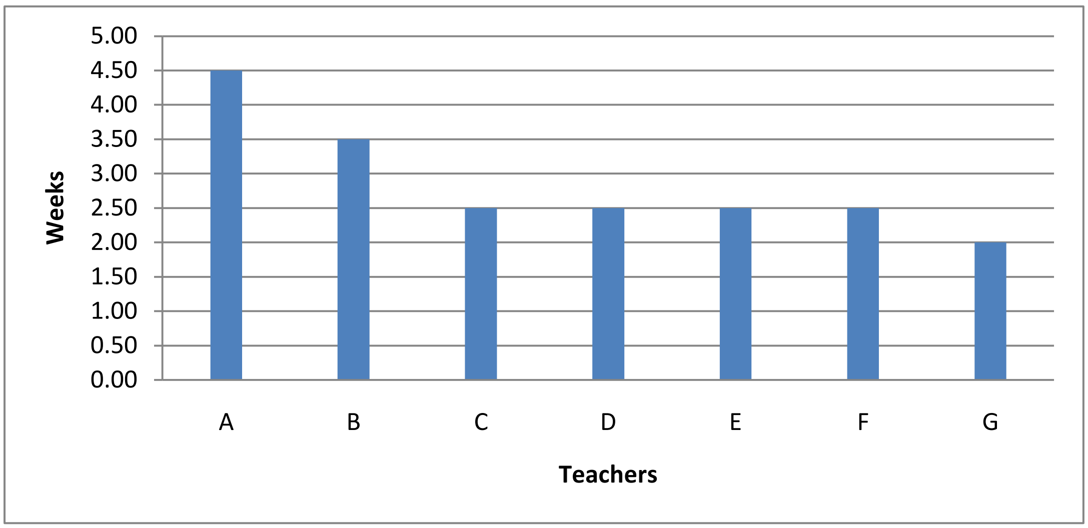

Figure 4.1 Amount of time, in weeks, the seven teachers use to teach the content unit of evolution.

When interviewed, four of the seven teachers stated they needed approximately two to three weeks to teach evolution in the high school biology classroom. The time teachers need to teach evolution ranged from four and a half weeks down to two weeks with the average time found at 2.8 weeks of instruction. Some teachers, such as teachers A and B, went on to say they would like more time to go into more detail to the concepts found in evolution. Teachers A and B both stated at some point that they could use more weeks, if not months, to teach evolution. Teacher B specifically says he would like to have six months to teach the concept but he also explains that he can only teach the unit in the time of 3-4 weeks suggested by the academic calendar provided by Gwinnett County. Other teachers, including teachers C, D,E, F and G stated they are perfectly happy with the amount of time given to teach evolution and would not change anything.

Teacher C, who currently uses two to three weeks to teach evolution, explained that it was very difficult to teach evolution as a new teacher. He stated, "When I first started teaching it (evolution) I probably could have finished it in a week. And, then after teaching and getting ideas from other people, I was able to spend a little bit longer. But as a new teacher it was hard for me to figure out what to do." Over the years Teacher C has been able to collaborate with other teachers to gather lesson plan ideas and become more comfortable with teaching this unit. Teacher E spends two to three weeks on teaching evolution but has never become confident in the area of evolution, and actually dreads teaching the unit. Teacher E stated: "This is one of the reasons I really don't like teaching evolution. I am not comfortable teaching something that students take so personally."

Focus Topics and Difficulties within Unit

The theory of evolution encompasses several smaller concepts to explain the theory as a whole. According to the textbook used by Gwinnett County, *Prentice Hall Biology* (Miller and Levine, 2008) the theory is divided into concepts such as adaptations, natural selection, micro and macroevolution, and evidence for evolution: the fossil record, geographic distribution, homologous body structures, and embryology. It is assumed that with only three to four weeks given to teach this unit a teacher cannot realistically give the same amount of time and attention to every concept of every unit. The textbook used during this study has four chapters focused on evolution, with each one broken into three to four sections. To teach all of the information presented would possibly take months. The fact that teachers must choose which concepts to focus on is not only found in the evolution unit, but virtually every unit (researchers' personal experience). Thus, teachers must choose which topics to give more attention to and this ultimately leads to sometimes "skimming" the others concepts. During the interview each teacher was asked which areas of focus presented by the AKS regarding evolution they spend the most time on. The following results were found:

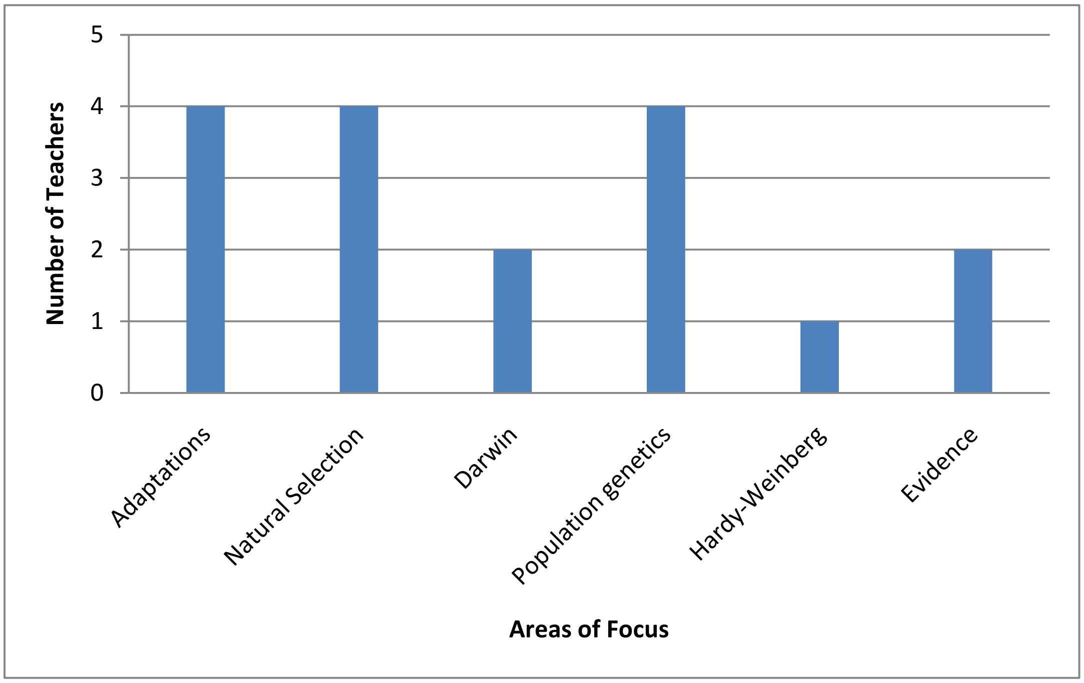

Figure 4.2 Topics within the unit of evolution teachers give more focus to. Answers only reflect those teachers that participated in the current study.

During this portion of the interview teachers were not provided a list of topics to choose from but were asked generally "Are there any areas of the unit (of evolution) that you focus on more or give more attention to than others?" As seen from Figure 4.2 the topics mentioned by teachers include: Adaptations, natural selection, Darwin, population genetics, Hardy-Weinberg, and evidence. Several teachers in the study gave more than one answer. Teacher B stated he gives more attention to Darwin, Natural Selection, Hardy-Weinberg, and population genetics. Throughout the remainder of his interview, however, he tended to focus more on Hardy-Weinberg and Population Genetics because his most successful lessons came from these topics. Teachers E and G stated they each give more attention to natural selection and adaptations, respectively. Of the six topics, four of the teachers interviewed chose adaptations, populations, and natural selection. Five teachers answered that they were comfortable with these topics or that they were backed by evidence. Teacher E stated his reasoning is “because they are an AKS and are proven true”. Teacher G stated he focused mainly on Natural Selection because, “… it’s something that continues to happen now and it will be easy to give the students something to relate to.”

When certain teachers were asked which topics they find most difficult or which they stay away from completely, Teachers B, C, and E explained they found human evolution to be the most difficult. Teacher G finds simply beginning the unit itself to be the most difficult aspect of teaching evolution. Teachers A and D, stated they have no real difficulties with teaching any parts of evolution regardless of the fact they must give more attention to different topics. No teacher mentioned giving more attention to human evolution or the origin of life. Regarding origin of life Teacher B stated: “I spend some time on the origin of life. My background isn’t great there and the evidence is subjective so the kids have a little difficult time. So I don’t spend too much time just because of my lack of knowledge and the lack of evidence.” Perhaps teachers’ perceptions of evolution are formed due to a lack of knowledge on the subject. Teacher C mentioned when he first started teaching he could have taught the entire unit in one week simply due to lack of resources. Teachers A, B, C and E all mentioned they have difficulties teaching human evolution. Teacher A discusses his problems teaching human evolution stems from student perspectives: “it’s just the whole idea where humans come from; you know they kind of believe in the specialness and want to believe in the specialness that humans are the separate entity.” He explains that he, personally, does not have a conflict with evolution and religion but most of his students struggle with this area of human evolution.

Strategies and Activities

The main focus of this study was to investigate, describe and analyze different strategies and lessons teachers use to teach the unit of evolution at the high school level. The following table lists different activities collected from each teacher interviewed. These activities represent a sample of those that each teacher uses within the evolution unit.

Table 4.1 Different activities used by teachers used in the evolution unit, categorized based on Nature of Science and Science Content.

Teacher	Activities Related to Nature of Science	Activities Related to Science Content
A	"Sex, Drugs, and Rock n Roll", adapted from Stephen J. Gould (C9), Peppered Moth Survey	Class Discussion
B	Teddy Graham Bear Lab (C5), Camouflage Lab	Guided Reading bookwork, Class Discussion
C	Teddy Graham Bear Lab, Squirrel Island	Peppered Moth Graph (C2)
D	Rat Island (C4), Phylogenetics Tutorial Project (C3)	Peppered Moth Graph (C2), Foldables (C8), Graphic organizers,
E	Woolly Worm Lab (C1)	Foldables (C8), Graphic Organizers, Worksheets
F	M & M Lab (C13), The Latest Beak Activity (C14)	None mentioned
G	The Latest Beak Activity (C14)	Worksheets, Guided Reading Bookwork

Activities can be found in Appendix C.

As a follow up to discussing different activities used during the evolution unit, teachers were also asked whether they feel the activities they use are inquiry-based. Teachers categorized lessons as inquiry based on the nature of the activity. Laboratory activities involving hands on learning and requiring the student to gather the data and information were more likely to be considered "inquiry-based" activities. Some teachers classified their activities as inquiry based, such as the Teddy Graham Lab and Rat/Squirrel Island, but depending on when the teacher uses these they might not use all features of inquiry teaching as mentioned by Meadows (2009) and Jenson (2008). These activities may be good sources of features of inquiry such as Engagement. As stated in the Introduction, inquiry-based learning has many features and levels. Many of the activities listed are used after the teacher has explained the concept and after the teacher guides the students through the beginning steps of the activity. Teacher E explained that he tries to stay away from inquiry activities during the unit of evolution. Teacher E states, “Doing activities for evolution is difficult to model” thus he tends to focus on notes and discussion, but also includes activities such as the Woolly Worm activity in which the students pretend they are birds to study natural selection.

When asked about inquiry-based laboratory activities Teacher F explained, “The kids that I teach are lower level and kind of freak out if I make them do too much critical thinking.” He goes on to explain that even though he does not consider activities such as the M&M Lab and The Latest Beak activity to be inquiry-based, they still give the students a visual representation of the mechanisms of evolution to better help them understand the concepts of adaptations and natural selection. Several teachers interviewed also agree that along with the labs and activities the students also need the traditional “bookwork” to help them understand evolution. When asked about the ratio of bookwork and labs used in the classroom Teacher G stated he uses each about 50% of the time “because I feel like there is a lot of material they will need to understand bookwork wise. Yet you still want to be able to provide them with enough hands on materials and I think they need the visualization as well.” The hands on and visualization can be classified under the second and third features of inquiry discussed by Meadows. The second feature of inquiry allows students to evaluate the evidence while the third feature has students form explanations for the evidence. A teacher could easily add more features of inquiry by having students compare their explanations with other scientific explanations, which is feature four.

All teachers agreed that discussion is an important aspect of the unit of evolution. It is important for students to not feel their belief systems are threatened. One teacher said he would allow an evolution versus religion debate in his classroom. Teacher G stated, “I think it would help because not all students have the same beliefs and those that share those beliefs should be able to see why they feel a certain way and the students that didn’t have certain beliefs it would allow them to understand where those students are coming from. I just think both approaches would allow students to get a good understanding [of evolution]." The six other teachers interviewed stated they would oppose an evolution/religious debate. Teacher E simply stated "NEVER" while others, such as Teacher C, explained, "I just don't feel comfortable and don't have enough knowledge about different religions or different theories of how the earth was created, I'm very just simple minded and that's it." When asked about sharing personal beliefs in the classrooms all seven teachers were opposed. Teachers B, D, and E stated that they would talk with students about their beliefs outside of the classroom, but never during class instruction.

CHAPTER 5: DISCUSSION

Strategies Collected and Analyzed

Based on the interviews it appears that teachers interviewed in this study focus more on lessons that involve students visualizing the processes of evolution and deskwork that encourages the students to practice the concepts they have learned in class. Activities that were collected were categorized based on whether or not students are held accountable for gathering the evidence, forming their own explanations, and communicating their findings. Of the Nature of Science activities listed in Table 4.1, only three of the ten laboratory activities include the students having to explain their findings and presenting their data to the class. These activities include “Sex, Drugs, and Rock n’ Roll”, Squirrel/Rat Island, and the Phylogenetic Tutorial Project. The other activities involve the students gathering data, but never interpreting the evidence further than the review sections found at the end of the lesson.

While each of the lessons submitted show how natural selection may occur in a simulation, this topic, along with adaptations, were the only topics mentioned in interviews that required the student to complete laboratory and hands on activities. In *The Missing Link*, Lee Meadows (2009) discusses the importance of using inquiry to teach the concept of evolution. His style of teaching does not force the resistant student to change his or her belief system, but simply helps the student understand that the evolution theory is based on evidence. This study has found that only two of the seven teachers use inquiry based on all five essential features from the National Resource Council (2000) that Meadows uses as a guideline in his method. Depending on how a teacher uses certain lessons, each activity could be differentiated to further include the fourth and fifth features of inquiry-based teaching

Laboratory activities and lessons provided by interviewees have similar goals yet slightly different approaches. Squirrel Island and Rat Island both have students “create” a species of squirrel or rat that would survive certain conditions. The goal of each activity is to allow students to give their animals different adaptations. What this activity lacks though, is the fact that evolution and mechanisms such as natural selection do not simply *give* different species these adaptations to survive. In reality, if you were to place a rat in the desert or any other extreme change from its’ normal habitat, then the rat would likely die. Students may become may become confused and learn that organisms can *acquire* traits on demand, when this is not the case at all!

In 1809, Lamarck proposed his hypothesis of acquired traits suggesting a use or disuse principle to explain how organisms gain or lose adaptations resulting in survival (Prentice Hall, 2008). Although Lamarck was one of the first to develop a hypothesis of evolution, he was later found to be wrong due to lack of supporting data. To use activities that suggest organisms are able to pick and choose the adaptations they need for survival teaches the hypothesis of Lamarck, not Darwin! Some activities that may be better suited to show the mechanisms of natural selection are the Woolly Worm or Camouflage Lab.

The Woolly Worm Lab and Camouflage Lab involve having a population with many variations. In both activities the variation is color. The Woolly Worm Lab involves “worms” made of pieces of yarn of various colors while the Camouflage Lab involves small dots (made from a hole puncher) of different color paper. Since these two labs show the same mechanism of natural selection and adaptations a teacher could use either activity. The main difference between the two activities is that Woolly Worm works best outdoors and Camouflage Lab can work indoors with handmade environments.

As previously mentioned the Woolly Worm lab involves worms made of yarn in various colors. This activity requires set up before class starts and a grassy area large enough for the entire class to participate. Prior to class, the teacher should choose several different colors of yarn (see Wooly Worm

Lab in Appendix D for examples). The teacher will need approximately 2 inch worms of each color. Once the yarn is cut the teacher should find the outdoor location, at some high schools teachers used the football field and spread out the worms all over the field broken (or given area used) that is divided into square meters to provide population numbers. When class starts the students become the predators and "worms" are the prey. Students can be put into small groups or partners, assigning the roles of either predator or recorder. The students who are "birds" will have a short allotment of time to go and collect as many "worms" as possible. When the time is up the "birds" should tell the recorder how many of each color worm they were able to collect. The "worms" collected are considered dead and cannot reproduce, but the worms left on the field are able to reproduce so the teacher adds one more of each surviving color to the field (students should not look where the teacher is placing the yarn during this time.) The "birds" are then given another opportunity to collect as many "worms" as possible. Once the recorder has information collected for several generations of worms each group can then graph their data and see that the color of the yarn was in fact an adaptation. As a class the teacher can also lead a discussion ensuring the students understand that variations can sometimes lead to adaptations that help an organism survive, and also help the students understand that the organism could not choose or acquire the adaptations. Teachers could easily account for mutations by simply cutting a small number of strings into smaller or larger pieces to see if this would have an effect. The teacher could also present a new color to the population. Making these small changes could then lead to a discussion of how evolution could occur due to mutation becoming adaptations.

The Camouflage Lab is very similar and takes place indoors. Instead of having an outdoor environment the teacher can give each group of students a piece of wrapping paper, or any paper that has some kind of design or color pattern. The concept is the same as the Woolly Worm Lab; one student will take several different colors of hole-punched paper and spread it over the "environment" and another student will be given a time frame to collect as many dots or "organisms" as possible. The colors collected are recorded, and the original student will add more of the surviving colors to the "environment" for the next generation. After several trials have been completed the students can graph their data to see which color was best suited for the environment. A difference between this activity and the Woolly Worm lab is that the teacher can offer many different "environments" by giving different groups paper with different patterns. This would allow a class discussion of how one trait may be an adaptation in one environment, yet that same trait may not be an adaptation in another environment.

Another lab that demonstrates how variations can be adaptations is the Peppered Moth activity. This activity is used by four of the teachers who participated in this study. Instead of letting the students gather the data; this activity shows the students a table of data that provides the year and the number of different colors of moths. Students graph the data and see that during the Industrial Revolution the color of the moth changes from a light color, when there was not as much pollution, to a dark color, when pollution worsened due to factories. Students are then asked to explain reasons for the change in color and they are lead to the conclusion that as the pollution covered trees and buildings, the lighter moths died off due to predation and left the darker moths to survive and reproduce, thus making them the fittest for the given environment.

While this activity gives good graphing practice to the students, and allows them to come up with the conclusion on their own, this activity is flawed. The peppered moth has come under criticism as we learn more about the feeding mechanisms of the predators of the peppered moth. It turns out that the original researcher, Bernard Kettlewell, had many problems with his experiments that lead to doubt among the scientific community (www.truthinscience.org, 2010). Some of these experimental flaws included releasing too many moths thus creating a predatory breeding ground, placing them on trunks of trees where they are not found naturally, and releasing them at the wrong time of day (2010). Any and all of these flaws could provide misconstrued results. The data collected does not reveal large-scale evolution of a population either. This species of moth studied can show phenotypic expression of either color combination. Although his activity is flawed in background information, it is still suitable for showing small changes of frequency between members of the same population; however the teacher should not use this activity to show large-scale evolution of an entire species.

Natural Selection is a topic that four of the seven teachers interviewed said they focused on greatly during the unit of evolution. Activities discussed include: Teddy Graham Bear Lab, Woolly Worm Lab, Camouflage Lab, M & M Lab, and the Beak Activity. All of these activities give the students a chance to visualize natural selection of a "species" within one class period, whereas in nature this process can takes hundreds of years. Each activity includes a species of prey, which is represented by Teddy Grahams, pieces of yarn, paper, M & Ms, and even dried pasta respectively. With each lab the student is the predator and preys on the different "species". With the student picking the different traits they prey on, or being told which traits to prey on, they can see how this effects the prey population. This is very similar to the peppered moth; however the student is responsible for gathering his or her own data and evidence to show the mechanism of natural selection, and not depending on the teacher to provide all of the information.

The Teddy Graham Bear Lab is very similar to the previously discussed Woolly Worm and Camouflage Labs yet takes even less set up by the teacher and includes practice with the Hardy-Weinberg equation for population changes due to allele frequency changes. A procedure for this activity is found in Appendix D entitled: "The Hardy-Weinberg Theorem and Teddy Grahams". This activity may seem simple to students who prey on "happy" bears, but after gathering the information they must apply the Hardy-Weinberg equation and explain their results in terms of allelic frequency. Before doing this activity it is important that the teacher has explained the equation and how to apply it to data sets. The county where this study took place has the evolution unit after genetics thus students should have prior knowledge regarding alleles and genotypic expressions.

The Latest Beak activity is very easily differentiated between the different features of inquiry. This differentiation can include when the lab is used (beginning or end of unit), but it can also be differentiated based on how the teacher explains and implements the activity. In general this activity involves the students picking a “beak”. The beak choices include: tweezers, spoons, forks, and toothpicks. Once the students have a beak, they are given different food sources such as rubber bands, dried macaroni pasta, paperclips, and beans. (The teacher can change both the beak selection and food selection based on materials available.) Students must be able to “eat” certain foods at different times with their beaks. If a student is not able to get enough food, then he or she “dies”. The activity continues and students are able to see which beak is best fit for different food types. It also shows that when a food source is taken away or changes, the beak does not automatically adapt with the source. Once a student has picked a beak, they may not change the beak when the food source changes.

The Latest Beak Lab models both natural selection and adaptation, both of which are concepts that participants in this study say they give more focus to. Unlike the Rat and Squirrel Island activities, students are not allowed to choose to change the adaptations for the beaks. In The Latest Beak activity students are able to see that when the food source does not match the feeding mechanism, they cannot choose to adapt. This lab is also a good visualization for natural selection due to the fact that survival of the fittest can mean different things for different species depending on available resources. This activity allows the student to see that fitness of beaks depends on the available food source. Many students tend to equate fitness with strength and size (researchers’ observations), when in nature this is not the case; an organism that survives well in the forest may do poorly in the desert.

Teacher G stated that he struggled most with starting the unit of evolution due to its’ controversy and Teacher E also stated that he struggles with the unit due to the students taking the topic so personally. One activity that could possibly ease a student into the scientific mindset and ease the hardships of teaching evolution is the activity that includes the article, “Sex, Drugs, and Rock n’ Roll” which is actually an adapted version of Stephen J Gould’s essay, “Sex, Drugs, Disasters, and the Extinction of the Dinosaurs” which was originally published in *Discover Magazine* in 1984. A teacher could use either the adapted version or the full article for the class activity. Teacher A mentioned that he uses this article to introduce the unit of evolution; one could even do this without telling the students what the new unit is.

The article presents three ideas, or hypotheses, of how the mass dinosaur extinction played out millions of years ago. Students are asked to read the article and decide which hypothesis has the most scientific support. The first hypothesis involves sex. In the article Gould suggests that global warming during the Cretaceous period raised the body temperature of the huge lizards, thus making it so they could not reproduce. The second hypothesis explains how flowering plants, angiosperms, evolved around this same time. The dinosaur extinction could have been due to the fact that these angiosperms were producing psychoactive chemicals (drugs!) that the dinosaurs were ingesting. Gould explains that mammals would most likely avoid these plants due to their bitter taste, or, if mammals did eat these toxic plants, the liver would be able to break the toxic compounds down.

The third hypothesis discussed is rocks. The rocks idea discusses the asteroid that hit the earth approximately 65 million years ago. Gould explains that even though this asteroid would not kill all life on site, it would create a dust cloud that would block sunlight for a significant amount of time, ceasing the process of photosynthesis and forcing the earth's temperatures to drop dramatically. Mammals would be able to survive due to their small size at the time and small needs for energy for survival.

In the teacher instructions the author who adapted this article for classroom use, Teacher A, points out that although all three ideas are good and even plausible, the last one has the most scientific support. According to this activity, the teachers' instructions explain that the sex hypothesis is short on scientific evidence because testes do not fossilize well enough for us to study optimal reproductive temperatures. The drugs hypothesis is also lacking because we do not know how the dinosaur taste buds or how livers worked because they do not fossilize either. This idea is simply an inference based on the evolution of angiosperms coinciding with the dinosaur extinction.

The final hypothesis of the asteroid has the most scientific evidence. Even though no one was there to witness an asteroid hitting the earth, we can study the levels of iridium found in the earth's crust. Iridium, which can only come from an extraterrestrial body such as an asteroid, shows up in the earth's crust during the same time frame of the dinosaur extinction. This hypothesis also leads us to more experiments and tests regarding the mass extinction. For more background information Walter Alvarez (1997) offers a full explanation of the collision that caused the extinction in his book *T. rex and the Crater of Doom.*

"Sex, Drugs, and Rock n' Roll" is a good starting activity for the evolution unit because it lets the students find and gather the information needed to explain what a useful scientific theory or hypothesis is. While reading the article students are encouraged to discuss which of the hypotheses they think have the most scientific support and why. Through guided discussion, the teacher can explain that some concepts can be explained in many ways, however, in a science classroom, we must focus on the scientific hypotheses. The article goes on to explain that the first two ideas could indeed be correct, but they lack still lack evidence. Students will relate this to the controversy of evolution. In this controversial unit many believe teachers should include other ideas of how life originated and how it changes over time such as teaching creationism or intelligent design. A major problem is that these two ideas are not scientific because they are not backed by scientific evidence and cannot be tested.

A teacher can utilize "Sex, Drugs, and Rock n' Roll" to discuss with students that although there may be several plausible ideas to explain how organisms change over time, in a science classroom the focus must stay on the scientific theory, which happens to be evolution in this case. Once the students do not feel their belief systems are being threatened they may be more inclined lose their apprehensions and stay focused on knowledge rather than belief. For the students that are not resistant, this lesson is still a good reminder about the difference between scientific theories and plausible ideas that lack evidence.

The Phylogenetic Tutorial Project collected is one the few activities that involves all five features of inquiry. Students are put into small groups (3-4 students) and are given the task to organize different "animals" into the correct evolutionary sequence. In order to complete the task students must first observe and categorize the "animals" based on similarities and differences found. Students must then create their phylogenetic (evolutionary) tree that shows the relationships and evolution of these organisms. Once the students have their ideas about where certain "animals" should be placed, they are allowed to share their explanations with the teacher, and finally each group will present their phylogenetic trees to the class and explain the placement of each organism. Even though the "animals" found in the Phylogenetic Tutorial Project are imaginary, students can relate them to animals that exist now. This project takes the students through each feature of inquiry, which includes letting the students compare and discuss their explanations.

Other activities mentioned by the teachers interviewed include guided reading bookwork, Foldables, and Graphic Organizers. All of these activities can be useful in a classroom so long as they are utilized properly by using them to either assess knowledge throughout the unit or as reinforcing study tools students can use. Foldables and Graphic Organizers are an excellent way to help students organize the information and thoughts in a creative way that they can use to study and reflect on throughout the unit. The Foldable mentioned by Teacher E can be found in Appendix C. He uses the Foldable to help students organize concepts of different patterns of evolution: Coevolution, Divergent Evolution, and Convergent Evolution. To implement the Foldable, students list the types of evolution on "doors" which open to have the information listed on the inside. This allows the student to be able to quiz him or herself and to help better learn the concepts of evolutionary patterns. The Graphic Organizer is a way the students can organize notes more visually with topics organized together in a flowing manner. One example of a Graphic Organizer is a Frayer Model, which is an adaptation to a concept map. An example is shown below in Figure 5.1

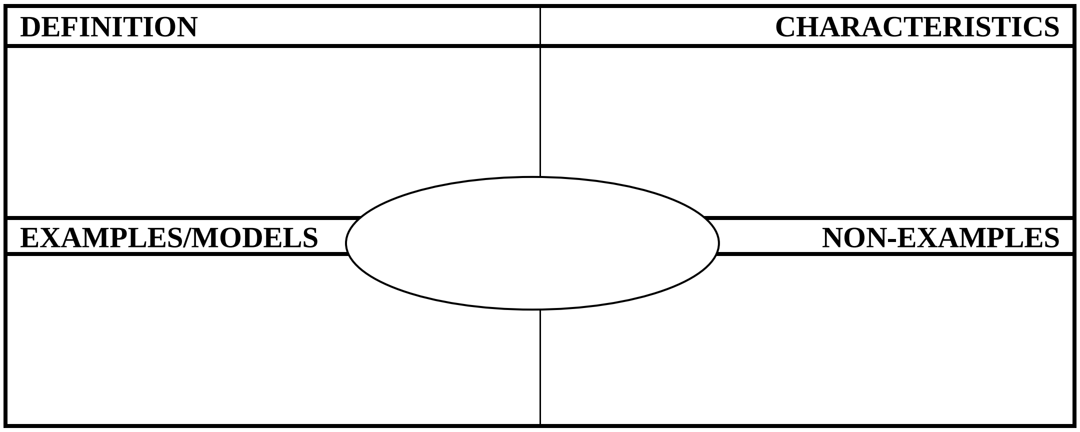

Figure 5.1 Frayer Model Template. Can be used with multiple concepts to organize data.

The Frayer Model can be used to organize data on the overview of evolution itself, or a teacher could break evolution into several smaller topics such as coevolution, natural selection, adaptive radiation, and use multiple Frayer Templates. The concept being discussed is placed in the center circle of the model and the student adds information to each appropriate section.

As stated previously, participating teachers tend to give activities surrounding visualization activities and comprehension activities such as bookwork and Graphic Organizers. No teacher offered any activities or lessons based on the origin of life or human evolution. Perhaps this is because these two areas of evolution are the most difficult to teach due to the "subjective evidence" as stated by teacher B, or simply because of the difficulties these topics bring to the classroom. The fact that many teachers do not cover these topics could be due to the standards used by Gwinnett County (see Table 2.3). The standards for this unit (as with any other unit) are open for interpretation by the teacher. The standards do involve fossil records and the change of populations over time (SCBI_B2005-12), but phrases such as "human evolution" and "origin of life" are never specifically stated. The teacher has a choice of interpretation when planning the unit of evolution. Perhaps the teachers interviewed choose to simply stay focused on other organisms, and not go into detail regarding humans in particular. A teacher making these choices of omission is still teaching the standards required by the county and avoiding possible conflict in the classroom.

Although no human evolution activities were mentioned during the interview process of this study that does not mean these activities are not available. The University of Georgia has an extensive skull activity that is an excellent resource for students to actually see the evolution of the primate family by using skull replicas of actual species. Students get hands on experience with the skulls during the experience. They are required to each handle a particular skull either individually or in groups (depending on the size of the class). The students must first gather evidence about their skull by taking measurements and then use a dichotomous key to find the genus species name of the skull they have. Once all students have found out which skull they have they must then work together to put together a "family tree" following the correct timeline of evolution of the different species. This is an excellent way of first showing the similarities and differences between humans and other hominid and primate species along with seeing the different branches of phylogeny and timescale.

As the skull program grows, more teachers are requesting visitations and demonstrations. In 2008 a teacher could request the skulls only a few weeks before the date needed, and currently in 2010 teachers needs to put in the request months in advance to guarantee a time slot. This goes to show that more teachers are becoming comfortable with teaching human evolution in the classroom despite the difficulties and controversy this topic may cause. In my own experience I have found that students have a hard time arguing with the evidence right in front of them. Hopefully the students do not see this as a challenge to their belief system, but simply as scientific evidence that humans are animals that change over time just like all other animals.

Self Reflection

Even as a child, the topic of evolution has always intrigued me. Before I knew who Charles Darwin was or of the mechanisms and terms that go along with the theory, I saw my world as one of change. When I was six years old I had dreams of becoming a paleontologist and imagined digging up dinosaur bones in my backyard. Needless to say when Stephen Spielberg's *Jurassic Park* came out I was in the front row sitting with my dad aching to become part of the action. While growing up, I noticed that many of my peers had a common question about dinosaurs: if dinosaurs existed then why aren't they in the Bible? This question led a few of my friends to reject the idea of fossils altogether, but I never understood the conflict.

My passion for dinosaurs later extended to a passion for science and observation as a whole. Even though I did not enjoy my high school biology class, I still appreciated the subject and went on to make biology my college major and, finally, I became a high school biology teacher. When I first started teaching in the Fall of 2007, my goal was to give my students the opportunity to love the subject as much as I still do by giving them hands on lessons and allowing them to gather their own data regarding each unit. In high school my clearest memory of biology class is sitting at a desk and answering questions out of the book with very little hands on activities. I vaguely recall covering the unit of evolution at all.

My first year of teaching was a rollercoaster of lesson planning, grading, meetings, and coming up with new and fun ways to teach different concepts. I was lucky enough to work at a high school that valued collaborative teaching and sharing ideas. Due to these collaborations and sharing times I was able to gather many different strategies my very first year, and from then I was able to adapt these ideas to my own teaching style. My favorite unit to teach has always been evolution. I love the challenge of helping students learn a very difficult topic, and I have grown so much since that very first year of teaching, especially in this area. Throughout my four years of experience I have gathered and adapted several different lesson ideas. Every year I try to add something different to my plans; whether it is a brand new activity, or simply an adaptation of one I have already used. I am by no means an expert, but evolution is a topic that I truly enjoy. It is very intriguing to be able to look at the fossil record for a given species and visually see the differences between the organism now and those that lived over a thousand years ago. It is also amazing to be able to see all of the organisms that once existed but now don't, such as the dinosaurs!

We can learn so much about our world by simply being open to look at and understand the evidence we have. Some may see this evidence as a threat to their belief system, and others may view it as puzzle with an infinite amount of pieces to fit together. I fall into the latter category. I have always been able to separate religion from science. When there are overlapping ideas I use categories; science answers the “how” and religion answers the “why”. Throughout this study I have grown stronger in both realms.

In my first year of teaching, my strategies and plans were mostly based off of other teacher’s ideas. To start out my unit of evolution I decided to do something different from the rest of the biology department. I used the skull activity to begin the evolution unit. I learned that year to keep some ideas to myself, or at least to let other teachers make their own reservations for the skulls. That year I had four other teachers ask to take part in the activity. Four teachers may not sound so bad, but multiply that by 150 students that each teacher brought and we ended up reserving the school’s auditorium! Despite the large numbers of students the activity was a success, and my students were officially opened up to a world of evidence they had never seen before.

The next year I used the skulls again, except this time I told the other teachers they could reserve their own dates! That year, because of the smaller number of students, they were able to work with more skulls and get a more in-depth experience. Using this unit as an opening activity seemed to answer so many questions the students had right at the beginning. I was not telling them to accept the information, but allowing them to first understand the evidence.

Despite incorporating the skull activity into my unit, my first experience with student resistance towards evolution was during my first year of teaching. About a week into the unit of evolution one student raised his hand to ask a question. Instead of simply asking his question when called upon, this student came to the front of the class to question me as directly as possible. After having everyone’s attention in class he smiled victoriously and asked, “If evolution really exists, then why are men missing a rib? God had to take it away to make women!" I remember feeling speechless, and a little surprised at the confidence the student conveyed. After the student sat down I attempted to break down the prior knowledge he had been building up by explaining that we all have the same number of ribs despite gender. I am not sure what this new knowledge meant to the student, or if he even let the correct information in.

Prior knowledge can play a huge factor in the classroom. At times, when it is correct, prior knowledge can help the students gain more knowledge and build more detail. However, when a student has prior knowledge that is wrong, the teacher has to first re-teach the incorrect concepts before moving on. From this incident I learned it is very important to assess prior knowledge, and learn what I can build on, and what I must reconstruct.

My lesson plan for evolution changes a little every year. Some activities are changed or taken away completely! One example of an activity I no longer do is Squirrel Island. This activity was discussed previously because teachers who were interviewed use this activity as well. I have examined this activity over the years and I feel it does not properly teach the concepts found in evolution. This activity appears to more reflect Lamarck's incorrect theory of acquired traits. When assessing students' knowledge on adaptations after completing this activity, many students were confused regarding how an organism got an adaptation in the first place. Students were under the impression that an organism could change itself depending on the environment it is placed in, which is not the case! When teaching adaptations and natural selection I now have activities where the students can see that an organism can die in a certain environment if it does not first have a variation that allows it to survive.

Throughout the years I have also incorporated more activities where students gather evidence and come to their own conclusions. Several of these activities involve comparing DNA strands of different organisms to see the biochemical evidence for evolution along with the visual evidence. From the DNA strands students can see the chemical similarities and differences between organisms and gain a better understanding of what it means to be "related" to another organism. Table 5.1 includes different lesson plans used during my first, second, and third years of teaching. Over the years not only have I made changes to lessons, but I have been able to collaborate with new teachers on lesson ideas. I find that it is important on a personal level to make changes to my lessons in order to keep a fresh and up-to-date view. The world of science is constantly changing and being updated with new information and knowledge. It is very important we give students the most up to date information possible so they are prepared when they go onto higher levels of learning.

During my second year of teaching the Science Coordinator attempted to change the evolution unit regarding the placement on the academic calendar and the time allotted to teach evolution. In 2007 the academic calendar gave evolution 3 weeks after the genetics section. In the beginning of the 2008 school year the science coordinator for the county emailed the new academic calendar changes including moving evolution to the second unit of the year and only allowing one week. This was a prime example of an educational leader fueling the controversy of evolution education. By attempting to move this unit the science coordinator was demeaning the theory by not allowing an appropriate amount of time to teach the theory and also by not allowing the students to first learn key concepts such as DNA and genetics that are important factors of evolution. Several teachers wrote letters of objection (myself included) and just a few days later the change was revoked: The unit of evolution continues to follow the unit of genetics and DNA.

By my third year of teaching I was more confident in my lesson planning and teaching strategies, and I continued to add different styles and activities. I also transferred schools that year and began working with a new set of teachers. This helped to add to my teaching strategies even more. Teachers are known to "beg, borrow, and steal" ideas and lessons. At my first high school we were all willing to help each other out with ideas and this resulted in us using the same types of materials and lessons. When I transferred to my current location I realized that there were so many more ideas and lessons from other groups of teachers at different schools. At the time of transfer the high school was a brand new, thus all the teachers came from different schools and we all had different lessons and strategies for teaching different units. During this year I gathered new activities for evolution that were based on students analyzing data and evidence to go along with my several visualization activities.

Another factor that has helped me become more successful at teaching evolution has been completing this study. I have had the opportunity to discuss with other teachers different strategies for teaching evolution along with dealing with adversity, time commitments to the unit, and difficulties within the unit of evolution. Gathering this information has helped shape my own evolution unit and teaching strategies. By collecting different activities and strategies I have increased my own database of options to use during my unit. I have adapted several activities to my teaching style, and I have also adapted several strategies such as Graphic Organizers and Foldables for units other than evolution. By discussing how other teachers deal with adversity in the classroom during the evolution unit I have become more confident when handling students who are resistant to learning evolution. By implementing the article "Sex, Drugs, and Rock n' Roll" at the beginning of the unit I have been able to better explain to my students why evolution is the scientific explanation for changes over time, but that it does not mean other ideas are not necessarily wrong, they simply are not scientific. To better visualize how my teaching strategies have changed throughout this study in regards to the unit of evolution Table 5.1 has been included and a list lesson plans for years one, two, and three.

As seen from Table 5.1 several activities for this unit have been changed over the three year time period. Activities such as the "Hunting for Bunnies" and "Rat Island" were not used at all during the third year of teaching while The Bean Lab has been used each year for visualization purposes. Just as the activities and plans for evolution have changed over time, so have my notes. During the third year I gave activities that allowed students to gather evidence before giving students the notes. This was done in an attempt to allow the students to understand the concepts on their own and using the notes as a reinforcement to ensure comprehension. This is the opposite of the first year of teaching when I used the activities to supplement the notes given.

One area that I need to work on is using more features of inquiry as suggested by Lee Meadows. Many of my lessons and activities may be considered to fall within the first, second and third feature of inquiry simply by the placement of the activity in the unit and how much information I provide the students regarding instructions. Many of the activities I incorporated during my third year of teaching allow the students to investigate the physical or biochemical evidence and then come up with their own explanations and conclusions. In the future, to meet the fourth and fifth features, I plan to have the students compare their explanations with other students and have them communicate their final conclusions either as a class or as a written assignment. Perhaps by coming up with their own conclusions they will better understand the concepts.

In my classroom, my goal is to provide students with several hands on activities that show the concepts I am teaching. To ensure the concepts are being understood by the students, I include Graphic Organizers and guided reading materials, but the focus stays on inquiry-based instruction and hands on activities. One aspect that has not changed throughout my years as a teacher is that I have always felt that differentiation is important during all units to make sure all students are reached regardless of learning style. Over the years I have strived to become better at differentiating my lessons and assessments by gathering ideas and coming up with new ways to teach.

Reflecting on lessons and activities is important during any unit, but I have found it to be particularly helpful in the evolution unit. Evolution is a concept that could potentially affect a student's belief system. This unit is not only learning about how life works, but learning about the scientific explanation of how life started and continues to change. Several students have their own misconceptions and prior knowledge that does not match up with the scientific evidence. Reflecting on activities and inquiry in the classroom could help the student be more willing to accept the scientific knowledge. With this being said, please note that it is never my goal to change a student's belief system, but an outcome of changed perspectives is very possible within this unit. Students should be able to discuss results and evidence gathered during class and to the concepts together with guidance and support in the classroom.

Even if a student never accepts the evolution theory, it is important they understand the concept and why it is the unifying framework for biology.

Table 5.1 Lesson plan overview comparing activities used during the first, second, and third years of teaching. For a description sample activities see Appendix D.

Day	Year 1: 2008	Year 2: 2009	Year 3: 2010
1	UGA Skulls	-"Sex, Drugs and Rocks"- group work (C9)	-"Sex, Drugs, and Rock n' Roll"- Read and work on questions individually (C9)
2	-Bunny Hunt - Introduction to Evolution Notes	- human evolution: UGA Skulls	- "Sex, Drugs, and Rock n' Roll"- follow up, group discussion. (C9) -Ticket out the door: List five things you already know about evolution
3	-Finish Notes - Patterns of Evolution Foldable	Human Evolution: UGA Skulls	- Explorations Through Time computer lab
4	- Peppered Moth Survey (C2)	- Primate Hand Lab	- Biochemical Evidence for Evolution Lab (C7)
5	- Natural Selection with Beans lab: (C6)	- Explorations Through Time Computer Lab	-Using Comparative Genetics to Evaluate Evolutionary Relationships (C11)
6	- Adaptation Pine Needles Lab	-Notes over introduction to Evolution: Darwin, Natural Selection	- Notes: Darwin and Natural Selection
7	- Rat Island (C4)	-Notes continued: Patterns of evolution	- Finish Notes
8	-Rat Island Day 2	- Patterns of Evolution Foldable- (C8)	- Phylogenetic Tutorial Project (C3)
9	-Present Rat Island animals	Create a Species Project (Rat Island Modified)	-Geological Time Scale Flipbook (C12)
10	Review	- Work on Species Project	-Fossil Study (C10)
11	Test	-Finish Species and present to class	- Finish Fossil Project
12		- Pine Needle Lab- Variation	- Patterns of evolution Notes: Coevolution, Divergent Evolution, Convergent Evolution
13		- Predator Prey Lab	- Finish notes - Patterns of Evolution Foldable (C8)
14		- Darwin's Birthday Party: Natural Selection Game	- Natural Selection with Beans Lab (C6)
15		- Review	- Review
		- Test	Test

I have had several students stand firm on the stance that they will not accept evolution no matter how convincing my strategies are. Even though this is sometimes the case, I still feel I am productive as an instructor of evolution. As a teacher it is not my job to change belief systems or make someone accept any of the scientific theories presented. Sometimes the best I can do is ensure that the students have all of the knowledge they need to make their own decisions about what they choose to accept. This is also an area I have improved upon over the last few years. During my first year I questioned how people couldn't understand evolution and did not understand why others saw evolution as some kind of belief system itself. After interviewing other teachers, and hearing their own stories from teaching this unit, I have come to accept that it is simply not my job to make students accept the science.

Over the last three years of teaching I have come to realize that I never teach a unit the exact same from year to year. Every year I reevaluate my lessons and I work with other teachers to get new ideas for lessons in my classroom. I feel this is what makes me a successful teacher. I constantly try to make the concepts taught more accessible to my students. What works with one set of students, may not be as successful with the next set. I feel it is important each year to learn and understand my students, so that I can better help them learn and understand the knowledge I teach in the classroom. I cannot imagine there ever being a time when I give the same exact lesson twice; my aim is to continue to add ideas and strategies to my database each year.

CHAPTER 6: CONCLUSIONS AND IMPLICATIONS

The aim of this study was to gather and analyze different strategies different teachers use within the content unit of evolution. Through this study I have found that components missing in the classroom are evaluation and communication of data and concepts taught. Students go through the features of inquiry but stop at the third feature of forming explanations. As stated in the results, only two teachers mentioned labs that involve students presenting their data and discussing their explanations. Future studies could determine whether or not these features are necessary for student acceptance of concepts found in the evolution theory.

Evolution is a concept that implies controversy simply by the name. I have known teachers who don't refer to this unit as evolution, but as "Descent with Modification", or the unit of "Change over Time". There could be many reasons causing this change of title, a few of which may involve personal conflicts a teacher may have with the unit, or a teacher wanting to avoid a controversy in the classroom. The controversy of evolution needs to be dealt with at the level of the high school classroom. By gathering different strategies and activities this study has begun the process of finding out first how teachers are teaching the unit; and in the future this may lead to more studies of what teachers can do differently to help high school students better understand the all encompassing topic of biological sciences. High school teachers are responsible for preparing students for the college level of learning. Changing a unit's name in order to avoid a conflict (personal or public) does not make the unit go away or make it become less important to the scientific community.

Areas that teachers struggle most with include topics such as human evolution and the origin of life. Although these topics are not mentioned specifically within the GPS or AKS standards, they are both topics that involve evolution and they are both arguably the cause of the religion versus evolution conflict. Other areas of concern are how to do deal with resistant students, or simply dreading the inevitable conflict this topic can cause in the classroom. The seven teachers interviewed during this study appear to be able to put their personal beliefs aside in the classroom and stay focused on the scientific concepts. Only two teachers mentioned that they would be okay with giving an alternative assignment for the unit, while all others agreed that evolution is a state, as well as county, standard and students should be accountable for all information taught during this unit (SCBI_B2005-12).

Of the several different activities collected during this study, none fully follow the inquiry-based instruction presented by Lee Meadows found in *The Missing Link*, and few follow the guidelines given by Judy Jenson in *NSTA Tool Kit for Teaching Evolution*. Although some of the lessons include the feature of inquiry-based teaching, most were based on visualization (laboratory activities) and content (Foldables). Both types of strategies can be successful, but both lack important steps in that is prevalent in any scientific concept: Gathering evidence and communicating results. Because evolution often clashes with different belief systems, it is possible that within this unit students may be more likely to accept the scientific theory if they are allowed to make their own conclusions based on evidence rather than being told the facts.

While this study is a start in the investigation of evolution education, there are several other studies that can be done to further understand how evolution is being taught and to find out which strategies are most successful. In future studies more schools across Georgia could be included to assess whether different school systems teach the subject of evolution in different ways. To find which strategies and techniques are most successful, a study that involves pretests and posttests could be given in classrooms that use different techniques. The current study assumes inquiry-based learning is the best, but this is not necessarily the case. Regardless of how and when the evolution unit is taught, the teacher must be well prepared and include many different teaching strategies to better educate the students. A controversy that has been going on for the past century will not end over night, but with the correct approaches perhaps teachers can start breaking down this misunderstanding by confidently and accurately teaching evolution as both a scientific fact and process in the classroom.

Although we continue to gather evidence in support of the scientific theory of evolution, the fact remains that people take the subject very personally. In order to educate the community that evolution is not under fire in the scientific realm, we must first start helping students better understand the concepts in the classroom. This study is a small step in breaking down the barriers so many people have against evolution. By collecting different strategies and assessing the ways evolution is being taught in the classroom, we can now investigate further to find which of these strategies works best for student comprehension of evolution.

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APPENDIX A: SAMPLE INTERVIEW PROTOCOL QUESTIONS

- How long have you been teaching?
- How long have you taught biology at the high school level?
- How long do you spend on the unit of evolution?
- Are there any areas of the unit that focus on more or give more attention to than others?
    - If yes:
        - What are those areas?
        - Why do you focus more on them?
        - How long to spend on that section?
- Do you feel there should be anything added to the AKS standards of the unit of evolution?
    - If yes:
        - What topics should be added?
    - If no:
        - Should any standards be taken away?
            - Why?
- How much time do you think is adequate to effectively teach the unit of evolution?
- How much time do you realistically use to teach evolution?
- On the academic calendar provided by Gwinnett County, where do you think evolution best fits?
    - Why?
- During your planned unit of evolution do you provide your students with more activities and labs or more desk work such as book work and worksheets?
    - Why?
- What are some specific labs and activities used?
    - Which are the most successful? Why?
    - Do you consider these labs and activities to use inquiry? Why?
- What is the most difficult topic to approach in the unit of evolution?
    - How do you teach this topic?
    - Do you use more desk work or more inquiry activities with this topic?
- Have you ever encountered student adversity toward evolution?
    - How do you handle this in the classroom?
- If a student were to object to learning evolution in the classroom and refuse to complete the tasks given how would you handle this situation?
- Do students ever ask you about your personal feelings toward evolution?
    - If so:
        - Do you discuss your beliefs in class?
- Do you think it is appropriate for a teacher to discuss personal beliefs in the classroom? Why/Why not?

- There is a very strong debate between religion and science when it comes to the topic of evolution. Would you ever (or have you ever) allow a classroom debate regarding the religion/evolution controversy?
- Do you think allowing students to talk about their beliefs regarding evolution in a controlled and safe environment would be helpful to students in order to help them understand the science background of evolution better?
- In your own opinion, do you think you effectively and objectively teach students the standards of the unit of evolution? Why, why not?

APPENDIX B: INTERVIEW TRANSCRIPTS

Transcripts: Teacher A (Interview)

Researcher: So my first question is how long do you spend on evolution?

A: Well you know that I am teaching mostly AP courses

R: Yeah

A: And it's a long unit. Actually one of the things I begin at the beginning of the year is kind of introducing evolution as the fundamental organizing principle of biology.

R: mhm

A: so um we start there and we start with trying to explain what science is, you know and that science is a way of learning using observation and that ya know and whatever we can observe is what we can use in science. There's a reading that we do called sex drugs disasters and the extinction of dinosaurs and the main jist of the article is that science cannot work with uh questions and ideas that cannot be tested uh empirically, by measuring, counting, testing do experiments. So that limits the scope of science and does not mean that things that can't be tested can't be true. It just means that science has no way of talking about them. And the reason I begin there is because to me that's really where the big arguments which are kind what I think are misunderstandings are um really take place related to evolution. I think the difficulty is that people don't understand that the whole endeavor of science is explaining things and using observation. So things like religious faith, and those types of topics you know science has nothing to say about them. It's not hat science can disagree with them, it says those are things outside the boundaries of science

R:Yeah

A: And so you know once we kind of establish and say science can deal with those kinds of questions but it can't deal with questions that have to do with revelation or we might we might say subjective understanding. One example we talked about both is saying, you know, I believe that love is the most important thing in the world and I bet a lot of people feel that way, I believe that being truthful is the most important thing in the world, or even an important principle. But those are not things we can measure or prove using scientific understanding, so say to me those are more important than scientific truths, and yet science has nothing to say about them

R: Right

A: so it just points out that there are different ways of knowing. And then once you've kind of established that, then it's very easy to help them understand why creationism falls outside of the realm of science

R:Right

A: You know we talk about what is the beginning understanding of talking about creationism is faith, and if you begin at that point you realize that science doesn't have anything to say about that. So creationism is a religious viewpoint related to science but it's not a scientific viewpoint. Um so then we get to the point of talking about evolution, and you know no matter how much it makes sense to me, it's still an emotional topic so I always try to say something to them like this is how science understands you know how things have changed over time

R: mhm

A: And uh, it does not mean that necessarily you have to accept these ideas, but it is important to understand them

R: Right

A: and you know to understand how science figures things out. Is that a longer answer than you…

R: that was awesome, you actually covered a lot of my questions. So you gave me a lot to write about. So you say we all know evolution is very emotional to students, especially since they are very young and don't really have a good understanding. Which is where we come in and try to give them an understanding. Have you ever encountered in your classroom student adversity toward evolution?

A: Student what?

R: Adversity, they just refuse or disagree in class

A: Yeah. Well you know one of the things we try to do, and it's not necessarily uh something every teacher can really say, but I acknowledge to them that faith is very important to me, um and that in terms of priority it's more important to me than my scientific knowledge. But that I don't find them contradictory

R: Right

A: Um and that you know that I think that what my faith tells me is a different sort of thing than what my scientific understanding is.

R: Right

A: For me, science and my religious faith don't really have conflict. But I also say it's not really fair to say that for everybody because people who have what I would call a literal understanding of the bible and they start talking about the literal interpretation of the bible and then that does , I think those folks their gonna have difficulties.

R: Right

A: ya know, um the one thing I do try to tell them though is I don't think there's any faith perspective that fears knowledge, so when we're, as a person of faith I always say to them it seems important you should know what science says and how it comes to this understanding even if you feel like you're not going to choose to accept it. You know because I don't think any faith perspective says we don't want to be exposed to knowledge and viewpoints. But most of the time, once you kind of uh help them see there's different kinds of knowing you get that answers can be true and still not testable by science

R: Right

A: Or matters can be truth but not be testable by science it kind of diffuses and they kind of have to defend their turf.

R: Definitely, that's what really helped with the sex drugs and rocks article, that helped me a lot with that. Um, let's see. Going to different labs or activities for evolution, do you do many hands on activities or labs or anything like that?

A: well in AP um I mean I think once they've been through the units in AP and they see the enormous amounts of information and the enormous amounts of thinking that kind of makes so much sense. I mean once they realize that whole idea of evolution is built in to DNA, the idea of mutations and genes then it ya know becomes a lot more difficult to say evolution doesn't happen, then they might say ok macroevolution doesn't happen or evolution is used to limit evolution to certain species. But once you start talking about basic things like well ya know talking about population genetics and say evolution is just a change in the frequency of certain genes or alleles from one generation to the next, that's kind of hard to debate and they realize that, the smart students realize that. Once they realize that then they're like ok I accept that it's just the whole idea where humans coming from, you know they kind of believe in the specialness and want to believe in the specialness that humans are the separate entity

R: right

A: And uh then ya know, I don't really try to expand their religious viewpoints too much but occasionally when I see students struggling I say you know it seems to me that um a god who creates a world that is constantly changing is a much more impressive god than someone who stamps a fixed impression of the world. So you know I, that always just struck me as people limiting god with the perception of an unchanging world more than, it has more to do with their own inability to figure it out rather gods ability to accomplish it so.

R: Um Lets see

A: You know one of the things I think that's kind of an immeasurable quantity though is simply being how emotional (interruption by intercom). The same thing saying that all types of knowing are not provable. All types of our beliefs are not necessarly reasonable either. So theres so much invested in religious beliefs that makes it ya know uh dangerous territory to tread on with kids

R: Right

A: I find it a lot easier to teach it AP though

R: why's that?

A: Most of the kids have a more sophisticated way of putting their world together

R: Right

A: and sometimes in CP you have kids that are, you know, just things that are, they put their world together a little bit more um simply

R: Right, they sometimes need something more concrete to look at

A: Right

R: You have answered almost all of my questions. So...

A: this doesn't really help you but I have a buddy of mine whose teaches religion at the university of illionios and he actually got a government grant and is doing a study about the south on public schools that teach the bible. There are public schools that teach religion class

R: I didn't know we could do that

A: Well it happens in the deep south, and in the Midwest there are conservative areas there, um and they tread a narrow line in terms of the constitutionality. But ya know, it's just real interesting talking with him about you know um. Their more what I would call very homogeneous areas where there's not as much diversity, but still there are classes and a number of schools that still teach it. So we talk a little but about evolution and that would be a lot more difficult to teach in those areas.

R: I can imagine so. I mean whenever I am faced with questions of religion I just tell them I am not qualified to teach that. I am a science teacher, I didn't go to seminary school or anything like that, I'm not qualified to teach you about those things because that it what your faith tells you and so I encountered a little bit this semester

A: well and that's a good way of saying, basically this is a different way of knowing and it's not, it's really not science

R: exactly, it answers questions that science can't attempt

A: Our representative, what do you call her, our county um board of education , I can't remember what you call her, our representative. She has a big asterisk line about this particular topic in science

R: Yeah…

A: She's uh, every time we have meetings trying to you know differences about trying to cut and set standards in science, she would always come and we would go round and round about it and uh but you're right, there are a lot of science teachers who are kind of stuck on this particular topic as well and probably are less faithful to what the state requires us to do than we I might think. I mean I know a guy at South who he got himself in hotwater a few times for talking about it but.

R: I remember last year when they tried to move evolution to what one of the first weeks of school and make it last only a week, do you remember that?

A: mhm

R: Yeah that was worrying

A: Well they seem to want to try to avoid conflict as much as they can. I mean there are parts and times they used euphemisms Change over time instead of using the word evolution

R: Exactly

A: And another thing I think, and this is another thing I say um, That is Do you believe that dinosaurs existed, and almost all of them say yes, but you'll find an occasional student that says no I think those are fake. Obviously the earth has changed and so I say to my AP students, I say we all agree that evolution occurs, what's really up for grabs is how and why the change has occurred on the earth. I mean that's what the theory of evolution is, I mean students quite often don't understand that evolution itself is not what's theoretical in science, science agrees that the earth has changed. What is theoretical is the how and why, the mechanism of evolution, that's what Darwin proposed for us, that's what Lamarck proposed for us- a mechanism by which evolution occurs. You can if you choose to say things changed because god made the change on earth. Um it's not a scientific explanation for evolution but its I just I want them to at least acknowledge that it's different. There are some pretty sophisticated kids though, you really find it difficult when you have a really bright kid indoctrinated in certain viewpoints. And uh you know usually I'll tell em I'll say well there are people who say these things and I don't really think they're anywhere close to the big heart of what science is. Science is saying or what scientists are saying, these people are peripheral voices, and so and then I'll say I just really don't believe science has a big conspiracy to try to ya know hoist some crazy idea, I just feel like science is constantly changing, and ya know, they, I don't know, It's one of those things, you would kind of like at some point assess at the end of the year how students viewpoints have changed about evolution , I've never tried to do that.

R: I've thought about that too, I would like to do that

A: But I think it's a dangerous thing because then you really asking them, did I change your perspective, and I think there are kids who'd be real resistant to that and I think you'd have a hard time getting an honest viewpoint from the kids. Maybe it did really change their viewpoint but I do think that it kind of opens their eyes that to not believe in it, then you'll have to do some mental gymnastics ya know just to try to get around the whole idea

R: Exactly

A: Anyway, I have a really nice set of classes this year

R: I have been really lucky with my students for the past 2 years of teaching evolution. Because when I was doing my practicum work in Barrow county I came in at the evolution unit and um there was one student and they, she sat out. She went to the library during science everyday they were talking about evolution. She had papers and alternatives, but they completely backed her and her parents. And she said ok, just to not make waves, so I thought that was kind of a disservice to the students, I mean she needs to know these things. And then she can make up her own mind and all that stuff. But my kids I mean I teach CP all day but there usually pretty good, especially starting with your article, this semester it kind of let them see you know just the different ways of thinking and the different ways of knowing, and it went over really well. I opened with um just the warm up question, How old do you think the earth is? And I put A 1000s, B millions, C Trillions. And in every class I had one or two hands that would say 1000s, and then I said all right, let's go. But uh, Yeah I also think it's very important not tostart slowly bc this is their belief system, that they've had their entire lives, that they've been building upon. You don't want to say, oh you're wrong, You have to listen to what I'm telling you I mean anyone would be defensive at that.

A: We all have things that are fundamental to the way we put our world together. If somebody challenges that, maybe it's not evolution maybe its… but if someone challenged that, or ya know, whether it's your parents love for you, you know whatever, but it ya know, there are things that we don't allow them to be shaken, they're beliefs we don't allow to be shaken and for some people this is one of those little toothpicks that kinda seems to be connected to their faith which has to remain nonviolated. There's a teacher here at grayson, Mr **** that you know he is an incredibly bright guy but I know that he believes the earth is 6,000 or something um and I fought out the scientific idea or scientifically stated ideas that uh laws of thermodynamics and this and that and but when it comes down to it, we're really, we're just arguing we're not, there's not really much to be gained by our discussion because it's a part of it inextricably tied to his belief system. And in that sense like well ya know Im not going to make any headway there.

R: Yeah I did have one student. Stand up last year in third period and he was you know one of the kids who was never here always in ISS and he just stands up, very vocal kid and he's like, well if this is the case then how come guys only have 11 ribs, what happened to the other rib? And I was like,ohh sorry but I mean he knew that! Ya know and …

A: He Knew something, and it's not true

R: Yeah, it's not true at all, and I was like you might save that question for your anatomy teacher.. yeah so this is good. That's really all I had to really talk about unless there's anything else

A: No and you know you want to paint them a visual picture. I always talk about the peppered moth bc that's such a wonderful story of change in the environment and its obviously changed. People can't say well you can't ever see evolution, well you do with the peppered moth, we do with certain species and finches on the Galapagos, you know where we see the beak size fluctuate and that and you know I can see how certain people cannot stand those infinismal changes to say that could become a new species, but if they had a chance to kind of walk themselves through other discussion then I think it kind of helps them understand it and to me that's the whole value of the liberal arts education, I don't think we're just teaching the students to be um mechanics or doctors, we're teaching them to be humans, so I think there's a value in many ways

R: going along with the peppered moth I always ask my students how many of you have had a flu shot? Why do you think you need that flu shot, why didn't the one from last year work? It changed! And I think once the kids can get their minds around the little parts like that we all know about flu shots and now we all know about the beaks of the finch and everything like that ya know we can slowly get around that and then we can start looking at the bigger picture. Good stuff and I guess that's it.

Transcript: Teacher B (Interview)

Researcher: How long would you prefer to spend on evolution?

B: On the calendar we have three weeks.   I would like to spent about six months. There is so much of it that ties into the DNA and genetics and once the kids grasp and understand how it works; it's the basis of biology. So I cram it into three weeks, but if I could have a fourth week that would be great. But we can get it done in that amount of time. But it's one of those topics where you could go on forever.

R: I think we could even spend a year on it. Um Are there any areas that you focus on or give more attention to than others or do you try to keep everything equal?

B: Um. I spend some time on the origin of life. My background isn't great there and the evidence is subjective so the kids have a little difficult time. So I don't spend too much time just because of my lack of knowledge and the lack of evidence. We get into the early evolutionary contributors like Malthus and Dalton and some of those folks, I mention them and how they contribute to Darwin. I spend a decent amount of time on Darwin and how he came about his theories. There was video I share with them Darwin's Secret notebooks, which was inside the American stocks and how they really didn't help him as much as the Galapagos and he was there before the Galapagos. And it all kind of came together at that point and then we spend time with the type of natural selection and the mechanisms, and its one of those things where I would like to spend more time on all of those but it's one of those things where I have to squeeze them in 3 weeks. I might spend a little longer with my gifted kids so they can see the allele frequency changes and understand how populations can evolve even though there's not a lot of mutation happening, but where there's just traits being selected for and selected against.

R: Let's see. Do you think with the AKS we have, do you think anything could be added or taken away from it. Are there things that shouldn't be emphasized or things that aren't emphasized enough?

B: Uh, I would have to look over some AKS. I have AKS sheets correlated to those as far as questions go, and I haven't gone back to look and see how much the AKS has changed. I am assuming what's on my AKS sheets are still valid. For the most part it's a pretty good, raw, general covering of evolution. What I am glad not to see is years ago before you probably even thought about teaching biology they wanted to include Intelligent Design. It was about a fraction of a millimeter from being included in the state coverage . It was going to be up to the county and I had issues with that bc I really teach my evolution evidence based, and anything belief based doesn't come into relevance at all and I would emphasize to the kids that. I allow them to incorporate the two only if they want to.

R: So give them the knowledge and they can do what they want with it.

B: Right and even I have taught kids who are real fundamental Christians that oppose the ideas of evolution, and an argument I always have for that is before you fight the battle you must know your enemy.

R: exactly

B: And what you want to accept this as evidence then what would you use? If you are to argue with somebody then you need to make sure you know what the arguments are coming from so you can better defend yourself.

R: Last year, when they tried to move evolution on the academic calendar to the very beginning and I believe they gave us a week or two..

B: I was one of the big voices that emailed concerns bc to understand evolution- it is the basis of biology as the way we teach it, but you have to have background in biochemicals, and genetics and structure for it to make sense. You could do a big picture but you have to come back to talk about allele frequencies and mutations that the kids would have difficulty… I mean you could have one amino acid, well they don't know how that amino acid would affect and they don't know- it would have been a disaster trying to teach it that way!

R: Right, so are you happy with where it is or where would you put it if you could put it anywhere.

B: It would have to be after DNA and genetics, because you have to have both of them.

R: And we already do DNA and genetics first, so agree. Are there any kinds of activities or labs do you promote in the classroom?

B: Um, we do a Hardy-Weinburg , what I call the teddy graham lab with the happy bears and sad bears- selecting for happy bears, and we just look at the frequency change through natural selection pressure. I also do an adaptation, or camouflage as adaptation where its similar to the wooly worm lab, mine is using fabric, I have 2-2 ½ feet of different fabric and they get different colored dots, and they have a population of a hundred they start with and they scatter there predators, and we use the camouflage adaptatio . The problem with a lot of labs is that evolution is a long process and unless you can show the kids generational time they don't grasp it. So unless you get some sort of bacterial transformation and bacterial resistance, which Rick may do with the AP classes, but with the expense we can't do it all in other classes. So really just the natural selection labs.

R: And you think they are successful to getting the point across to the kids?

B: yes the kids really understand the survival, and it's funny bc I have, Darwin has the 6 points so I have the ****** 5 with Mutation, Variation, adaptation, survival, evolution , and its funny bc the kids really pick up on those bc I have them answer that type of question probably 4 times before the test and they're familiar. The mutation that causes a variety of colors will probably blend in the with the lab that I do, the difference now is the differences in the adaptation are the ones that now are surviving so they have evolution as a change in the population so they see that particular color. So they really grasp that frequency so I think it really does a good job of that.

R: Good, Are there any aspects of evolution that are more difficult to approach and how do handle those difficulties if you have them?

B: Probably the most difficult is the primordial soup, getting to the first cells, that when you look at Miller and Uryes explanation and talk about the protocells and the endosymbiant theory you can see the piece start to come together but theres still 500 million years of a jump that you have to do and its hard for me to grasp so I know its hard for the kids to grasp. The problem I see is there's really they could grasp and have no problems accepting the mutations causing variations which become adaptations. They don't have any problem with that, even people that are opposed to evolution- but they see how that could happen. What they have some difficulties with is the big jumps, where you go from looking like a tapier to looking like an elephant. Where there's major homeobox changes and as a result the kids can't see that because they haven't ever seen that! So it's a little harder from to grasp the major changes, but the minor changes there's no difficulty with those.

R: Have you ever encountered student adversity? I have only been teaching two years so I have actually every year I have had one or two kids, like last year I had one kid who said “If this is true then how come guys only have eleven ribs, what happened to the 12th rib?” And I was like “I have 12 ribs”

B: Kids tend to have a lot of misconceptions. I really don’t ever have any problems because I do a really big thing at the beginning of the year where I talk about beliefs and then evidences and it’s a science is/ science is not activity. SO the kids know that science is evidence based and beliefs are not. And when we get to the evolution unit I kind of reiterate that. But I still have, probably in the 20 years I’ve been teaching I have had probably three kids where anytime I said anything about evolution they just roll their eyes and just real, it was real hard to get them to grasp any of the gists bc they were just so adamant. I have taught superintendents children before, I have taught principals kids I have taught clergy’s children, I do have, I have had a ballpark of kids come through and rarely any of them ever have problem with it bc I present it as a scientific theory based on evidence and bc I’m not trying to force it into their belief system they are ok with it. Most them- except for the three.

R: So if you did have a student to just completely object to the unit and refused to do assignments- this comes from when I did my practicum in B**** county when I just got there there was a student and she had her parents and they made a huge deal out of it so they gave her alternative assignments in the library, so what do you think you would do if administration wasn’t an option and you got to handle it…

B: If I had to handle it, bc it is state mandated curriculum they are responsible for knowing what it says regardless of where it fits into their family or not and if it went to parents and then administration and they needed alternate assignments, the assignment would end up being over something with evolution anyway. So I don’t know what aspect, because it is part of the state curriculum, I don’t know what aspect they could use to get around it.

R: Right, and I am not sure how they did it in B******* county.

B: it’s probably one of those things where if the parents are hollering loud enough you do what you have to do.

R: I think that’s kind of what happened. Do kids ask you about personal beliefs?

B: Yes

R: Do you answer them in class?

B: Um I try not to, but after class some of the kids will ask questions and I’ll share a little bit, not – I don’t go into a lot of detail with them because I merge the two where there is a creator and I go to church every Sunday and it had to get started somewhere somehow- but once its gotten started it is left to its own to develop and evolve, and we are now where we are bc of that development. And I don’t have a problem merging the two together where some of the kids bc they don’t have a strong enough religion understanding and are relatively new evolution they have a more difficult time and I don’t share in class bc they don’t have a foundation in either of the two at this point and for them to try to merge two partials- would make more of a mess than anything.

R: do you think maybe since they don't have a great foundation in either one and a lot of that might be bc they're young- do you think that they would be able to do that when they are older?

B: Yeah, I mean as a college student they would still probably be a little bit less understanding but you can see as you get a little bit older. But in the church and in the sciences things become a little more clear and your beliefs may change a little bit as far as the details but the overall foundation doesn't change. It's just how the pieces fit together.

R: Right, I've never really had a problem with having either one in my life.

B: It's funny bc The catholic church is a supporter of evolution.

R: I have read so many articles on people trying to figure out where this big debate is coming from, and one article was really interesting and they interviewed clergy members to see if it started higher up in the church, if they were feeding this stuff into the kids. The clergy members said they had no problems that obviously evolution is happening. So I have read some really interesting articles

B: Evolution is an issue where it's so- I don't want to say Bible based- but they take the word literally sometimes and we'll have a lot of difficulty deviating from that and in the bible there's no mention of things before modern animals. So the dinosaurs and such, there's no biblical basis for them.

R: Have you ever considered (I don't know if you have ever done this) but have ever considered having a religious/evolution debate?

B: Nope, never considered, never would because religion is a belief and knowing that I go to church every Sunday- but it has no place in a science classroom. Now I do bring up church a lot as examples.

R: whenever my kids ask about it I tell them you know what I'm a science teacher, I haven't gone to school for religion or anything like that. So you need to leave that for your pastor who minister or whoever else you have. But, I tell them I will answer questions after class, but never during class.

B: Right. There are those that are really passionate and give them a partial response and I might share with them

R: all right, is there anything else you'd like to discuss.

B: is there anything else you need?

R: Those are all of my questions and I am just getting a feel for how people approach evolution in the classroom. All of my questions have been covered.

B: Well probably the biggest key, for me anyway is making sure the kids realize that its an evidence based theory and it's a scientific process, whereas religion is a belief based system and we have no business trying to change beliefs and and beliefs have no business trying to change scientific theories. And the kids are ok with that. They learn in sicence that science is not a belief, and they've probably already developed that understanding. And that I think is the key to having them being able to be comfortable with evolution and they realize that they don't have to believe in it. Some of my kids will ask me if I believe in evolution and I say absolutely not, because it's a scientifically based theory backed with evidences and I agree with the evidence but it doesn't come down to me believing in it. And someone will look at me bc it doesn't really answer their question that evolution is a belief.

R: Right and they have to get past that. It's not a belief system, you don't go to evolution church. Well that is all I need. Thank you

B: Hopefully that was helpful

R: it was very helpful thank you.

Transcript: Teacher C (Interview)

Researcher: So I have some basic questions, How long do you spend on evolution? I know we have the academic calendar, but do you follow that specifically?

C: I think I spend 3 weeks, let me check my handy dandy notebook. Yes 3 weeks

R: Do think we should give more or less time to evolution?

C: well I think it's about right. When I first started teaching it I probably could have finished it in a week. And then after teaching and getting ideas from other people I was able to spend a little bit longer. But as a new teacher it was hard for me to figure out what to do.

R: Going along with the activities and everything what kind of class activities have you incorporated into your unit?

C: I do a lot with adaptations. Um and so one thing I incorporate is the Squirrel Island habitat, do you need me to explain it?

R: I know that lesson that's ok.

C: and I do other stuff with evidence of evolution, biochemical evidence, comparing dna strands, peppered moth, looking at fossils and how they change over time

R: do you think that these activities and labs are successful at conveying the information to students?

C: I do. Bc when you first start talking about evolutions they don't really know what route your going to take, they don't know what your going to talk about. SO I think the activities help them see that organisms do change over time.

R: All right, are there any areas in your unit that you give more attention to than others?

C: adaptations, I definitely do a lot more with adaptations. I odn't do a lot with human evolution bc it's a little touchy subject and I don't feel like I know enough about it. Like when you(referring to interviewer) have the skulls , idon't know enough about all of that.

R: So over the three weeks on evolution how much do you spend on adaptations?

C: Um let's see, I can probably, like with activities and everything that I do I spend 3-5 days

R: so 3-5 days out of the three weeks?

C: mhm, I spend very little time on human evolution, and I'm always trying to cram in population genetics and stuff like that.

R: DO you think think there should be anything added or possibly taken away from the AKS that we have in general

C: mm, I don't really know that I would add anything

R: would you take anything away?

C: I would probably take away a little bit of the population stuff and stabilizing, directional, and disruptive selection. Maybe I just don't know it enough but I feel like it's kind of thrown in there. The only thing I would like to get better at or add would be um evolution, like more of a broad view of evolution of animals, or evolution of kingdoms.

R: yeah that would be good. Um so I remember last year when they were trying to move evolution on the academic calendar to first semester change it to a week to two weeks. Would you want to move evolution, or do you think it's good where it is now?

C: I would not want to move it to first semester at the beginning. Because I would definitely feel like I would just throw stuff in then bc to talk about different adaptions but not cover ecology yet would be hard um I think it would also be hard to talk about any kind of biochemical or DNA evidence or anything like that bc we haven't talked about DNA.

R: Right (Intercom interference)

C: So I think it's pretty good where it is

R: Have you ever encountered student adversity?

C: not a lot, really I haven't simply bc when I start the unit I talk about what the word evolve means and it s a change over time, and we're focusing on organisms changing over time and adapting to their surroundings. Now I don't know if that's the right thing to do but that's kind of what I use so far. And I fell like by saying that I don't get some of the adversity.

R: Right. So when I did my practicum at barrow county I came in right on evolution and there was one student that refused and they were having a huge problem with her and the family, and so they ended up giving her alternative assignments and she had to go to the library. So if you were to have a student object to this how do you think you would handle it? If administration wasn't an iddue how would you handle this, would you give alternative assignments?

C: I think I would just talk to her and say you know we're not going to talk about how the earth was created or who created the earth, we are just focusing on how organisms change over time and I thin kthat if you look at the animals you have to agree that they change and adapt to their surroundings. And if she was still adamant about it and her parents were still adamant about notr doing it then I would be fine with giving an alternative assignment. I would not, I personally, honestly its not evolution and the topics of evolution I'm not passionate about them at all, I would not want to force her to make her feel uncomfortable. But I would tell her when it comes to midterms and tests she would have to know it.

R: Right. (Interuption) Would you ever express you personal feelings in the classroom

C: no never

R: Do you think you would ever allow a class discussion between the whole religion …

C: no, I just don't feel comfortable and don't have enough knowledge about different religions or different theories of how the earth was created, I'm very just simple minded and that's it.

R: All right well that all I have, you have helped me a lot

C: good I'm glad.

Transcript: Teacher F (online interview)

Researcher: Thank you so much for helping me today

F: No Problem, glad to do it

R: So let's get started with some basics. How long have you been teaching?

F: I've been teaching for about 6 years, and I've taught both middle school and high school in several different counties. It feels like I've been teaching forever, though!

R: Great how long have you taught biology at the high school level?

F: I've only taught Biology at the high school level for one year, but I taught life science in middle school for two years before that—but not consecutively

R: So are you comfortable teaching at the high school level now that you're here?

F: Oh yeah, it's great to have somewhat adult conversations with students.

R: About how long do you spend on the unit of evolution now at the high school level?

F: This year we spent about three to four weeks on evolution.

R: Are there any areas of the unit that focus on more or give more attention to than others?

F: yes

R: What are those areas?

F: Well, I tend to focus a lot on adaptations and how they relate to natural selection. You know, the kids relate to adaptations well and seem to enjoy scenarios of "survival of the fittest". I also focus a lot on evolution as a vocabulary term, which means "change over time" and give lots of examples of how organisms have changed. Things like antibiotic resistance and the pictures of ancient horses compared to those of today. We also look at Darwin's finches and the peppered moths as examples.

R: Why do you think you focus more on those topics?

F: A lot of times it is because of the religious conflict. I've found that the kids don't really resist it if we talk about it in those terms. It is hard for them to argue about evolution because they can see examples of how organisms, especially animals, have changed over time. They also like to know about all the weird adaptations that unusual animals have. They seem to get into it more if I don't talk about the origin of species.

R: Right, How long to spend on adaptations and natural selection then?

F: Probably about a week on adaptations and a week or so on natural selection. Then we talk about the homologous structures, DNA similarities, vestigial organs, etc.

R: Gwinnet County uses the aks as standards to teach our subjects. Do you feel there should be anything added to the AKS standards of the unit of evolution?

F: I think they are fine the way they are currently. The kids are able to get the concept without being completely turned off to the idea of evolution. I think if we added anything, it might be too much for the religious ones to bear. But if we took anything away, I don't think they'd get everything they need to understand the basics of the theory

R: How much time do you think is adequate to effectively teach the unit of evolution?

F: I think that the 4 weeks is adequate, mainly because we already talk a little about adaptations and food chains at the beginning of the year with ecology. They sometimes already kind of have the big picture by the time we get to evolution.

R: How much time do you realistically use to teach evolution?

F: 3-4 weeks. If I have extra time, then I have the kids do simulation activities on the computer or as a lab.

R: On Gwinnett County's academic calendar provided by the county where do you think evolution best fits?

F: I might have a really hard time answering this. It could fit in so many places, but students really need the units about cells, meiosis, and genetics to really be able to understand. It should maybe be at the end of the year even after classification since some of the concepts in classification are useful in talking about evolution things like common ancestors and closely matched DNA.

R: During your planned unit of evolution do you provide your students with more activities and labs or more desk work such as book work and worksheets?

F: I think I do more of the bookwork and worksheets. A lot is because of time constraints and student motivation and behavior. I don't really think that my students really connect a lot of our labs with the content they're learning. I use a large variety of techniques though, to teach like power point presentations video clips creative projects like fashion a fish, computer labs with simulations, and games and lab activities along with some book work and some worksheets.

R: What are some specific labs and activities used?

F: This year we used a computer game simulation and did a lab that I call “Survival of the Fittest Jelly Bean” to simulate natural selection. In the jelly bean lab the groups have different colors of Easter grass that they dump multicolored jelly beans into. They do several trials of picking up the jelly beans that are easiest to see. After they’re done they tally the number of each color jelly bean left. They should have more of the colors that match their grass which shows “survival of the fittest”.

R: That sounds awesome

F: Another lab we did was about the shape of bird beaks to show how adaptation works. The kids are given different “beaks” to try to pick up food. Each group member will have a different “beak” and they use the tweezers, toothpick, a spoon, a straw, and maybe something else. Then they get different kinds of food for each trial to see which beak is better for which type of food. The foods we use are marshmallows, pasta, cheerios, rice, a cup of water, and maybe something else. I can’t remember.

R: Do you think these labs are successful at getting the students to understand the concepts?

F: I think both of those labs are pretty successful because the kids actually see how the processes work. They are able to see why organisms change over time and understand that natural selection is how it happens.

R: Do you consider these labs and activities to use inquiry?

F: Somewhat. The kids that I teach are lower level and kind of freak out if I make them do too much critical thinking. They have to figure out what kind of data to collect for the beak activity and tell how bird beaks are an example of adaptation and natural selection. With the jelly bean lab they have to come up with their hypothesis and tell if it was supported at the end. Then they have to explain why they got their results.

R; I know you are short on time today

F: Yeah I’m sorry

R: Don’t worry I have a lot of information from you and thank you so much!

F: No problem happy to help out.

Transcript: Teacher G (Interview)

Researcher: All right thanks for your time today. How long have you been teaching?

G: First year

R: and so this is the first year you have taught biology at the high school level.

G: mmhm

R: How long do you plan on spending on the evolution unit?

G: Probably 2 ½ weeks

R: All right how much time to think is needed to adequately teach evolution?

G: I think you can definitely teach it in that 2 ½ week time span.

R: are there any areas of the unit of evolution that you plan give more attention to than others such as natural selection, …

G: Natural selection will probably be a big thing and will probably be discussed the most often.

R: Why do you think you'll focus more on natural selection?

G: Because it's something that continues to happen now and it will be easy to give the students something to relate to.

R: OK, and out of the 2 ½ weeks how much time to do you think you will spend on natural selection?

G: about a week

R: from the aks standards do you think any topics should be added to the AKS or do you think they are ok?

G: I think they're ok

R: DO you think anything should be taken away from the aks?

G: nope

R: On the academic calendar provided by gwinnett county evolution falls after genetics, do you think this is a good place to put it or do you think it should be moved?

G: I think it's a good place to put it. Its gonna fall after cells and genetics

R: They have actually tried to move it to the first few weeks of school…

G: that would be horrible.

R: During the planning of the unit of evolution do you plan on providing your students with more activities and labs or more bookwork and worksheets? And why

G: I would say it would probably be 50-50. Um just because I feel like there is a lot of material they will need to understand book work wise. Yet you still want to be able to provide them with enough hands on materials and I think they need the visualization as well.

R: Do you have any specific labs or activities that you plan on using?

G: Not right now

R: What is the most difficult topic to approach in the unit of evolution?

G: Probably the beginning

R: like introducing the topic?

G: yeah

R: how do you plan on getting through it?

G: Um making sure you have an open approach to all students regardless of their beliefs

R: have you ever or do you plan on encountering any types of adversity? And how do you think you'll handle it in the classroom?

G: I'm sure I'll encounter some, my idea is to show them enough facts without stepping on their beliefs. Bc I can lead with scientific facts and leave the beliefs alone.

R: if a student were to object to learning evolution in the classroom and the tasks given, how do you think you would handle the situation?

G: Um I might ask another teacher if the student can sit in their class and give them alternate assignments.

R: Do you think, or If a student were to ask you your personal feelings toward evolution do you think you would discuss your beliefs in class with them?

G: No.

R: going on, do you think it's appropriate to discuss personal beliefs?

G: I don't think its inappropriate, I just think depending on the students that you could rub a student the wrong way.

R: So right now there is a very strong debate between religion and science when it comes to evolution. Would you ever allow a classroom debate regarding this controversy?

G: Good question. I would and I would keep it under control but I would allow both sides to state their feelings.

R: do you think allowing students to talk about their beliefs regarding evolution in a controlled and safe environment would help them understand the science better?

G: yes

R: why do you think that would help?

G: I think it would help because not all students have the same beliefs and those that share those beliefs should be able to see why they feel a certain way and the students that didn't have certain beliefs it would allow them to understand where those students are coming from. I just think both approaches would allow students to get a good understanding

R: In your opinion do you think you will effectively and objectively teach the standards of the unit of evolution?

G: Yes

R: Why?

G: bc I'll be able to play that middle role and be able to make sure that no matter their beliefs they are getting the information that they need to know and all other personal beliefs they will be able to keep and just add on to it

R: Well that is all I have, thank you so much

G: you are welcome

Transcript: Teacher E (online interview)

Researcher: How long have you been teaching?

E: 4 years; going on 5

R: How long have you taught biology at the high school level?

E: 2 years; going on 3

R: How long do you spend on the unit of evolution?

E: About 2-3 weeks

R: Are there any areas of the unit that focus on more or give more attention to than others?

E: adaptations

R:Why do you focus more on adaptations?

E: b/c they are an AKS and are proven true

R: How long to spend on adaptations?

E: 3-4 days

R: Do you feel there should be anything added to the AKS standards used by Gwinnett County to the unit of evolution?

E: No, I'm fine with the current standards

R: How much time do you think is adequate to effectively teach the unit of evolution?

E: 2-3 weeks

R: How much time do you realistically use to teach evolution?

E: 2-3 weeks

R: On the academic calendar provided by Gwinnett County, where do you think evolution best fits?

E: Right after genetics; b/c it shows how organisms can adapt and change to their environment and change their genetic makeup b/c of that

R: During your planned unit of evolution do you provide your students with more activities and labs or more desk work such as book work and worksheets?

E: It's half and half, Doing activities for evolution is difficult to model

R: What are some specific labs and activities used?

E: Woolly worm lab is one of my favs. I also use a lot of foldables and graphic organizers, but mostly we do notes and discussion

R: Which activities are the most successful?

E: I feel the most successful ones are the activities in which they create a species or actually pretend like they are an animal like after teaching adaptations, they do an activity in which they create and draw a species that has special adaptations. Also, in the woolly worm lab, they pretend like they are birds hunting worms and they begin to understand population genetics.

R: Do you consider these labs and activities to use inquiry?

E: Don't think so

R: What is the most difficult topic to approach in the unit of evolution?

E: Human evolution

R: Do you use more desk work or more inquiry activities with this topic?

E: discussion

R: Have you ever encountered student adversity toward evolution?

E: yes

R: How do you handle this in the classroom?

E: I tell the students at the beg. Of the unit that evolution is sometimes considered controversial and that it is a theory. All of the things they will be learning have scientific proof behind them. When a student shows adversity, I tell them that I'm not debating their beliefs, I'm only teaching them scientific proof and evidence. They generally settle down after that. This is one of the reasons I really don't like teaching evolution. I am not comfortable teaching something that students take so personally.

R: If a student were to object to learning evolution in the classroom and refuse to complete the tasks given how would you handle this situation?

E: I would tell the student that they are still responsible for learning the material and I would tell them to go to the library and complete questions out of the book.

R: Do students ever ask you about your personal feelings toward evolution?

E: yes

R: Do you discuss your beliefs in class?

E: NEVER

R: Do you think it is appropriate for a teacher to discuss personal beliefs in the classroom?

E: I feel like this is a trick question. I'd like to say "yes", but I feel like I need to say "no". Yes b/c I think a healthy discussion of beliefs isn't harmful to the thoughts of students; "no" b/c I don't want to get in trouble with administration and parents. So its sometimes easier to just not discuss your beliefs at all so further reprimand does not follow.

R: There is a very strong debate between religion and science when it comes to the topic of evolution. Would you ever (or have you ever) allow a classroom debate regarding the religion/evolution controversy?

E: NEVER

R: Do you think allowing students to talk about their beliefs regarding evolution in a controlled and safe environment would be helpful to students in order to help them understand the science background of evolution better?

E: In the classroom- no; outside the classroom- yes

R: In your own opinion, do you think you effectively and objectively teach students the standards of the unit of evolution?

E: Yes, I cover all the standards.

R: Thank you so much for your time

E: Anytime

APPENDIX C: ACTIVITIES

(All sources are anonymous)

WOOLLY WORM LAB

In this lab you will study natural selection. During the exercise you will represent a predatory bird who feeds on wooly worms. The wooly worms are pieces of colored yarn that have been randomly distributed over an area on the school grounds. Some of the "wooly worms" will blend into the habitat while others will be easy to find. It is hoped that this lab activity will add to your understanding of natural selection.

PROCEDURE AND QUESTIONS:

1. During a short "feeding" period you will collect as many wooly worms as possible in the collection area.
2. Return to the lab and list the various colors of "worms" in the appropriate columns of Data Table 1.
3. Tally the number of each kind of worm you "ate" and record the numbers in Table 1 under appropriate columns. This will be the same number in Column B of Table 2.
4. Total the worms you found, and then divide by the number of kinds of worms available. This will give the average number of worms of each kind that you would expect to find if you collected them randomly, and all worms had an equal chance of being caught. This value should be entered in the C column of Table 2 as Expected number.
5. If the wool pieces were collected randomly, then the number of each color collected should be nearly equal. If the collection is random, then the differences between observed numbers and expected numbers could be attributed to chance. If the numbers are not evenly distributed, or are not close to the expected numbers, then selection of some colors over others must have occurred.

Data Table 1:

colors→	gold	red	beige	purple	yello w	green	navy	brown	black	rose
groups										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
total →										

Overall Total Worms Caught:

Questions:

1. In reality, what color worms would be most likely to survive predation by the “birds”?

2. In reality, what color worms are more likely to be preyed upon?

3. Factors which determine which organisms will survive and which will die are called “selective pressures.” Identify some of the selective pressures which determined whether worms were captured or escaped.

4. Which color worms are more likely to reproduce to make the next generation? (hint…you don’t get to reproduce if you’re dead)

5. How will this change the relative amounts of each color worm in the next generation?

6. How might the population be different after a hundred years has passed?

7. The differences in color we see in the wooly worm population are called variations. What genetic process gave rise to the variations in color?

9. What do we call this gradual change in color of the worm population that would occur over many generations?

10. Suggest a possible scenario for how these changes could eventually give rise to a new species?

Graph of data Table 1:

Lab: Peppered Moth Survey

Purpose: To observe the effect of environmental changes on the color variation of the peppered moth, *Biston betularia*.

Objective: Use research data to graph the results of an environmental adaptation in the peppered moth.

Introduction

Industrial melanism is the term used to describe the adaptation of an organism in response to industrial pollution. One example of rapid industrial melanism occurred in the peppered moth population in the area of Manchester, England from 1845-1890.

Before the Industrial Revolution, the trees in the forest around Manchester were light grayish green due to the presence of lichens on their trunks. A lichen is a mutualistic relationship between an algae and a fungus. Lichens are resistant to drought and cold weather and can also grow in harsh environments. Lichens are often the first organisms to enter barren (bare) environments but are very sensitive to air pollution. During this time, peppered moths that lived in the area were light with dark spots. This coloring served as camouflage against predators (such as birds) because they blended in with the trees. As the industrial revolution progressed, the trees became covered with sulfur dioxide, which turned the tree trunks black. Over a period of 45 years, the peppered moth population changed to a predominantly dark species with only a few light-colored moths remaining.

In this investigation, you will observe the effects of industrial melanism in the peppered moth population over the course of several years.

Materials

Graph paper

Colored pencils

Procedure:

1. Table A represents data from a 10 year study of the same species of a peppered moth. The numbers represent moths captured in traps for 10 consecutive years. The traps were located in the same area each year.
2. Using the data in Table A, construct a graph comparing the numbers of each variety of peppered moth. Label the axes, title the graph and use different colors or a key to represent your data.
3. Use the graph and the information given in the introduction to answer the questions about the peppered moth population.

Table A

Year	Number of Light Colored Moths Captured	Number of Dark Colored Moths Captured
1	556	64
2	537	112
3	484	198
4	392	210
5	246	281
6	225	357
7	193	412
8	147	503
9	84	594
10	56	638

Analysis and Conclusion Questions

1. What is the scientific name for the peppered moth? ____
2. What does the term industrial melanism mean? ____

____

3. What is a lichen? ____

4. Where are lichens usually found? ____

5. What can destroy a lichen population? ____

6. What color were most of the peppered moths before the industrial revolution? ________________
7. What color were most of the peppered moths after the industrial revolution? _________________
8. What caused the trunks of the trees to turn from light to dark between 1845-1890 (be specific)?

____

9. What could have caused the first moth to change from a light color to a dark color (think of DNA)?

   ____

10. Which variety of the peppered moth increased over the 10 year period? ______________________
11. How does the term "Survival of the Fittest" relate to this situation? __________________________

____

12. Using the data on the graph, what can you conclude about the population of peppered moths in the sampled area of England between 1845-1890? ____

____

13. What could be done to return the environment of the peppered moths back to its original state? ____

14. What do you think would happen if it were returned to its original state? ____________________

____

15. What effect would cleaning up the environment have on the peppered moths? _______________

____

Phylogenetics Tutorial Project

Introduction

This exercise introduces the problem of classification, relationship, and character coding. It is intended to be a "fun" way of getting you to think about basic issues in Evolution, and to give you some practice with Evolution and the Scientific Method.

The "animals" shown in this handout are called Caminalcules. Caminalcules are artificial animals created by the late Professor Joseph Camin of the University of Kansas as part of a study of how taxonomists classify real organisms. Although these are imaginary animals, the principles and ideas that you will use to classify them are the same as scientist use in real world.

Purpose

In this exercise, we will use Caminalcules to explore the problem of classification, with emphasis on using the evidence you have before you to determine an evolutionary tree. Upon completion of this exercise you should:

1) understand that there are many possible classifications

2) develop ideas about character states and how they relate to classifications

3) have a good grasp of how to construct an evolutionary tree

4) construct an evolutionary tree displaying the natural clustering or grouping of Caminalcules based on their taxonomy

5) Justify your reasoning to the classs

Please note that this exercise only has you looking at taxonomy (i.e. the physical or structural adaptations of these animals). The behavioral and physiological adaptations can not be observed, as these are imaginary creatures. Corresponding organs and other body parts that are alike in basic structure and origin are said to be homologous structures (for example, the front legs of a horse, wings of a bird, flippers of a whale, and the arms of a person are all homologous to each other).

The process of phylogenetic classification is best understood by actually attempting to construct a phylogenetic cladogram (phylogenetic tree, or phylogeny). To construct a **phylogeny**, we need knowledge of similarity (in this case only structural) to group organisms into "natural clusters." Natural clusters describe clusters of organisms that result from the processes of evolution such as adaptive radiation. Think of this as constructing a family tree. Organisms that closely resemble each other are more likely to closely related than two organisms that do not look alike. This means that the two similar organisms have shared a common ancestor more recently than the two organisms that do not look alike.

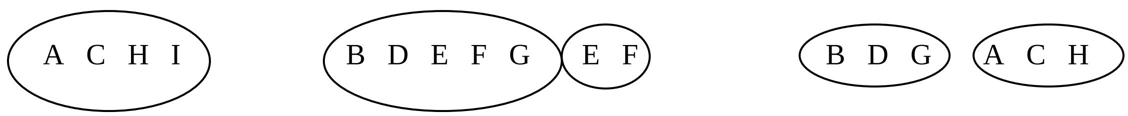
Procedure

In this exercise, you will construct a phylogenetic tree using the 29 organisms shown below using a large sheet of poster paper (provided by your teacher). Each organism is to be cut out and glued down on the poster board.

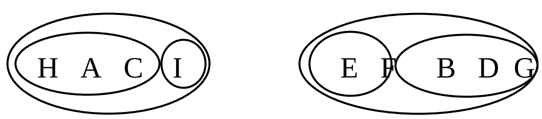
Getting Started: Background

All you know at this point in time is that these 29 organisms ALL EXIST TODAY, and are known to be related.

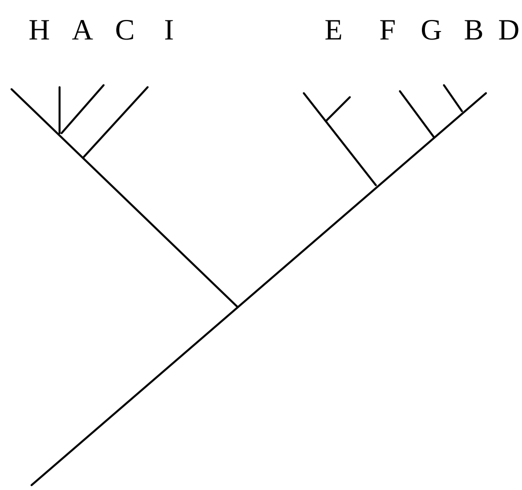
Begin by grouping like organisms together. Start by examining each organism and placing it in a group with other closely similar organisms. Be careful to only use ach characteristic once. See below for an example.



Next, look at the diagrams, and overlap them based on similarities. For example, do two of your groups have antennae? Think of this like a **Venn Diagram** that shows the grouping suggested by a given characteristic, for example, front legs. See below.



Finally, convert the Venn Diagrams directly to a cladogram as shown below.



The diagram should reflect shared characteristics as time proceeds. Different animals are all at the same time level (across the top) since they all live today. A line branching to each animal shows where, and relatively how long ago it shared a common ancestor with another organism. Good luck, and remember to ask your teacher as you have questions.

At the end of this project, you and your group will briefly present your poster to your teacher and classmates. During this time, you will explain your groupings, and answer questions from your classmates and teacher.

Caminalcule Grading Rubric: The following Rubric will be used to evaluate your Projects. NOTE, not all group members must receive the same grade. Non-participation will be reflected in your individual grade.

1). Neat and clearly legible

Writing is neat, good use of space, straight lines, general appearance is orderly.

2 - 4 - 6 - 8 - 10

2). Correct Structure of a Phylogenetic Tree

i.e. there is a branch for each group, and a limb for each organism in that group on an appropriate branch, and all organisms are shown to exist at present time

2 - 4 - 6 - 8 - 10

3). Grouping of organisms is logical

All organisms on a given branch of the phylogeny or “tree” fit that branch based on physical characteristics.

2 - 4 - 6 - 8 - 10

4). Sequence of groups is logical

Each branch of the tree appears in a sequential order, and closely related groups are placed closer together than more distantly related groups.

2 - 4 - 6 - 8 - 10

5). Appropriate physical characteristics used to group organisms

Example; Each grouping is done using appropriate physical characteristics, and these characteristics are consistent. i.e. all organisms in a group have forelimbs, similar body shape, etc., and branches show these similarities between different groups appropriately.

2 - 4 - 6 - 8 - 10

6). Each Branch of the phylogeny shows appropriate time

For Example, all branches don’t come out of the “trunk” at the same place, but appear in order from bottom to top.

2 - 4 - 6 - 8 - 10

7). All group members participate equally

2 - 4 - 6 - 8 - 10

8). Presentation is clear, speakers are loud

2 - 4 - 6 - 8 - 10

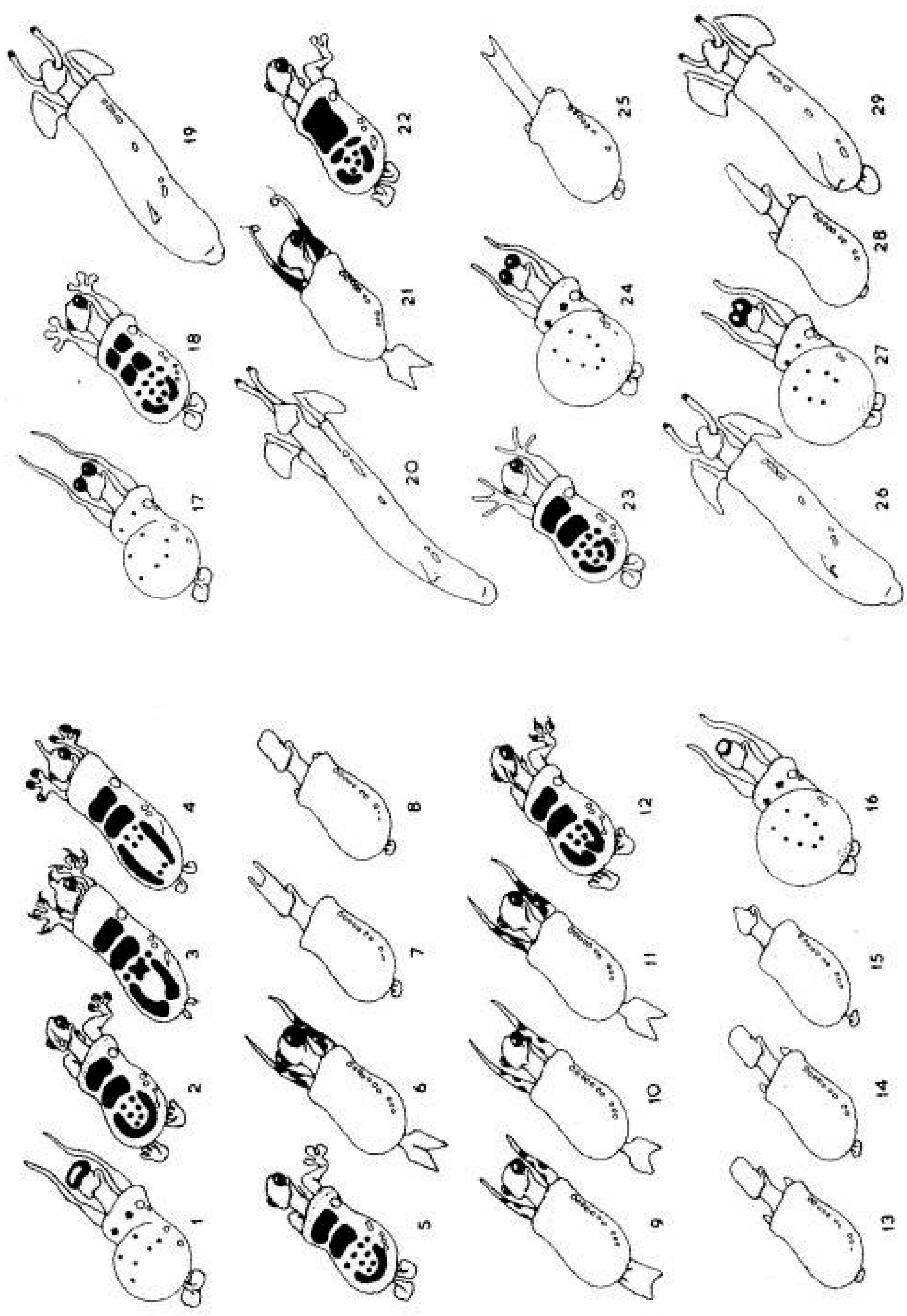
9). Questions are answered in a direct and straight forward manner

2 - 4 - 6 - 8 - 10

10). Explanations are appropriate for phylogeny, and questions are answered appropriately

Example; If you realize a mistake, explain it rather than just ignore it, and answer questions based on what you have done, not on what you would like to have done.

2 - 4 - 6 - 8 - 10



RAT ISLAND

Evolution in the Making

Activity:

Each group will receive a description of an island. Your job is to use your creativity to imagine how rats would adapt to your particular island in order to survive and reproduce.

Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. …Drawing of your Evolved rat with adaptations.
5. Explanation of how each of the adaptations allow your rat to survive better than other rats.

Island A:

The island is fairly flat, with an occasional hill. The ground is soft dirt, and several species of shrubs grow towards the center of the island. There is no animal life on land; but the water is teaming with fish. The island is surrounded by a coral reef which keeps the predators out. The shore is sandy with no algal growth. Fresh water is available.

RAT ISLAND

Evolution in the Making

Activity:

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Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. Drawing of your Evolved rat with adaptations.
5. Explanation how each of the adaptations allow your rat to survive better than other rats.

Island B:

The island has a rocky shoreline. Numerous tide pools dot the island along the shore where the wave action is somewhat sheltered by rock outcrops. The tide pools host barnacles, abalone, sea urchins and crabs. Algae grows all around the island; however, it is quite sparse in the tide pools where the various animals feed. The current is quite strong along the rocky outcrops where the algae grows best. Fresh water is available.

RAT ISLAND

Evolution in the Making

Activity:

Each group will receive a description of an island. Your job is to use your creativity to imagine how rats would adapt to your particular island in order to survive and reproduce.

Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. Drawing of your Evolved rat with adaptations.
5. Explanation how each of the adaptations allow your rat to survive better than other rats.

Island C:

The island is somewhat barren. A few species of cactus thrive on the bare rocks. A large cactus-eating tortoise inhabits the island. A species of very large bird nest on the island annually. They build their nests on the rocks, and protect their eggs from the sun by standing over the nests with outspread wings. The nests are always found on the windy side of the island which is somewhat cooled by offshore breezes.

RAT ISLAND

Evolution in the Making

Activity:

Each group will receive a description of an island. Your job is to use your creativity to imagine how rats would adapt to your particular island in order to survive and reproduce.

Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. Drawing of your Evolved rat with adaptations.
5. Explanation how each of the adaptations allow your rat to survive better than other rats.

Island D:

The island is an extinct volcano. Vegetation on the island changes with the altitude moving up the volcano. Grasses grow at the base. Further up the slope the grasses give way to low shrubs. Half way up, the island becomes quite lush; tropical plants and trees dominate the landscape. At this altitude, the island experiences frequent rain showers. There are two species of birds that inhabit the island. One is a raptor which preys upon the smaller birds. The other fishes the waters approximately one mile offshore. Both nest in trees.

RAT ISLAND

Evolution in the Making

Activity:

Each group will receive a description of an island. Your job is to use your creativity to imagine how rats would adapt to your particular island in order to survive and reproduce.

Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. Drawing of your Evolved rat with adaptations.
5. Explanation how each of the adaptations allow your rat to survive better than other rats.

Island E

This island has steep cliffs but is mostly covered with grasses. Trees are very sparse. Moles, Rabbits, and certain birds make their homes within the grasses. The temperature stays fairly warm year round. Rainfall is moderate and there are small ponds scattered throughout the island. Hunters occasionally travel to this island to for sport hunting. They bring dogs.

RAT ISLAND

Evolution in the Making

Activity:

Each group will receive a description of an island. Your job is to use your creativity to imagine how rats would adapt to your particular island in order to survive and reproduce.

Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. Drawing of your Evolved rat with adaptations.
5. Explanation how each of the adaptations allow your rat to survive better than other rats.

Island F

This island is extremely lush with vegetation that varies from palms bearing fruit to vines and bushes with delicious berries. The island has warm temperatures year round and abundant rainfall. Monkeys and hedge hogs are the main inhabitants of this island. There is an active volcano that erupts nearly every year. Due to this the area nearest the volcano is barren for miles due to recent eruptions.

RAT ISLAND

Evolution in the Making

Activity:

Each group will receive a description of an island. Your job is to use your creativity to imagine how rats would adapt to your particular island in order to survive and reproduce.

Within your group, discuss some advantages that would allow a rat to survive the conditions on your island better than others. The adaptations should allow the rat to survive and reproduce in other words EVOLVE. The group will present the following information all of which should be drawn on a large sheet of paper.

1. Detailed Drawing of Island including all other animals on the island. Include a name for your island.
2. Create an elaborate story on how the rats ended up on the island, include how long they have been on the island in order to change so much.
3. Drawing of a Normal rat comparing to….
4. Drawing of your Evolved rat with adaptations.
5. Explanation how each of the adaptations allow your rat to survive better than other rats.

Island G

This island is cold with frozen ground for about 9 months of the year. Penguins and seals often are seen here. There is very little rainfall here but it snows quite often. During the remaining three months of the year the temperature is around 70 degrees. There are several mountains on this island with many caves. Evergreen trees are the main plant life seen here. However, during the warmer months weeds and small shrubs grow quickly.

Teddy-Graham Lab

Introduction

Charles Darwin's unique contribution to biology was not that he "discovered evolution" but, rather, that he proposed a mechanism for evolutionary change-**natural selection,** the differential survival and reproduction of individuals in a population. In *On the Origin of Species*, published in 1859, Darwin described natural selection and provided abundant evidence in support of **evolution,** the change in populations over time. However, at the turn of the century, geneticists and naturalists still disagreed about the role of selection and the importance of small variations in natural populations. How could these variations provide a selective advantage that would result in evolutionary change? It was not until evolution and genetics became reconciled with the advent of population genetics that natural selection became widely accepted. Ayala (1982) defines evolution as "*changes in the genetic constitution of populations*." A **population** is defined as a group of organisms of the same species that occur in the same area and interbreed or share a common **gene pool,** all the alleles at all gene loci of all individuals in the population. The population is considered to be the basic unit of evolution. Populations evolve, not individuals.
In 1908, English mathematician ***G. H. Hardy*** and German physician ***W. Weinberg*** independently developed models of population genetics that showed that the process of heredity by itself did not affect the genetic structure of a population. The **Hardy-Weinberg theorem** states that the frequency of alleles in the population will remain the same regardless of the starting frequencies. Furthermore, the equilibrium genotypic frequencies will be established after one generation of random mating. In this scheme, if **A** and **a** are alleles for a particular gene locus and each diploid individual has two such loci, then **p** can be designated as the frequency of the **A** allele and **q** as the frequency of the **a** allele. Thus, in a population of 100 individuals (each with two loci) in which 40% of the alleles are **A**, **p** would be 0.40. The rest of the alleles (60%) would be **a**, and **q** would equal 0.60 (i.e., p + q = 1.0). These are referred to as **allele frequencies.** The frequency of the possible diploid combinations of these alleles (AA, Aa, aa) is expressed as

$$p^2 + 2pq + q^2 = 1.$$

This theorem is valid only if certain conditions are met:

1. **The population is very large.** (The effect of chance on changes in allele frequencies is hereby greatly reduced).
2. **Matings are random**. (Individuals show no mating preference for a particular phenotype)
3. **There are no net changes in the gene pool due to mutation, that is, mutation from A to a must be equal to mutation from a to A.**
4. **There is no migration of individuals into and out of the population.**
5. **There is no selection; all genotypes are equal in reproductive success.**

Knight/2000/Hardy-Weinberg Lab

Basically, the Hardy-Weinberg theorem provides a baseline model in which gene frequencies do not change and evolution does not occur. By testing the fundamental hypothesis of the Hardy Weinberg theorem, evolutionists have investigated the roles of mutation, migration, population size, nonrandom mating, and natural selection in effecting evolutionary change in natural populations. Although some populations maintain genetic equilibrium, the exceptions are intriguing to scientists.

NATURAL SELECTION IN TEDDY GRAHAMS.

*You are a bear eating monster. There are two kinds of bears that you like to eat: happy bears and sad bears. You can tell the difference between them by the way they hold their hands. Happy bears hold their hands high in the air, and sad bears hold their hands down low. Happy bears taste sweet and are easy to catch. Sad bears taste bitter, are devious and hard to catch. Because of this **you only eat happy bears**. The happy trait in bears is caused by the expression of a recessive allele. The homozygous recessive condition being happy. The sad trait is a caused by a dominant allele. New bears are born every year (when they are hibernating in their den [cardboard box]) and the birth rate is **one** new bear for every old bear left from the last year.*

Procedure:

1. Obtain a population of 10 bears and record the number of happy and sad bears and the total population number. Using the equations for Hardy-Weinberg equilibrium, calculate the frequencies of both the dominant and recessive alleles and the genotypes that are represented in the population. The happy bears would be the q^2 genotype.

Ex. If 5 of the 10 bears are happy, then 10 out of 20 alleles would be happy alleles. Therefore the q^2 number would be **.5**. You must then determine the q number by taking the square of .5

2. **Now, go hunting!** Eat 3 happy bears. (If you do not have 3 happy bears then eat the difference in sad bears)
3. Once you have consumed the bears, obtain a new generation from your den (the box). You should only remove 7 additional bears from the den for a total of 14 bears.
4. Repeat the procedures again, be sure to record the number of each type of bear and the total population.

Generations	**p^2 (sad)**	**2pq (sad)**	**q^2(happy)**	**p**	**q**
(initial)					
1					
2.					
3.					
4.					

Describe what is happening to the genotype and allele frequencies in the population of Teddy Grahams?
What would you expect to happen if you continued the selection process for additional generations?
How would the frequencies change if you were to now select for the sad bears?
Why doesn't the recessive allele disappear from the population? How is it protected?

Name:__________________ Period:______

Natural Selection with Beans

Background Information:

Predators are the driving force in all communities. They keep populations of prey under control and exert powerful selective pressure on prey such as small rodents and herbivorous insects. Predators and parasites are constantly removing large numbers of insects and other prey from their habitats but very few populations are completely removed. Some survive to reproduce and pass their traits on to the next generation. Why do some organisms survive and others do not?

Over time, organisms that are prey for other predators have evolved appearances and behaviors that help them escape predation. Every insect species has some form of protection from predators such as camouflaging, noxious taste, cryptic behavior, intimidating appearance or behavior, toxic chemicals, or mimicking noxious or dangerous prey. In this lab you will be the predator and the beetles (beans) will be the prey. The beetles are all one species, but there is much variation in their population.

Materials:

Graph paper
Multi-colored beans

Procedure:

1. You will be working in groups of 5-6. The instructor has scattered 500 beetles (beans) in the designated area. You will need to record all information on the data tables below throughout the entire lab.
2. When the instructor tells you to go, you will have 2 minutes to find as many beetles as possible in the designated area.
3. In your group, calculate the number of surviving beetles/beans for each color (100 minus how many you found) and record this in Data Table 1.
4. Send one person to give your information to the instructor (# of surviving beetles for each color).
5. The teacher will give you the class information to record in Data Table 2.
6. To calculate the number of offspring for each beetle color we will do the following:
    a. Allow each surviving beetle to be paired up and reproduce. Each pair will have 2 offspring. If there is an odd number of surviving beetles, one beetle will not have a mate ☹
    b. For example, if 20 beetles survived they would pair up to make 10 couples. Those 10 couples would have 2 offspring each giving us a total of 20 offspring.
    c. Record the number of offspring in Data Table 2
7. We will add the offspring to the population and repeat Steps 2-6 for the next 2 generations.
8. After you have recorded all group and class data, you will use Data Table 2 to graph the total number of beetles for each generation. You will need to use a different color line or symbol for each beetle.

Data Table 1: (GROUP DATA)

	Generation 1	Generation 2	Generation 3	Generation 4
Beetle/Bean Color	Number of Surviving Beetles	Number of Surviving Beetles	Number of Surviving Beetles	Number of Surviving Beetles
Green				
Black				
Brown				
Red				
White				
Speckled				

Data Table 2: (CLASS DATA)

	Green	Black	Red	White	Speckled
GENERATION 1					
Number of Surviving Beetles					
Number of offspring					
Total for Generation 1					
GENERATION 2					
Number of Surviving Beetles					
Number of Offspring					
Total for Generation 2					
GENERATION 3					
Number of Surviving Offspring					
Number of Offspring					
Total for Generation 3					
GENERATION 4					
Number of Surviving Beetles					
Number of Offspring					
Total for Generation 4					

* To calculate the total for each generation you will add Number of Surviving Beetles + Number of Offspring.
* You will use Data Table 2 to graph the total number of beetles for each generation. You will need to use a different color line or symbol for each beetle.

Analysis and Conclusion (5 points each):

1. What is Natural Selection and how did it relate to this lab? ______________________________
____
2. Which variation of beetles survived and reproduced the most offspring? ________________
3. Referring to your answer in question 2, how were they able to survive? ________________
4. Explain how Survival of the Fittest relates to this lab. ______________________________
____
5. Did every allele (color) survive to the 4th generation? ________ Explain why or why not. __________
____
6. Explain how the distribution of the alleles (gene pool) changed from generation 1 to 4 (be specific about every color). ____
____
____
____

Name ______________________ Date ______________________

Biochemical Evidence For Evolution

28

If two organisms have similar DNA molecules, they have similar proteins. Similar proteins have similar amino acid sequences (orders). Thus, if amino acid sequences are similar, DNA of the organisms is similar.

Scientists believe that similar DNA sequences indicate a common origin. The more similar the DNA of two living organisms, the more closely related they may be to one another.

Hemoglobin, a protein in red blood cells, has been studied. Scientists know the specific amino acids and their arrangements in hemoglobin molecules of humans, gorillas, and horses.

In this investigation, you will

(a) count and record differences in the sequence of amino acids in similar portions of human, gorilla, and horse hemoglobin.

(b) count and record the molecules of each amino acid present in similar portions of human, gorilla, and horse hemoglobin.

(c) use these data to show how biochemical evidence can be used to support evolution.

Procedure

Part A. Amino Acid Sequence

Figure 2 on page 110 represents the amino acid sequence of corresponding portions of the hemoglobin molecules of horses, gorillas, and humans.

- Read the amino acid sequences from left to right beginning at the upper left-hand corner of Figure 2. Compare the sequences of humans to the sequences of gorillas and horses. An example of a sequence difference between humans and gorillas is shown in Figure 1.

- Record in Table 1 the total number of differences in the sequences of gorilla and human amino acids. Then repeat this procedure for horse and human, and for gorilla and horse.

TABLE 1. NUMBER OF AMINO ACID SEQUENCE DIFFERENCES

ORGANISMS	NUMBER OF DIFFERENCES
Gorilla and human	
Horse and human	
Gorilla and horse	

Part B. Numbers of Amino Acids

- Count the number of each kind of amino acid in human hemoglobin. Record the totals in the proper column of Table 2.

- Count each amino acid in the hemoglobin of gorillas and horses. Record these in Table 2.

Human:	Val	His	Pro	
Gorilla:	Val	His	Gly	← This is a sequence difference between human and gorilla.
Horse:	Val	His	Pro	← This is a sequence difference between gorilla and horse.

This is not a sequence difference between human and horse.

FIGURE 1

FIGURE 2

Human:	Val	His	Leu	Thr	Pro	Glu	Glu	Lys	Ser	Ala	Val	Thr	Ala	Leu	Try
Gorilla:	Val	His	Leu	Thr	Pro	Glu	Glu	Lys	Ser	Ala	Val	Thr	Ala	Leu	Try
Horse:	Val	Glu	Leu	Ser	Gly	Glu	Glu	Lys	Ala	Ala	Val	Leu	Ala	Leu	Try
Human:	Gly	Lys	Val	Asp	Val	Asp	Glu	Val	Gly	Gly	Glu	Ala	Leu	Gly	Arg
Gorilla:	Gly	Lys	Val	Asp	Val	Asp	Glu	Val	Gly	Gly	Glu	Ala	Leu	Gly	Arg
Horse:	Asp	Lys	Val	Asp	Glu	Glu	Glu	Val	Gly	Gly	Glu	Ala	Leu	Gly	Arg
Human:	Leu	Leu	Val	Val	Tyr	Pro	Try	Thr	Glu	Arg	Phe	Phe	Glu	Ser	Phe
Gorilla:	Leu	Leu	Val	Val	Tyr	Pro	Try	Thr	Glu	Arg	Phe	Phe	Glu	Ser	Phe
Horse:	Leu	Leu	Val	Val	Tyr	Pro	Try	Thr	Glu	Arg	Phe	Phe	Asp	Ser	Phe
Human:	Gly	Asp	Leu	Ser	Thr	Pro	Asp	Ala	Val	Met	Gly	Asp	Pro	Lys	Val
Gorilla:	Gly	Asp	Leu	Ser	Thr	Pro	Asp	Ala	Val	Met	Gly	Asp	Pro	Lys	Val
Horse:	Gly	Asp	Leu	Ser	Asp	Pro	Gly	Ala	Val	Met	Gly	Asp	Pro	Lys	Val
Human:	Lys	Ala	His	Gly	Lys	Lys	Val	Leu	Gly	Ala	Phe	Ser	Asp	Gly	Leu
Gorilla:	Lys	Ala	His	Gly	Lys	Lys	Val	Leu	Gly	Ala	Phe	Ser	Asp	Gly	Leu
Horse:	Lys	Ala	His	Gly	Lys	Lys	Val	Leu	His	Ser	Phe	Gly	Glu	Gly	Val
Human:	Ala	His	Leu	Asp	Asp	Leu	Lys	Gly	Thr	Phe	Ala	Thr	Leu	Ser	Glu
Gorilla:	Ala	His	Leu	Asp	Asp	Leu	Lys	Gly	Thr	Phe	Ala	Thr	Leu	Ser	Glu
Horse:	His	His	Leu	Asp	Asp	Leu	Lys	Gly	Thr	Phe	Ala	Ala	Leu	Ser	Glu
Human:	Leu	His	Cys	Asp	Lys	Leu	His	Val	Asp	Pro	Glu	Asp	Phe	Arg	Leu
Gorilla:	Leu	His	Cys	Asp	Lys	Leu	His	Val	Asp	Pro	Glu	Asp	Phe	Leu	Leu
Horse:	Leu	His	Cys	Asp	Lys	Leu	His	Val	Asp	Pro	Glu	Asp	Phe	Arg	Leu
Human:	Leu	Gly	Asp	Val	Leu	Val	Cys	Val	Leu	Ala	His	His	Phe	Gly	Lys
Gorilla:	Leu	Gly	Asp	Val	Leu	Val	Cys	Val	Leu	Ala	His	His	Phe	Gly	Lys
Horse:	Leu	Gly	Asp	Val	Leu	Ala	Leu	Val	Val	Ala	Arg	His	Phe	Gly	Lys
Human:	Glu	Phe	Thr	Pro	Pro	Val	Glu	Ala	Ala	Tyr	Glu	Lys	Val	Val	Ala
Gorilla:	Glu	Phe	Thr	Pro	Pro	Val	Glu	Ala	Ala	Tyr	Glu	Lys	Val	Val	Ala
Horse:	Asp	Phe	Thr	Pro	Glu	Leu	Glu	Ala	Ser	Tyr	Glu	Lys	Val	Val	Ala
Human:	Gly	Val	Ala	Asp	Ala	Leu	Ala	His	Lys	Tyr	His				
Gorilla:	Gly	Val	Ala	Asp	Ala	Leu	Ala	His	Lys	Tyr	His				
Horse:	Gly	Val	Ala	Asp	Ala	Leu	Ala	His	Lys	Tyr	His				

Name _______________ Date _______________

TABLE 2. NUMBER OF EACH AMINO ACID				
AMINO ACID	ABBREVIATION	HUMAN	GORILLA	HORSE
Alanine	Ala			
Arginine	Arg			
Aspartic acid	Asp			
Cysteine	Cys			
Glutamic acid	Glu			
Glycine	Gly			
Histidine	His			
Leucine	Leu			
Lysine	Lys			
Methionine	Met			
Phenylalanine	Phe			
Proline	Pro			
Serine	Ser			
Threonine	Thr			
Tryptophan	Try			
Tyrosine	Tyr			
Valine	Val			

Analysis

1. Where is hemoglobin normally found? _______________
2. Circle those words which correctly apply to or describe hemoglobin: protein, carbohydrate, composed of amino acids, chemical molecule, composed of DNA.
3. How many different kinds of amino acids are present in these three animals' hemoglobin? ___
4. (a) Which amino acid is most common in all three animals? _______________

   (b) Which amino acid is next most common in all three animals? _______________

   (c) Which amino acid is the least common in all three animals? _______________

5. Use your data from Table 1 to answer these questions.

(a) How similar are the amino acid sequences of human and gorilla hemoglobin? ____________

(b) How similar are human and horse hemoglobin? ____________

(c) How similar are gorilla and horse hemoglobin? ____________

6. Of the different types of amino acids found in hemoglobin,

(a) how many are present in the same exact number in humans and gorillas? ____________

(b) in humans and horses? ____________

(c) in gorillas and horses? ____________

7. On the basis of your answer to question 6,
(a) how similar are the chemical makeups of human and gorilla hemoglobin? ____________

(b) how similar are human and horse hemoglobin? ____________

(c) how similar are gorilla and horse hemoglobin? ____________

8. Which two animals seem to have more similar hemoglobin? ____________

9. The sequence of amino acids corresponds to the sequence of base molecules in DNA. Are the base sequences of DNA most similar in human and gorilla, gorilla and horse, or human and horse?

____

10. In numbers, explain how the base sequences (genes) for hemoglobin formation on human chromosomes differ from those in gorillas. (How many bases are different?) ____________

11. What genetic mechanism may have been responsible for this base sequence change? ____________

____

12. Give reasons for supporting or rejecting the following statement. Upon examination, segments of human and gorilla DNA responsible for inheritance of hemoglobin should appear almost chemically alike. ____________

____

____

13. Give reasons for supporting or rejecting the following statement. Evolutionary relationships are stronger between living organisms which have close biochemical (protein) similarities than between living organisms which do not have close biochemical similarities. ____________

____

____

____

Patterns of Evolution Foldable

Directions: Fold your paper in half like a hotdog bun. Then fold it in half, and then in half again. Your paper will have 4 sections. Take a scissor and cut one side of the paper along the folded line so the paper "flips up" when opened revealing the inside of the foldable. The 4 sections you've created will be labeled as follows:

1. Divergent Evolution
2. Convergent Evolution
3. Adaptive Radiation
4. Coevolution

Under the flaps you must include this information:

- Examples of each (include 2 drawings of each)
- A description of the term
- A description of the examples you included

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Sex, Drugs, and Rock 'n' Roll: Why the Dinosaurs Disappeared

As a teenager of the sixties and seventies, I often heard parents and society's leaders cry out against the evils of those three themes which so fascinate our younger generation --- sex, drugs, and rock 'n' roll. In a recent essay, renowned paleontologist Stephen J. Gould outlined three popular **hypotheses**, which scientists have proposed to explain the disappearance of the dinosaurs. These proposals conveniently connect with the three evils our parents predicted would cause the downfall of our own society. Heck, maybe the story of dinosaur disappearance can instruct us in ways that might prevent our similar demise. Here are the three ideas Gould summarized in his essay.

Sex: Testes, the male structure in animals that produces sperm, will only work in a narrow range of temperature. In fact, the testes of mammals all hang outside the body in a scrotum, because the temperature internally is too high for the sperm to thrive. Perhaps you have heard of males that were temporarily infertile from lounging too long in hot tubs. (Hopefully, no teenager will conclude that they can depend on this as a means of birth control.) Reptile testes, on the other hand, are housed inside the body. That may be a good thing, as most reptiles have pretty poor ground clearance under their bodies as they scramble along. Ouch!

In the 1940's three respected scientists, experts on living and fossil reptiles, performed a well-documented experiment on the temperature tolerances of alligators. They studied changes in the body temperature of alligators using rectal thermometers. (No scientist would be silly enough to try poking a thermometer under a gator's tongue, though I'm not certain I want to go messing around with the other end either.) What they discovered was that larger alligators, once warmed up, took longer to cool back down. This makes sense because of their greater volume to surface area ratio. In other words, as an organism gets larger, the space inside their skin (Volume = length x width x height) grows faster than the surface area of their skin (Area = length x width). Big ol' dinosaurs would have had a devil of a time shedding that extra heat once they got too hot.

Extending this research from alligators to the dinosaurs, these scientists suggested that a warm up in global temperature during the Cretaceous period could have gradually raised the temperature of these creatures. While not directly killing these behemoths, their body temperatures would have stayed above the optimum temperature for the testes and their sperm, eventually sterilizing all the males. Dinosaurs were done in by natural contraception.

Drugs: According to the fossil record, flowering plants or *angiosperms* in fancy science lingo, appeared toward the end of the dinosaurs reign. Many of these plants contain *psychoactive chemicals* (translated *drugs* in simpler language) called alkaloids. Besides their potential for producing drug-induced states in animals consuming even modest amounts of them, they also can collect in the body as toxins with lethal results. Modern mammals tend to avoid plants containing these chemicals due to their bitter taste. Furthermore, mammals luckily are supplied with livers, which have the capacity to break down these chemicals if accidentally (or purposely) ingested. This works unless we *choose* to consume just too much of them.

In the 70's, a UCLA psychiatrist suggested that dinosaurs, without the sophisticated taste buds of mammals, would have gladly gobbled up the lush plants unaware of the drug experiences that awaited them. Moreover, without livers sufficiently evolved to handle these toxic alkaloids, the *highs* would have been followed by digestive problems, sickness, even death. You may remember the moaning stegosaurus in the movie *Jurassic Park.* Same idea. Moreover, when all the herbivores disappeared, the carnivorous dinosaurs were soon to follow. Thus, the appearance of angiosperms more than accidentally coincides with dinosaur extinction

Rocks: Okay, I nudged the title a little. So it's not rock 'n' roll. It's just rocks, or asteroids, to be specific. In 1979, a father-son, physicist-geologist team argued that an asteroid of huge proportions (about 10 kilometers across) struck the earth some 65 million years ago. This asteroid would have collided with the earth with a force greater than the megatons of nuclear weapons held by all the earth's superpowers. However, the scientists were not proposing that the asteroid or asteroids simply smushed all the dinosaurs flat, sending them to extinction. What they suggested was that such a collision would have raised an enormous cloud of dust, generated by particles thrown aloft by this impact. The dust cloud would be so thick and covering so much of the earth, that it would block the sun's rays for significant period of time.

The evidence for this collision is the presence of the element iridium, a rare metal virtually absent from the rocks normally occurring in the earth's crust. Most of the iridium found in the crust arrives on objects striking the earth from space. Geologists date the layers of rocks containing iridium to the period coinciding with the age of dinosaur disappearance.

Without sunlight, photosynthesis would cease and temperatures around the earth would plummet. Much of the algae in the ocean, and simpler plants on land with brief life cycles, would die right away. Seed plants with their seeds dormant in the ground might eventually rebound. But the cold-blooded dinosaurs, dependent on the producers to support their food chain, would not have made it through, dying of starvation and freezing. The tiny (at that time) mammals, with their meager needs for food and better temperature regulation, could have survived.

Challenges for the Reader:

1. As all three of the hypotheses cannot be true, which hypothesis do you believe best explains the phenomenon of the dinosaur extinction?

2. Outline the key points of the explanation that make it more compelling than the others.

3. What is the scientific method? (Outline these ground rules for doing science.)

4. How do the methods of science relate to investigation of these three hypotheses about dinosaur extinction?

If you're interested, here's the original story:

Gould, Stephen J. 1985. *The Flamingo's Smile.* "Sex, Drugs, Disasters, and the Extinction of Dinosaurs", 417-426. New York: W.W. Norton and Co., Inc.

Name ____________________

Date ______________ Class ______________

HOLT **BIOSOURCES**
LAB PROGRAM
INQUIRY SKILLS

B8 *Fossil Study*

Skills
- determining the evolutionary relationship of fossils based on age and morphology

Objectives
- *Analyze* characteristics of fossils to place them in similar lineage groupings.
- *Compare* the placement of fossils in rock strata to determine the relative age of fossils.
- *Develop* a model evolutionary tree based on the morphology and age of fossils.

Materials
- 11 in. × 17 in. paper (4 sheets)
- tape or glue stick
- scissors
- sample fossils
- ruler
- marker

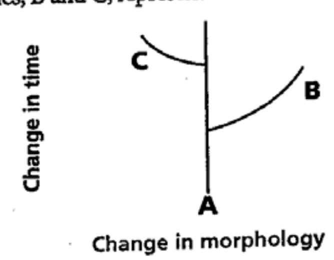
Purpose

In this lab, you will categorize fossils by similarities in morphology and age. You will then draw an evolutionary tree that depicts the relationship of these fossils.

Background

Fossils are traces of organisms that lived in the past. When fossils are found, they are carefully excavated and then analyzed. One part of this analysis is to determine the age of the fossil. The absolute age of a fossil can be determined through radiometric dating. In **radiometric dating**, the amount of a certain radioactive element is compared to the amount of its decay element. Because the decay rate of the radioactive element (its half-life) is constant, the ratio of the two elements tells scientists the age of a fossil. Analysis also includes a study of the **morphology**, or physical characteristics, of the fossil so that it can be identified.

The age and morphologies of fossils enable scientists to place the fossils in sequences that often show a pattern of changes that have occurred over time. This relationship is frequently depicted in a diagram called an evolutionary tree. An **evolutionary tree** is a diagram showing the relationships between species and the morphological changes that have occurred between species over time. The diagram below is an example of an evolutionary tree. Line A represents the original lineage, and the two branches, B and C, represent two new lineages that evolved from A.



There are two major theories on how evolution takes place. Many scientists believe that organisms evolve through a process of slow and constant change called **gradualism**. Another theory states that some species evolve through the process of punctuated equilibrium. In punctuated equilibrium, species evolve very rapidly over a short time and then remain the same for very long periods.

Procedure

1. Tape together the four sheets of paper along their 17-in. edges. Copy the data chart below onto the paper. The "Fossils" column should be *at least* 8 in. wide. Except for the Idahoan period, use 5 in. of space for each time period's row. For the Idahoan's row, use only 1 in. of space. The time periods listed in the chart are fictional. Be careful to copy the time periods in the correct order.

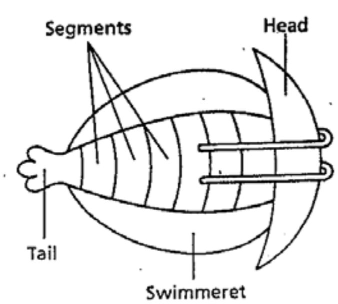
Fictional Time Periods

Time period	Began (years ago)	Duration (in years)	Fossils
Idahoan (the present)	30,000	30,000	
Californian	80,000	50,000	
Montanian	170,000	90,000	
Colorodian	320,000	150,000	
Oregonian	395,000	75,000	
Texian	445,000	50,000	
Nevadian	545,000	100,000	
Ohioian	745,000	200,000	
Wyomingian (oldest)	995,000	250,000	

2. The group of "fossils" you will work with are of fictional animals from the fictional genus *Crustaceus.* Each fossil on your fossil sample sheet (page 33 of this activity) is marked with the time period to which the fossil has been dated. Cut out each fossil, making sure to include the time period marked below it. You will need this information later.

3. Arrange the fossils by age. On your data chart, place each fossil next to the period identified with that fossil. The term *upper* means a more recent part of a period. The term *lower* means an earlier part of a period. Thus, fossils from an upper period should be placed near the top of the space allotted for that period, and those from a lower period should be placed near the bottom. If the period identified for a fossil is neither upper nor lower, place the fossil in the middle of the space. Place fossils from the same time period side by side. Do not tape or glue them in place yet.

4. While keeping the fossils in proper age order, arrange them by morphology. To give you an idea of what body parts to look for, examine the example of *Crustaceus,* with its labeled body parts, in the diagram at right. Then, carefully examine the morphology of each fossil. Begin by examining the oldest fossils, and work in sequence to the most recent. Note any changes from one time period to the next. Arrange the fossils using the following steps:



a. Center the oldest fossil at the bottom of the "Fossil" column.

b. Throughout the chart, those fossils that appear to be exactly the same as the fossils preceding them chronologically should be placed directly in a vertical line with each other.

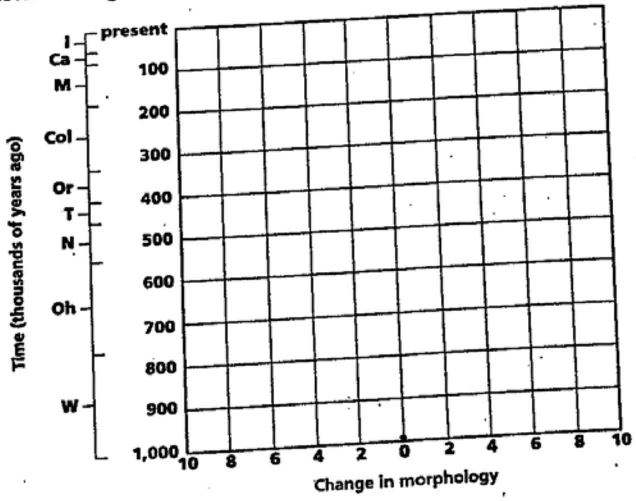
c. The first fossil that appears different from the one before should be placed 1/2 in. to the left of the fossil before it.

d. During a certain period, the fossils will be split into two branches. In other words, one fossil from that period will show one type of change, and another fossil from the same period will show a different type of change. When this occurs, place one of these fossils 1/2 in. to the left of the fossil from the preceding time period. Place the other fossil 1/2 in. to the right of the fossil from the preceding time period.

e. After the point of branching, place each fossil in the left-hand branch that exhibits a change 1/2 in. to the left of the fossil preceding it. In the right-hand branch, place each fossil exhibiting a change 1/2 in. to the right of the fossil preceding it.

5. Once all fossils have been placed correctly according to time and morphology, tape or glue the fossils in place.

6. Draw an evolutionary tree on the following graph for the fictional genus *Crustaceus.* The number 0 on the *Change in Morphology* axis denotes the physical appearance of the original (oldest) fossil. Each tick mark to either side denotes a change in morphology from one fossil to the next-youngest fossil.



7. Dispose of your materials according to the directions from your teacher.

8. Clean up your work area and wash your hands before leaving the lab.

Analysis

9. Give a brief description of the evolutionary changes that occurred in *Crustaceus*. Refer back to the labeled diagram of *Crustaceus* above to review the terms used to describe the various body parts of the organism.

10. During which period did the fossils start to differentiate into two branches?

11. In what period does the common ancestor of the *Crustaceus* species of the Montanian period appear?

Conclusions

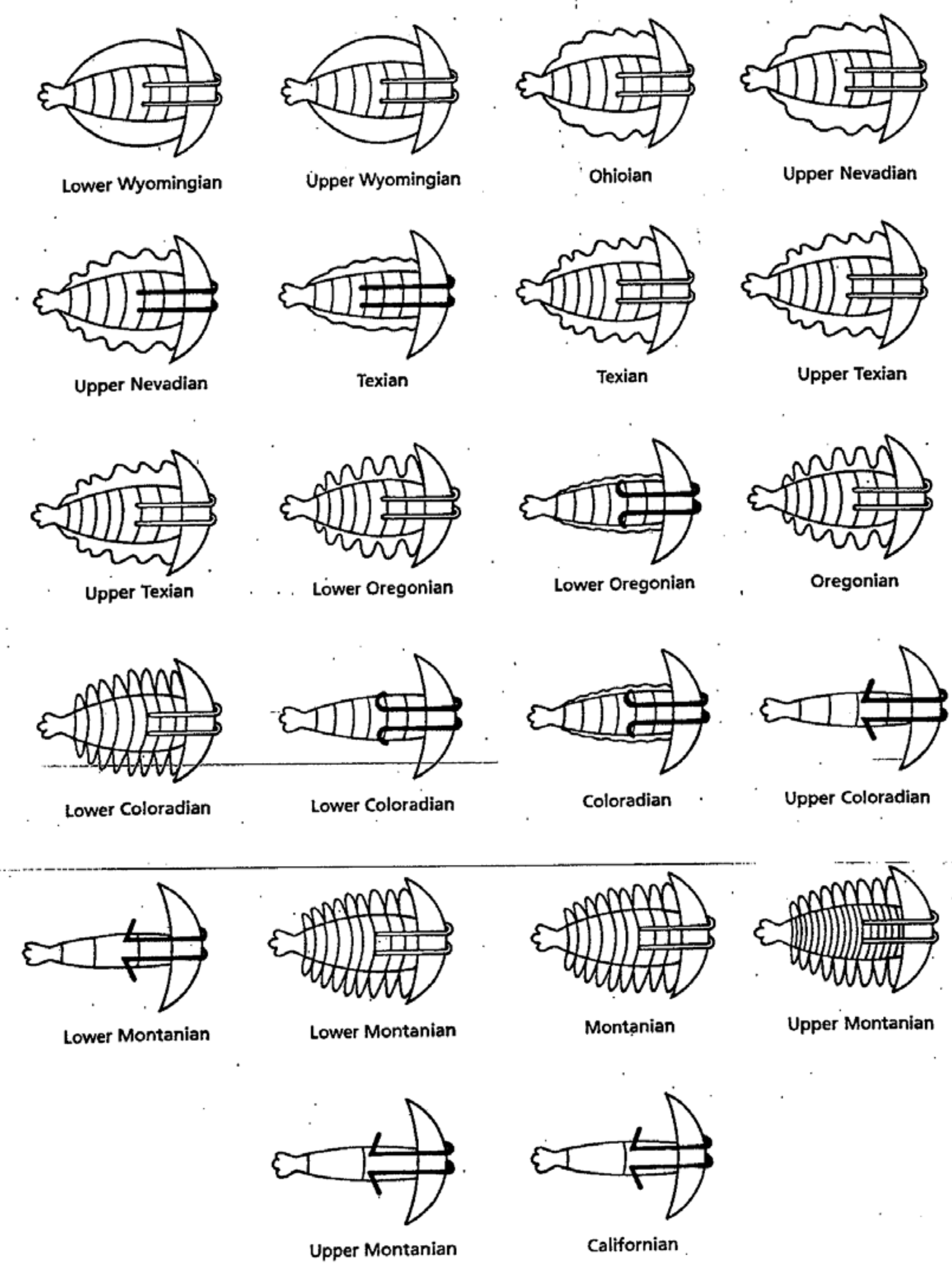
12. No examples of *Crustaceus* survive today. Determine when the genus became extinct. Support your answer.

13. Did the set of fossils show gradualism or punctuated equilibrium? Explain.

Extensions

14. Sketch an example of an evolutionary tree that shows punctuated equilibrium.

15. Research the evolution of the genus *Equus*, to which modern horses belong. Draw an evolutionary tree to describe your findings, or write a few short paragraphs to describe the changes to this genus over time.


Lower Wyomingian
Upper Wyomingian
Ohioian
Upper Nevadian
Upper Nevadian
Texian
Texian
Upper Texian
Upper Texian
Lower Oregonian
Lower Oregonian
Oregonian
Lower Coloradian
Lower Coloradian
Coloradian
Upper Coloradian
Lower Montanian
Lower Montanian
Montanian
Upper Montanian
Upper Montanian
Californian

INVESTIGATION 16

Using Comparative Genetics to Examine Evolutionary Relationships

Purpose

To compare the amino acid sequence of cytochrome C of several different organisms to see how closely related they are to humans and how long ago they shared a common ancestor.

Concepts

- Evolution
- Phylogenetic trees
- Mutation

Background

The fossil record is one of our strongest sources of evidence for evolution. There are remains of organisms not around today that show similarities to organisms present today. We can also look to organisms today to show how closely related they are. We can do this by comparing *homologous structures*, examining *biochemistry*, seeing *vestigial* organs, and comparing *embryos* in different stages of development. This lab will use *comparative genetics*.

Cytochrome C is a protein found universally in all organisms. It is comprised of a sequence of approximately 100 amino acids. The table shown in the procedure represents 1/4 of the sequence for nine different organisms. Each letter represents the name of one of the 26 amino acids. For purposes of this lab, it is not necessary to know what the letters represent.

Once this information is gathered, the sequences can be compared and a *phylogenetic tree* can be constructed. (See Figure 1) They depict in graphic form the evolutionary distance between organisms. Often referred to as a *molecular clock*, this method takes advantage of the predictable rate at which mutations occur in the DNA. Those organisms with the greatest number of amino acid sequence differences are considered to have diverged from a common ancestor the greatest number of years ago (1 and 6). If two organisms have few differences between them, but a large and approximately equal number of differences from some third organism, they would be closely related and likely to be found as twigs of a branch that are far removed from that third species (numbers 3 and 4, and number 1)

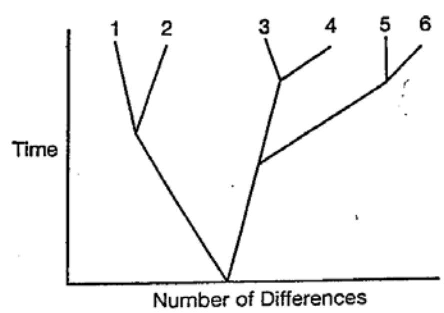


Figure 1

Materials

Pen or pencil

Safety

There are no particular safety concerns for this activity, but follow all normal laboratory safety rules.

Procedure

Part A:

1. Examine the table below listing the cytochrome C sequence for the nine different vertebrates.
2. For each vertebrate, count the number of amino acids that differ from the order listed for the human and record the data in Table1 in Part A of the Evolutionary Relationships Worksheet.

Horse	Chicken	Tuna	Frog	Human	Shark	Turtle	Monkey	Rabbit
Q	Q	Q	Q	Q	Q	Q	Q	Q
A	A	A	A	A	A	A	A	A
P	E	E	A	P	Q	E	P	Y
F	F	Y	F	Y	F	F	Y	P
T	S	S	S	S	S	S	S	S
T	T	T	T	T	T	T	T	T
D	D	D	D	A	D	E	A	D
K	K	K	K	K	K	K	K	K
N	N	S	N	N	S	N	N	N
K	K	K	K	K	K	K	K	K
G	G	G	G	G	G	G	G	G
I	I	I	I	I	I	I	I	I
T	T	U	T	I	T	T	I	T
K	G	N	G	G	Q	G	G	G
E	E	N	E	E	Q	E	E	E
E	D	D	D	D	E	E	D	D
T	T	T	T	T	T	T	T	T
L	L	L	L	L	L	L	L	L
M	M	M	M	M	R	M	M	M
E	E	E	E	E	I	E	E	E
K	D	S	S	K	K	D	K	K
A	A	A	A	A	T	A	A	A
T	T	T	G	T	A	T	A	æT
N	S	S	S	N	A	S	N	N
E	K	--	K	E	S	K	E	E

Part B:

1. In the same way as for Part A, count the number of differences in the fragments, but this time making comparisons between the pairs listed in Table 2 in Part B of the Evolutionary Relationships Worksheet. For example, compare the number of differences between the monkey and the shark, the monkey and the frog, the monkey and the tuna and the monkey and the human.
2. We can assume that these five proteins diverged from a common ancestor sometime in the past; they changed but did not replace this ancestor's protein over time. When a mutation occurs, the change is seen only in the organism with the mutation (and its offspring), not other members of the species. Therefore, there would be two varieties of the protein in the population. Using this concept, place the protein fragments on the phylogenetic tree on the worksheet and answer the Analysis and Conclusions questions.

Name:________________________________

Evolutionary Relationships Worksheet

Data and Observations

Part A

Species	# of differences
Horse	
Chicken	
Tuna	
Frog	
Shark	
Turtle	
Monkey	
Rabbit	

Data Table 1

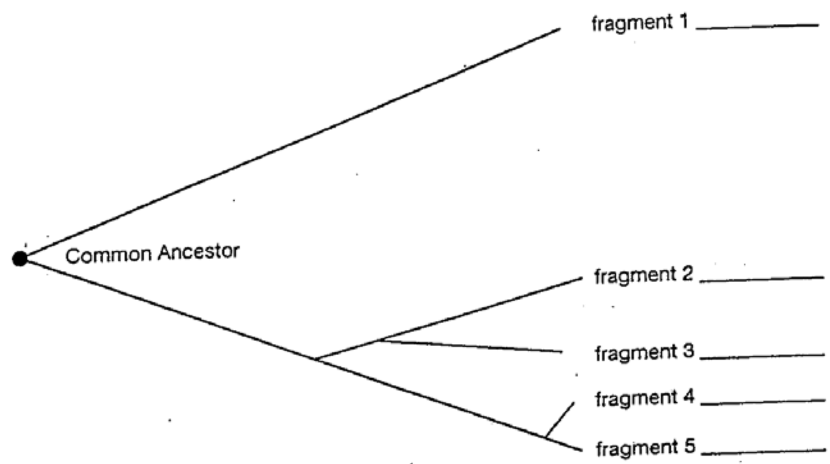
Part B

	Monkey	Shark	Tuna	Frog	Human
Monkey					
Shark					
Tuna					
Frog					
Human					

Data Table 2

Evolutionary Relationships Worksheet

Phylogenetic Tree



Analysis and Conclusions

1. Which of the vertebrates studied in this lab is most closely related to humans?

2. If you were just observing the organisms based on their outward appearance, would you have classified them the same way? Explain.

3. Recall that point mutations in DNA can change the sequence of amino acids in a protein chain. How many mutations occurred to change the cytochrome C of a tuna into that of a horse?

4. Describe why you put each fragment in its particular location on the tree.

5. Species X and Y have 25 amino acid differences. Species X and B have 10 amino acid differences in the same protein. Species Y and B have 27 amino acid differences.

   a. In the space at the right draw a simple phylogenetic tree to show these relationships.

   b. Which pair of organisms diverged from the ancestor first? Which pair probably diverged more recently? Explain.

   c. Which of the pairs of organisms are likely to have shared more characteristics than the other two pairs? Explain.

Geologic Time Scale Flipbook Instructions

1. Get 3 pieces of computer paper
2. Fold the paper into a flipbook so that you have 6 tabs. Label the flipbook according to the diagram below.

Your Name
Geologic Time Scale
Precambrian
Paleozoic
Mesozoic
Cenozoic

3. For the tab labeled **Geologic Time Scale** write the **definition of a Geologic Time Scale**. Use page 421 in your book.
4. For the remaining tabs: **Precambrian, Paleozoic, Mesozoic, Cenozoic** do the following:
    a. Use page 421 (Figure 17-5) to **write the time (millions of years ago)** that each era occurred.
    b. Use pages 429-434 to write **5 IMPORTANT facts about each ERA**. Each era has "periods." You do not have to write 5 facts about each "period"...just 5 facts about the whole era. Read through the periods to obtain your facts.
5. **DUE TOMORROW!!**

Geologic Time Scale Flipbook Instructions

1. Get 3 pieces of computer paper
2. Fold the paper into a flipbook so that you have 6 tabs. Label the flipbook according to the diagram below.

Your Name
Geologic Time Scale
Precambrian
Paleozoic
Mesozoic
Cenozoic

3. For the tab labeled **Geologic Time Scale** write the **definition of a Geologic Time Scale**. Use page 421 in your book.
4. For the remaining tabs: **Precambrian, Paleozoic, Mesozoic, Cenozoic** do the following:
    a. Use page 421 (Figure 17-5) to **write the time (millions of years ago)** that each era occurred.
    b. Use pages 429-434 to write **5 IMPORTANT facts about each ERA**. Each era has "periods." You do not have to write 5 facts about each "period"...just 5 facts about the whole era. Read through the periods to obtain your facts.
5. **DUE TOMORROW!!**

Name:_______________
Date:____ Period:_______

M&M Survival of the Fittest

We will use plain M&Ms to demonstrate lots of concepts like the continuation of the strength and robustness of the candy as a species.

Procedure:

1. **Hold two candies between your thumb and forefinger and apply pressure, squeezing them until one of them cracks and splinters. That one is the loser and is immediately eaten. The winner gets to go onto another round.**

While participating in this activity, think about what colors seem genetically tougher and which seem inferior? Occasionally you will get a mutation, a candy that is misshapen, or pointier, or flatter than the rest. Does this prove to be a weakness? On rare occasions you may find that it gives the candy extra strength. In this way the candy continues to adapt to its environment.

When you reach the end of the pack you are left with the strongest of the herd. Since it would make no sense to eat that one, you may challenge your classmates' winners. We will send the ultimate winner, the "True Champion" to M&M Mars, A Division of Mars, Inc., Hackettstown, NJ 17840-1530 U.S.A., along with a 3x5 index card reading, "Please use this M&M for breeding purposes." Any coupons that the company sends in return will be considered "grant money."

Questions

1. **Which color(s) seem to be the strongest?**

2. **Which color(s) seem to be the weakest?**

3. **What does the term "Survival of the Fittest" mean?**

4. **What is the difference between Natural Selection and Artificial Selection?**

5. **What are the four major points to Darwin's Theory of Natural Selection?**

The Latest Beak: a simulation of Natural Selection

Group Members:

a. ____________ b. ____________

c. ____________ d. ____________

Problem: Which bird "beak" will be able to pick up the most food?

Hypothesis: (*each* person is to write a hypothesis)

A. ______________________________

B. ______________________________

C. ______________________________

D. ______________________________

Data Tables:

A. Clothes Pin "beak"

Type of Food	Year 1 # of Pieces of Food	Year 2 # of Pieces of Food
Jelly Beans		
Pasta		
Gold Fish		
Twizzlers		
Nuts		
TOTAL NUMBERS →		

B. Chop Sticks "beak"

Type of Food	Year 1 # of Pieces of Food	Year 2 # of Pieces of Food
Jelly Beans		
Pasta		
Gold Fish		
Twizzlers		
Nuts		
TOTAL NUMBERS →		

C. Tweezers "beak"

Type of Food	Year 1 # of Pieces of Food	Year 2 # of Pieces of Food
Jelly Beans		
Pasta		
Gold Fish		
Twizzlers		
Nuts		
TOTAL NUMBERS →		

D. Spoons "beak"

Type of Food	Year 1 # of Pieces of Food	Year 2 # of Pieces of Food
Jelly Beans		
Pasta		
Gold Fish		
Twizzlers		
Nuts		
TOTAL NUMBERS →		

Conclusion Questions: Answer the following questions on the back of this paper. Use complete sentences. Everyone should contribute to the answers.

1. What are the variations (differences) among the birds?
2. What interaction occurs between the various birds as they gather food? Explain what you observed.
3. What would be the BEST "bird beak" for soft food? For foods that move? Explain.
4. From Year 1 to Year 2, why must some birds adapt to how they use their "beak" to gather food?
5. Explain some of the different adaptations used to gather food from Year 1 to Year 2.
6. Based on your data, which bird has proven to be best suited for their environment or shows "survival of the fittest?" Explain.
7. Which bird from this activity would have to overproduce to keep from extinction? Explain.

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