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Teaching the unifying theory of biology : a curriculum unit on evolution

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TEACHING THE UNIFYING THEORY OF BIOLOGY: A CURRICULUM UNIT ON EVOLUTION

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A CURRICULUM UNIT ON EVOLUTION

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ABSTRACT

This action research project developed an updated and expanded curriculum unit on the theory of evolution. The activities and assessments that were selected and designed for the curriculum followed the instructional theories of backward design and constructivism. Working as a community of learners, high school students were empowered to engage in experimentation, innovation, discovery, and problem solving as they participated in a series of lab activities designed to help them gain new understandings of the theory of evolution. The success of the unit was evaluated by looking at student work and assessing student levels of understanding, using both qualitative and quantitative methods. Since modern biology is based on the concepts of evolutionary theory, understanding evolution is an important goal for the biology curriculum, and it prepares students for making informed decisions in the 21st century. This curriculum unit, with its focused lesson plans and annotated bibliography of resources, is a valuable resource for any biology teacher seeking to help students understand the foundation of modern biology.

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TEACHING THE UNIFYING THEORY OF BIOLOGY: A CURRICULUM UNIT ON EVOLUTION

My first year teaching high school biology, at Seaside High in 2005, introduced me to some of the challenges experienced by many biology teachers in the United States. As I began instruction with one of my classes regarding Charles Darwin and the Voyage of the Beagle, I asked students to start a KWL on the theory of evolution. This is a chart constructed by students where they write down the things they know (K), things they want to know (W), and what they have learned (L, which is done after the unit). Imagine my surprise when I was reviewing their charts to find things like: "What was Charles Darwin "on" when he came up with the theory of evolution?", and similar statements indicating their total rejection of anything they had already heard about evolution. Although these attitudes were only expressed by two of my 60 biology students, these two students were quite vehement in their refusal to consider accepting anything in the evolution unit and wrote such "protest" statements as heading their papers "the silent majority".

As time went on, I continued to have conflicts with these two students quite often. I did try to reach out to them and encouraged them to read outside materials that supported their views of biblical creationism. I also told them that if they could find any articles that they wanted me to read, I was certainly open to doing so. However, I was firm in my refusal to consider including "Intelligent Design" as an alternative to the theory of evolution in the classroom. I felt certain that the state standards for teaching biological evolution in California prohibit any teaching of creationism (or supernatural forces as presented in Intelligent Design). I did consult with our department head and was told I was doing the best possible things under the circumstances.

By the end of the unit, I was completely frustrated by the constant tension I felt was created by these two students. Although I didn't realize it at the time, this is a common situation in biology classrooms across the United States, even more common in more traditionally conservative religious areas of our country. I also didn't realize at the time that the tension was a result of not dealing with students' prior beliefs and convictions so that they could be open to the possibility of learning about the theory of evolution.

Last August, I read a New York Times article called "A Teacher on the Front Line as Faith and Science Clash" (Harmon, 2008), written about a high school biology teacher in Florida. Reading about his struggle to teach evolution helped me recall my experiences in 2005, and helped provide a purpose for completing my research and thesis. For several years I have tried new things each year, but have not really being satisfied with the outcome in terms of student understanding and acceptance of evolution. I have also come to realize the complexity of all the issues involved, from social issues, to student misconceptions, to the inadequacies of the textbook. This action research project is a culmination of my quest to improve my teaching practice by developing a comprehensive curriculum unit on the theory of evolution.

Problem

Research shows that even though nearly half of all Americans believe that humans have evolved over time, only 26% favor teaching "evolution only" in public schools while 64% favor teaching creationism along with evolution (Jensen, 2008). With this cultural disconnect, it is a challenge for high school biology teachers to overcome some students' skepticism regarding learning about evolution. Indeed, 69% of biology teachers spend only 3-5 hours on evolution, and an astounding 25% of teachers spend at least 1-2 hours on creationism (Jensen, 2008). It's also interesting to note that in a survey of 18 other industrialized countries, the United States ranks second to last (Turkey is last) in a survey asking about acceptance of the theory of evolution (LePage, 2008).

In 1980 President Ronald Reagan stated that evolution is a "theory only", and endorsed the teaching of creationism in the nation's schools. The American Civil Liberties Union battled back against the movement towards creationism in schools, the end result being a Supreme Court decision in 1987 that barred the teaching of creationism in American schools (Larson, 2004). Since that time the controversy hasn't abated, resulting in a constant back and forth between the scientific community and conservative religious groups. The latest development is the Intelligent Design movement which debuted in 2000, and seeks to present "an alternative" to biological evolution by positing that living things have a "designer" rather than evolving through time (Miller, 2008).

The current debate over evolution can also be seen as a debate over what science really is, and why it is important to human society. As a science teacher, perhaps the larger, more important battle is to help students understand the nature of science, and why things such as Intelligent Design (and astrology, etc.) are not science. Biological evolution is proved by a convergence of evidence, from fossils, genetics, anatomical comparisons between species, and many more. Intelligent Design is impossible to prove because there is no evidence to support a supernatural designer (McComas, 2006). The key strategy for supporters of Intelligent Design is to say that if evolution is false, then it follows that there must be a “designer”. This line of reasoning is not valid for science, because it ignores the rules of what constitutes a scientific theory, such as relying on testable hypotheses and evidence.

Some in the scientific community see this as a larger assault on science as a way of knowing about the world. Although America has a strong link to science, and we as a people tend to be practical and want to see evidence for things, the debate over evolution shows a deep split in the American psyche (Miller, 2008). The conservative Discovery Institute, based in Seattle, which backs Intelligent Design with money and legal personnel, has stated a goal of splitting science from its “materialistic” basis and replacing it with a science consistent with “Christian and theistic values”. In other words, change the definition of science from being limited to the natural world (materialistic) to a “theistic science” that could include the supernatural as a valid element in scientific inquiry (Miller, 2008). The public relations for the Intelligent Design movement has been successful, as reflected by recent polls that show a majority of Americans support the teaching of Intelligent Design in schools (Miller, 2008). However, recent court decisions such as in Dover, Pennsylvania in 2005 have struck down Intelligent Design as a valid scientific theory suitable for biology classrooms.

Purpose

Students do not enter our science classes as “blank slates”. They tend to have “naïve explanations” about many science topics, including the theory of evolution that can interfere with their learning (Hartman, 2002). These misconceptions can result from false or incomplete information, limited experience, incorrect generalizations, or misinterpretations that result in a students’ basic understanding of a topic (Hartman, 2002). In order to overcome these misconceptions, teachers must identify them and use those in planning instruction. The overall strategy is to challenge the misconceptions, present the empirically accepted scientific ideas and concepts, and allow the students a variety of experiences to see the new ideas providing better explanations than the old ideas.

The level of conceptual change required to teach the theory of evolution calls for many lab experiences, as students need to be given explicit opportunities to test for themselves the utility of evolution and the model of natural selection (McComas, 2006). The biology textbook used at Seaside High School is published by Prentice Hall, and authored by Kenneth Miller and Joseph Levine. The two chapters on evolution occupy only 40 pages or about 4% of the total book. The first chapter presents information on the development of the theory of evolution and the second chapter focuses on evolution as genetic change. There are two "quick labs" (10-15 minute activities) and two full length lab activities. The main component that is lacking in the Prentice Hall textbook is a series of engaging lab experiences that will allow students to overcome their misconceptions. In addition, new discoveries about DNA are not included in the text, as it was written in 2002.

The "new" science of evolution is making amazing advances based on discoveries about DNA. Every change in an organism, from simple to complex, is due to changes in the DNA. Thus, DNA is a "living chronicle" of evolution (Carroll, 2006). Some of the recent discoveries in this field include "fossil" genes, bits of DNA that provide links to distant ancestors and former ways of life (Carroll, 2006). Mitochondrial DNA (a form of DNA passed from mother to offspring) evidence can be used to determine when and where the domestication of dogs started (Mindell, 2006). The genetic evidence for evolution provides an explanation for the "machinery" of the process, and ties in with student learning about genetics and DNA in the rest of the biology course.

Scientific education organizations in the United States from the National Science Teachers Association (NSTA), to the American Association for the Advancement of Science (AAAS) are actively advocating the teaching of biological evolution in high schools. There is a large amount of material available to help teachers develop more teaching resources for evolution, as well as practical tips for dealing with classroom controversy about the teaching of evolution. For example, the University of California Museum of Paleontology, the National Science Foundation, and the Howard Hughes Medical Institute sponsor an outstanding website called "Understanding Evolution", that not only provides teacher support and resources, but also interactive websites for students.

Formal Statement of Research Questions

- What are the challenges involved in developing student understanding of the theory of evolution?
- Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?
- Will the updated curriculum using new resources and technology produce better student understanding of biological evolution?
- How can different assessment instruments be used to measure student understanding of biological evolution?

The Community of Learners at Seaside High

My classroom is modeled as a "community of learners". Students work together in teams and groups, which helps foster this concept. The idea is to have students collaborate, teach each other, and become responsible for their own learning (Ladsen-Billings, 1995). Learning occurs within a social context as students share their ideas with their classmates in cooperative group settings (Clark, 1996). Knowledge is "constructed" and modified by individuals within a group context, then shared with others through positive social interactions (Clark, 1996). Encouraging students to engage in dialogue with one another can be a powerful way to change or reinforce conceptions (Brooks, 1999).

The idea of a community of learners is also one of the *Lessons from High Performing Hispanic Schools.* According to this study by Jay and Alicia Scribner and Pedro Reyes, one important aspect of culturally responsive pedagogy in these schools is that teachers provide a caring environment in which students are viewed as the most valuable resources of the school (Reyes, 1999). In addition, Reyes and Scribner found that in these schools teachers empowered their students to engage in experimentation, innovation, discovery and problem solving by encouraging shared knowledge and collaboration. In this curriculum unit on evolution, students are empowered to engage in experimentation, innovation, discovery, and problem solving as they participate in a series of lab activities designed to help them gain an understanding of the theory of evolution.

Democracies and the global community need scientifically literate citizens in order to chart our course for the future (Pace, 2003). The development of this curriculum unit helps students understand the foundation of modern biology, and prepares them for college level biology classes. The concepts presented in the unit also help students to become better critical thinkers as they examine evidence and learn the nature of the scientific thinking that led to the theory of evolution. This knowledge and ways of thinking become vitally important as our students enter the community to become future leaders and voters. As we face a future where modern biology is on the brink of giving us previously unimagined power over the natural world, from reshaping the human body to new environmental policies, citizens must be able to make informed decisions (LePage, 2008).

Limitations of the Project

This study was limited to a population of high school students on the central coast of California. There was no control group utilized, therefore, the results of the study reflect the implementation of the curriculum to all of the students. The results of the project are intended to serve any biology or life science teacher interested in updating their approach for teaching the theory of evolution. In addition, the process of constructing a curriculum unit using the approaches of constructivism and a community of learners would be applicable to teachers in other curricular areas.

Summary

This action research project is the development of an updated curriculum unit on the teaching of the theory of evolution to high school biology classes. A research based model curriculum was developed and implemented in biology classes at Seaside High in the spring semester of 2009. Subsequent chapters present the review of related literature, the methodology, and the data and results from the curriculum's initial implementation.

Appendices contain the curriculum unit, and an annotated bibliography of curriculum resources used. In addition, analysis of the initial results gave informed feedback on how the curriculum unit will be adjusted for next years students in order to better develop student understanding of the theory of evolution.

REVIEW OF THE RELATED LITERATURE

What are the challenges involved in developing student understanding of the theory of evolution?

The rationale for the project is established in this section as the argument is presented that evolution is the unifying theory of biology. Or as the geneticist Theodosius Dobzhansky stated "Nothing in biology makes sense except in light of evolution" (Wilson, 2007).

Why does evolution have a central place in the biology curriculum? It could be summed up in a single sentence: We live in the age of Darwin (Shermer, 2006). The theory of evolution provides a view of the world as a product of natural laws and the contingent events of history (Shermer, 2006). The success of western civilization is arguably based on science and technology, and on understanding and manipulating the world. Our continued success depends on this, perhaps more than ever (LePage, 2008). Our students' understanding of the principles of evolution will allow them to not only understand an ever-changing world, but also provide them with a unifying theory for the science of biology. Evolution provides a level of understanding linking morphology, physiology, biogeography, genetics, and the fossil record (McComas, 2006).

With that established, there are issues that make the teaching of evolution difficult. First and most problematic, there are innumerable myths and misconceptions surrounding the theory of evolution. Student misconceptions regarding evolution can be divided into three basic categories: philosophical, historical and cognitive (McComas, 2006). A major philosophical misconception is that students must be asked to reject their religion in order to "believe" in evolution. Any teaching of the theory of evolution must be prefaced with a thorough grounding in the nature of science. Students must have an understanding of what a scientific theory is, and how science is a way of knowing that is not at odds with religion. (McComas, 2006). This will allow them to understand why alternative "theories" such as Intelligent Design do not qualify as science.

Students should know that the expectation is to learn about the scientific theory of biological evolution, and that they do not have to give up any of their religious convictions in order to do so (Jones, 2007). Many students (and Americans in general) express distrust in science and fear that it is used to challenge their religious views (Jones, 2007). A 2001 Gallup poll revealed that 25% of Americans polled said they didn't know enough about the theory of evolution to say whether they accepted it or not, and only 34% considered themselves "very well informed" (Shermer, 2006). Among the top reasons why people don't accept the theory of evolution are:

- A general "resistance" to science.
- The theory of evolution contradicts the Bible.

- Evolution degrades our humanity; in that it implies we are simply animals (Shermer, 2006).

The goal in teaching this unit is to help students become informed about the theory of evolution in such a way so that they can accept it, regardless of their religious beliefs. The key is to give students enough background on the nature of science and how science and religion are different ways of viewing the world. A belief in God depends on religious faith, and acceptance of evolution depends on empirical evidence. (Shermer, 2007). In other words, God is beyond the realm of science, and science is outside the realm of religious belief. However, there is nothing inherently atheistic about science. This idea of "nonoverlapping magisteria", developed by Steven Gould, can be used to help students understand that science deals with facts and evidence and religion deals with morality (Pigliucci, 2002). In addition, scientific explanations of the natural world are compatible with religious explanations of divine agency and purpose (Jones, 2007).

Proponents of Intelligent Design (ID) "theory" seek to challenge the teaching of evolution in public schools by providing an alternative explanation for how species came to be. The main tenet of ID states that there is distinct difference between objects that are naturally designed, and those that are "intelligently designed". For example, the rocks that make up Mt. Rushmore, vs. the faces carved into them. ID proposes that "intelligent agents" have unique causal powers that nature does not (Shermer, 2007). Therefore, when we observe objects that we "know" only these agents can produce, we can infer the presence of a prior intelligence, even if we did not observe the actions of the agent responsible. The problem with this "theory" is there is no experiment that can be designed to collect data or evidence to support or refute it. Therefore, it fails the test of what science is, and falls into the realm of a philosophical discussion, i.e. religion.

Another tactic of proponents of ID is to try to "prove" their theory by saying that evolutionary theory is wrong. Michael Behe, one of ID's leading proponents, argues that many structures in living things are "irreducibly complex", and could not have been produced by evolution. If even one part of such structures were removed, it wouldn't function; therefore it couldn't have evolved over time. ID uses several such examples of irreducibly complex structures; the most commonly used are the bacterial flagellum, and the blood clotting mechanism (Miller, 2008). The argument concludes by saying that if the structures couldn't have evolved, then they must have been designed. Again, the problem with this approach is that there is no empirical evidence for their "conclusion", and it cannot be tested, therefore, it is not science (Miller, 2008). The other problem with this approach is the fact that evolutionary biologists have evidence to suggest that both the bacterial flagellum and blood clotting mechanism have evolved from other previous structures, evidence that ID proponents conveniently ignore (Shermer, 2007).

The development of the theory of evolution involved the work of many scientists, and evidence for the theory is widespread. Common misconceptions regarding the history of the theory of evolution is the belief that it was solely the work of Charles Darwin, and that there is not enough evidence to support the theory. Darwin's publication of "Origin of Species" in 1859 was the groundbreaking introduction of the theory of evolution by natural selection to the world. But there were other scientists, including Alfred Russel Wallace, whose work produced similar conclusions to Darwin's. Since that time, modern evolution theory has built on Darwin's principles but has included the component of genetics to add yet another category of evidence to the previous ones of direct human observations and the fossil record (LePage, 2008).

At the cognitive level, biological evolution has proven to be difficult subject matter for students to understand. There are three large concepts that compose the major learning challenges of biological evolution: evolution as change over time, natural selection as the mechanism for change, and variations in inherited characteristics as the "raw material" for that change (McComas, 2006). Students often arrive at the high school level with "naïve explanations" for all of these areas. For example, students tend to believe that changes in organisms are "acquired" in response to pressures from the environment, and those new traits or abilities can then be passed on to the next generation (McComas, 2006). This is called "Lamarkism", after Jean Baptiste Lamarck, the French biologist and early evolutionist (Gould, 1980). Although this idea appeals to common sense, the inheritance of acquired characteristics is not the same as natural selection. Students should come to a new understanding that natural selection is not a direct process, but rather a complex process over many generations in which the individuals better suited to their environment survive and pass on their genes to the next generation (Gould, 1980).

Data suggests that most Americans are not scientifically literate. Polls show that less than half of all Americans understand key scientific facts like electrons, antibiotics, lasers, and the Earth going around the sun (Pace, 2003). The result of this lack of knowledge is that many Americans can't tell real science from pseudoscience. For example, 36% of respondents in a poll thought that astrology was "very" or "sort of" scientific (Pace, 2003). What does it mean to be scientifically literate? It means that a person can deal with scientific matters that appear in public life with the same ease that an educated person would have in dealing with matters of politics, law, or economics (Pace, 2003).

Scientific literacy for the 21st century requires that students have a working knowledge of biology, including the theory of evolution. How is evolution relevant to our daily lives? By applying a single set of Darwinian principles to a vast diversity of subjects, including humans, we can help our students understand not only how life changes over time, but how all life is connected (Wilson, 2007). For example, biodiversity can be seen as the ultimate result of 3.8 billion years of evolution. The evolutionary "fruits" of biodiversity include many species of infinite value to humans, such as penicillin derived from a fungus (Mindell, 2006).

Antibiotic-resistant super-bugs such as MRSA (methicillin-resistant staph infection) are a growing problem. A basic knowledge of evolution allows students to understand issues important in our time (LePage, 2008). Our traits, diseases, and pathways to health are being shaped by evolution. A deeper understanding of evolution can provide a foundation for significant changes in perspective, and lead to greater social justice. We are all of one "blood" that began flowing in Africa, and the history of our migrations is recorded in our DNA (Jones, 2007).

Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?

High school textbooks have traditionally focused on two areas of evidence for evolution: the fossil evidence and comparative morphology. For example, the textbook used by the students involved in this study has three pages of information on the evidence for evolution. These three pages include generalized explanations of fossil evidence, homologous body structures (structures that develop from the same embryonic tissue, such as limbs), and similarities in early development (embryo comparisons).

There are three areas of new evidence for evolution: direct human observations, fossils, and "quirks and imperfections" (McComas, 2006). Direct human observations include such things as the HIV virus rapidly evolving strains resistant to antiviral medicines (Mindell, 2006). Direct human observations also include the analysis of DNA in different organisms and looking for common sequences that indicate shared ancestry. For example, the "eye-building" genes in fruit fly, mouse, and human DNA have been analyzed and scientists have concluded that the similarities between the three are so strong, that they are essentially the same protein (Carroll, 2006). This "Pax-6" gene is thought to be an example of "tool-kit" genes that are common in organisms from simple to complex, that are evidence of a common ancestor (Carroll, 2006). These examples illustrate the type of compelling, convincing evidence that can be presented to students.

These tool-kit genes also provide a rebuttal to ID argument of irreducible complexity. The human eye is another example of a structure that ID proponents claim is irreducibly complex, in other words, it could not have evolved form a simpler form. The PAX-6 genes are responsible for building eyes from simple to complex. Research has suggested that 200 steps over about 500,000 years could produce a camera eye (such as human) starting from a simple proto-eye (such as a micro-organism). Similar common genes have been identified that build hearts, muscles, nervous systems and limbs. Evidence shows that these genes are ancient, and therefore must have been in place in a common ancestor. The current diversity of life can be viewed as the product of using similar body-building tool-kit genes in different ways (Carroll, 2006).

Another new area of DNA evidence for evolution is the so-called "immortal genes". These are about 500 genes that are present in virtually identical form in all living things, from the simplest bacteria to humans. They are "immortal" in that they have withstood two billion years of mutation and natural selection and remained intact. Their functions involve universal processes in all cells; such as decoding of DNA/RNA, and the making of proteins. These common genes provide evidence of the power of natural selection to preserve the DNA record and the descent of life from common ancestors (Carroll, 2006).

It is estimated 99% of all species that ever lived are now extinct, and only a very small fraction of those are preserved as fossils and actually found (Shubin, 2008). Even so, the fossil record is a valuable source of evidence for evolution. The fossil record reveals the actual environments and transitional structures that have existed throughout the history of life (Shubin, 2006). For example, the fossil record enables us to trace the evolution of the horse from its ancestors on the Eurasian steppes 2 million years ago, to their domestication approximately 6000 years ago, and ultimately to the 200 breeds of domesticated horses that exist today (Mindell, 2006)

"Quirks and imperfections" encompass a variety of phenomena that provide evidence for evolution. Modern whales have a tiny pelvis for hind legs that existed in their land animal ancestors (Shermer, 2006). Humans have a coccyx, or tailbone, that is all that remains from our common ancestors' tails used for gripping branches and maintaining balance (Shermer, 2006). Pandas have "thumbs", that are actually extensions of the wrist in addition to the normal five digits, enabling them to eat bamboo with ease (Gould, 1980). These concrete examples can be presented to students to help develop their understanding of the concept of evolution as change in a species' physical characteristics, or adaptations, over time.

The biggest breakthrough in terms of evidence for evolution could be the ability to analyze the DNA of different organisms and show how they are related, and have changed over time (Carroll, 2006). Every evolutionary change between species, such as changes in physical characteristics, is due to and recorded by changes in the DNA (Carroll, 2006). Although biology students spend a large part of the course studying DNA, DNA evidence for evolution is not included in their textbook. Because DNA testing is so widely accepted in today's world, for example in court cases and paternity testing, this can be a powerful illustrative tool in teaching young students about evolution. In the "age of genomics", we have not only sequenced the human genome, but many other species as well (Fairbanks, 2007). By demonstrating how DNA provides evidence for evolutionary change, I can connect with my students' interest in up-to-date information provided by the latest technology.

Today's students are also keenly interested in how to connect what they are learning to their own life, or the "real world". How can I use examples of an "evolving world" to capture their interest? Using examples of domestication can be concrete examples of "applied" evolution (Mindell, 2006). Students often have questions about where domesticated animals come from, and by providing answers using evolutionary principles theory can be linked to the everyday world. Public health and medicine also can provide timely examples of evolution. Pathogens such as HIV and some bacteria can be observed to mutate, and evolve, in a short period of time (Mindell, 2006). Students can read about and discuss current topics such as antibiotic resistance (MRSA) which can be seen as a "real world" result of the evolution of bacterial species.

Will an updated curriculum using new resources and technology produce better student understanding of biological evolution?

The explanations of natural selection involve sophisticated concepts that are difficult for students to master. Natural selection is an abstract principle that normally involves huge amounts of time and complex processes. Many high school students are only beginning to have the mental structures necessary to understand evolutionary biology (McComas, 2006).

The guiding theory for developing this curriculum unit is constructivism. Students start with their prior knowledge and experience (including any misconceptions), and construct a "new" version of the topic throughout the course of the unit. Specific strategies are put into place to identify student misconceptions, and then by taking students through a variety of intellectually challenging learning experiences, they will come to a new level of understanding (Trowbridge, 2000). Pre-instructional assessments will be designed to identify students' level of knowledge of evolution. For example, students can be given a scenario of a change in a species over time, and be asked to provide an explanation of that change. Student responses can be analyzed to gauge their level of understanding and/or misconceptions regarding the theory of evolution by natural selection.

Students' prior knowledge including misconceptions regarding evolution is often "common sense" views of the world they have constructed through personal experiences and social interactions with others (Chiappetta & Koballa, 2002). These ideas have served students well in the past, and are difficult to replace. However, these common-sense views often differ from scientific views and do not allow the student to have a coherent, accurate picture of the world (Chiappetta & Koballa, 2002). Constructivist teachers engage students in experiences that might create contradictions to these misconceptions and then encourage them to come to new conclusions (Brooks, 1999). Traditional science teaching that presents information in an expository manner via lectures, textbooks, and other sources has not proven effective in overcoming misconceptions that are held by learners (Trowbridge, 2000). According to *A Report to the Nation for the National Commission on Mathematics and Science Teaching for the Twenty-first Century:*

> We are failing to capture the interest of our youth for scientific and mathematical ideas. We are not instructing them to the level of competence they will need to live their lives and work their jobs productively. Perhaps worst of all, we are not challenging their imaginations deeply enough (Pace, 2003, p.16).

Priority must be given to overcome our deficiencies in science teaching by considering different strategies, such as these four steps:

- First the action, then the words: Let students explore a concept, and then formulate their own explanation for phenomena.
- Talk through a new concept: Individually and in groups, students present and defend their explanations of phenomena.

- Teach the concept to someone else: Students become experts as they have to explain phenomena to each other, for example using the jigsaw method.
- Don't let the concept die: New learning will not overcome old misconceptions unless it has been experienced multiple times in new contexts. (Trowbridge, 2000,p.180)

Integrating technology into the instruction should also be a major goal, as research suggests that technology rich programs are more likely to result in significant gains in knowledge, and motivation (Hartman, 2002). This would include both presentation styles, such as animations, and student activities such as interactive web sites (Jensen, 2008).

There have been many recently published resource guides for teaching evolution that are invaluable resources in the development of an updated evolution curriculum. Activities can be selected that allow students to investigate the main concepts of the theory of evolution by natural selection. As they progress through the activities, they can construct new understandings of the concepts based on the results of their investigations.

Five up-to-date resource guides recommended by a variety of scientific education organizations, including NSTA (National Association of Science Teachers) and NABT (National Association of Biology Teachers) that were reviewed are:

- The Virus and the Whale: Exploring Evolution in Creatures Small and Large, published by NSTA Press in 2006.
- Investigating Evolutionary Biology in the Laboratory, published by the National Association of Biology Teachers in 2006

- Animal Coloration: Activities on the Evolution of Concealment, published by the NSTA Press in 2006.
- Evolution in Perspective: The Science Teacher's Compendium, published by NSTA Press in 2004.
- The Nature of Science and the Study of Biological Evolution, published by BSCS in 2005.

In addition, six resource websites that provide student activities were reviewed:

- PBS Evolution: www.pbs.org/wgbh/evolution
- University of California at Berkeley Understanding Evolution: evolution.berkeley.edu
- National Health Museum: accessexcellence.com
- Project MUSE at the University of Wisconsin: ncisla.wceruw.org/muse
- National Academy of Sciences Teaching About Evolution and the Nature of Science: nap.edu
- Evolution and the Nature of Science Institute: www.indiana.edu/~ensiweb

*These resources are reviewed and described in the annotated bibliography of this thesis project.

How can different assessment instruments measure student understanding of biological evolution?

In any curriculum unit, it is important to use a variety of assessment strategies to evaluate student performance. In addition, the evaluations should reflect what students are expected to learn and understand (Hartman, 2002). As the updated unit on biological evolution is presented, assessments will be developed to provide ongoing information of student performance and concept development. In this way, the effectiveness of the updated curriculum can be evaluated by looking at both the products that the students produce during classroom activities, and their understanding of the concepts as measured by formal assessments.

Diagnostic assessments can be used to provide insights into student ideas, thoughts, and skills and are particularly useful when teaching difficult subject matter, such as biological evolution (Chiappetta & Koballa, 2002). Examples of diagnostic assessments include surveys, pre-tests, concept maps, and solutions to open-ended problems (Chiappetta & Koballa, 2002). These types of assessments can provide valuable information both at the beginning of the unit, and as a way to check on concept development as the unit progresses. Assessment methods must be matched to the target that they are assessing in order to be effective (Stiggins, 2001). For example, in order to identify student prior knowledge of the nature of science and the theory of evolution, a true/false survey or essay question would be an effective option for assessment (Stiggins, 2001).

Several sample evolution curricula and research studies include pre-surveys and essay questions to evaluate student knowledge of the nature of science and the theory of evolution as diagnostic assessments to inform instruction. The Measure of Acceptance of the Theory of Evolution (MATE) survey is an example of a pre-instructional survey, developed in 1999 by Rutledge and Warden (Rutledge & Sadler, 2007). This survey has questions focused on the process of evolution, scientific validity of evolutionary theory, the evolution of humans, evidence of evolution, the scientific community's view of evolution, and the age of the Earth. It employs a range of possible answers from Strongly agree to Strongly disagree, and has been used mainly as a tool of researchers on university level students and pre-service teachers. The University of Indiana's ENSI website has a similar survey, developed by Robbins and Roy, although it employs true/false questions written specifically for identifying misconceptions about evolution and the nature of science. Administering, scoring, and evaluating such a survey at the beginning of the unit could provide a baseline for instruction by identifying student misconceptions about the theory of evolution and student knowledge of the nature of science (Robbins and Roy, 2007).

Essay questions given at the beginning of the unit can also function as diagnostic assessments. In the Robbins and Roy study, The Natural Selection: Identifying and Correcting Non-science Student Preconceptions through an Inquiry Based, Critical Approach to Evolution, the researchers gave an unannounced pre-unit essay quiz. Students were asked to write for ten minutes on two open-ended questions: 1.Explain the theory of evolution. 2. Do you believe in it? Why or why not? Students were encouraged to participate because all sincere answers were given credit. The students' unrehearsed, unprepared responses were believed to be an accurate reflection of their everyday understanding of evolution (Robbins and Roy, 2007). By analyzing the students' responses, the researchers were able to determine the percentage of students that agreed with the theory of evolution (59%) and how many were able to correctly explain it in a short paragraph (6%). The researchers then used the results from the essays as the basis for a 30 minute guided lecture/discussion. Assessments can be even more effective when they are used as feedback to help students improve their performance (Hartman, 2002).

So, by addressing common misconceptions in a non-threatening way that allowed students to remain anonymous in their mistakes, students could see, for example, that 41% of them wrote that humans came from apes (Robbins and Roy, 2007).

Essay questions used as pre-assessments could also be presented as situations or problems students must describe or solve that illustrate evolutionary concepts. Students' preconceptions regarding evolution can be revealed by asking them to describe how it "works" given a specific situation. For example, given a paragraph describing the different tortoises on the varied islands of the Galapagos, students could be asked how scientists would explain how a specific "carapace" or shell came to be. In a study conducted at Monona Grove High school, a medium sized high school in the Midwest, researchers used this question as a pre-assessment to document some of the common ideas held by students (McMahon, et al, 2006). In addition, students were asked to return to their initial explanations after the completion of the evolution unit, and re-visit them using the new understanding they gained during the nine-week unit (McMahon, et al, 2006).

Formative assessments are usually given during and after instruction to assess students' progress and understanding of the concepts being presented (Chiappetta and Koballa, 2002). Here again, the assessment must match the target, or what the students are being asked to accomplish. Assessments should be designed that evaluate how successfully a student completes the tasks assigned (Stiggins, 2001) For example, in an investigation in which students are asked to use evidence to solve a problem, a performance assessment could be developed using a rubric to evaluate how well students communicate the results of their investigation. Rubrics such as those developed by

Science Education for Public Understanding (SEPUP) at the Lawrence Hall of Science at the University of California Berkeley rate student performance from 0 to 4 and gives criteria for what constitutes each level of student performance of the task (McMahon, Simmons, Sommers, DeBaets, and Crawley, 2006).

Using rubrics as tools for formative assessments throughout the unit also helps students view learning as a process, and allows them to become more involved in the assessment (McMahon, et al, 2006). Students can see where their skills fall on the continuum and can be motivated to move up to the next level. The scoring rubrics are given to the students at the same time as the task, so that instead of focusing on grades, students can focus on the learning (Chiappetta and Koballa, 2002). The terminology used in the assessment also shifts the focus from a simple teacher generated "grade" to something they can achieve. For example, students will know that in order to move from "Basic" skill level to "Proficient", their work must include certain criteria (McMahon, et al, 2006). Well-constructed scoring rubrics allow students to know ahead of time how they will be graded and afterwards, how they are doing in the learning process (Chiappetta & Koballa, 2002). In addition, it gives teachers a structured way to gauge student attainment of the skills and knowledge needed for concept development.

Classroom instruction based on constructivism assesses student learning within the context of lessons and activities (Brooks and Brooks, 1999). Constructivist teachers analyze student products and artifacts as benchmarks and gather information to use in developing future activities and to evaluate instructional practices (Brooks and Brooks, 1999). Each lesson or activity presented in the unit will have a specific goal designed to address misconceptions and help students develop a new level of understanding of the theory of evolution. Since the goal of this curriculum unit is to develop a sophisticated understanding of the concepts of evolutionary theory, assessments for the activities need to be developed that can gauge the developing level of student understanding.

The purpose of summative assessments is to see if the students understand the concepts. After the students have completed the evolution unit, assessments need to be administered that can evaluate whether they have reached a new understanding of the theory of evolution based on the essential unit questions that guided the curriculum. What does it mean to understand? Students must be able to make sense of, and use, the knowledge they have learned and the principles underlying it (Wiggins and McTighe, 1998). In the case of the theory of evolution, understanding involves not only being able to answer knowledge level questions, but being able to apply that knowledge in authentic situations (Wiggins and McTighe, 1998). Given these assessment "targets", a reliable post-unit assessment is a combination of selected response and essay questions to evaluate knowledge, understanding, and reasoning proficiency (Stiggins, 2001).

Constructivist teachers seek elaboration of student's initial responses (Brooks and Brooks, 1999). Inclusion of the pre-assessment essay questions at the end of the unit assessment allows students to re-conceptualize and assess their own errors. Student elaboration also enables teachers to more clearly understand what students do and do not think about a concept (Brooks and Brooks, 1999). In the Robbins and Roy study, the researchers included the "Explain the theory of evolution" question that was given in the pre-quiz. They were able to conclude, by reading student responses on the unit exam, that 92% of their students were able to explain the concept correctly, compared to 6% before the unit was presented (Robbins and Roy, 2007). In the Monona Grove High school study, students were given their initial responses to the pre-assessment question about Galapagos tortoises as part of their final exam, and were asked to critique them. Student critiques of their earlier responses allowed them to be explicit about what they had learned since they formulated their initial explanations (McMahon, et al, 2006).

Researchers at Ohio State University also concluded that a combination of open-ended response (essay) and selected response questions are the best way to assess student understanding of the theory of evolution. The study was conducted there with undergraduate students from a large minority-serving urban university with a diverse population similar to Seaside High. One evaluation used five open-response questions designed to evaluate student understanding of evolution at differing levels of complexity. Their five questions focused on natural selection (the mechanism of evolution), and were written to parallel Bloom's Taxonomy, which organizes different types of knowledge by levels (Nehm and Schonfeld, 2007). Students had to demonstrate knowledge, comprehension, application, analysis, synthesis and evaluation of the process of natural selection (Chiappetta and Koballa, 2002). In this way, the Open-Ended Response Instrument (ORI) was designed to evaluate students' sophistication at solving different kinds of evolutionary problems. Researchers concluded that the ORI was a strong tool in evaluating the key concepts and remaining student misconceptions about natural selection (Nehm and Schonfeld, 2007).

A well constructed selected response test is a valid method of assessing knowledge and understanding of key concepts (Stiggins, 2001). In the Robbins and Roy study, researchers assessed student understanding of evolution with a unit exam that was 70% multiple choice questions that covered natural selection as well as fossils, comparative anatomy, and biochemistry as areas of evidence for the theory of evolution (Robbins and Roy, 2007). Researchers at Ohio State University used a multiple choice test called the Conceptual Inventory of Natural Selection (CINS) written by D.L. Anderson and K.M. Fisher. The CINS consists of twenty multiple choice questions that offers one correct response for each question as well as a series of distracters based on well-documented alternative conceptions (Nehm and Schonfeld, 2007). This test was designed by subject area experts to cover the key concepts of natural selection, with the twin aim of correctly identifying student knowledge and alternative conceptions. Researchers in the Ohio State University study concluded that the CINS demonstrated student knowledge of key concepts most efficiently when compared with the ORI and student oral interviews (Nehm and Schonfeld, 2007).

A combination of assessment strategies, selected according to the target to be evaluated, will be used to assess students before, during, and after the presentation of the unit on evolution. Assessments will be designed and constructed using research based strategies as I strive to gauge the effectiveness of the unit in helping students construct new knowledge of the theory of evolution. In addition, assessments can provide information on how the components of the curriculum unit need to be adjusted as the unit is evaluated in order to determine what needs to be changed for the following year's instruction.

METHODOLOGY

This action research project created an updated curriculum unit and annotated bibliography of resources for teaching evolution to high school biology classes. After preparing this curriculum unit, it was piloted with students in the spring semester of 2009. The success of the unit was evaluated by looking at student work and assessing student levels of understanding, using both qualitative and quantitative methods. The final piece was deciding how it should be adjusted and changed for the following year.

This curriculum unit is based on the California State Standards for Biology, Standards 7- 8:

- Evolution is the result of genetic changes that occur in constantly changing environments.
- Students know mutations are constantly being generated in a gene pool.
- Students know how natural selection determines the differential survival of groups of organisms.
- Students know a great diversity of species increases the chance that at least some organisms survive major changes in the environment.
- Students know how to analyze fossil evidence with regard to biological diversity, episodic speciation, and mass extinction.

Participants

The updated curriculum unit on the theory of evolution was presented to two biology classes, 51 students, at Seaside High School in February and March of 2009. The students ranged from ninth to twelfth grade, ages fourteen to eighteen. The community of learners at Seaside High is extremely diverse. The students' ethnicity is approximately 16% white, 14% African American, 42% Latino, 9% Filipino, 5% Pacific Islander, and 10% Asian. Approximately 20% of the students are English learners, and 54% receive free or reduced meals (www.cde.gov). The curriculum was presented as a regular part of the biology course, based on the state standards, and students were not given any information about the thesis project.

The students in the two classes are typical of the student population at Seaside High. As well as being ethnically diverse, they represent a wide range of abilities and backgrounds. Most students have taken Earth Science as an introductory high school science course, although the 9^{th} graders typically take physical science as 8^{th} graders. Students are purposefully placed in mixed range ability groups, and lower level English Language Learners are usually paired with more fluent speakers. Academic success as measured by students' first semester biology grades shows the 51 students in this study display the typical range of grades with an average of 78%.

Project Design

Using a technique called backward design, the evolution state standards were analyzed to identify the desired results, including student understandings (Wiggins, 1998). The backward design method for planning curriculum starts with the expectations for what students will understand and be able to do at the end of instruction. Assessments to determine whether students reach those expectations were written before instruction. Then, working backwards, the curriculum was put together around those assessments that focused students towards those final results. Guiding unit questions based on the state standards were written that break down the student understandings into discernable goals that take students step by step towards the expected outcomes.

Each guiding unit question was linked back to the research questions. For example, some of the guiding unit questions are: How was the theory of evolution developed? How do we know evolution has occurred, what is the evidence for evolution?

How does the theory of natural selection explain how evolution occurs? All of these guiding unit questions were explored via a focus on the research questions. For example, all three of the previously listed sample guiding unit questions involved students in new research and DNA related findings. From these "big ideas", lessons were designed to develop student understanding of the guiding unit questions. The guiding unit questions are based on the state standards combined with the research questions and these became the learning goals of the curriculum unit.

Each misconception that was identified during the pre-instructional assessments and student writing prompts helped design instruction by revealing areas in which students needed focused instruction in order to build new knowledge. For example, if students did not understand that the fossil record provides convincing evidence for evolution, careful sequencing of lab activities and student discussions was designed in order to develop new student understanding of the fossil evidence of transitional species. Then new writing prompts (warm-up questions at the beginning of class) quickly assessed whether students have overcome their misconceptions and developed new understandings as they consider a question, talk it over with a partner, and then share with the whole class (think-pair-share).

Deciding which learning activities to include in the unit involved careful planning for the entire three week unit. Each day's instruction was designed around one or more guiding unit questions. Using the model of a community of learners, emphasis was placed on interpretation of data with peer instruction in order to synthesize the concepts that students needed to understand evolutionary theory. In keeping with constructivist theory, lessons were also carefully sequenced to overcome misconceptions by developing new student understandings of the important concepts of evolution.

There is a large amount of material available to help teachers develop more teaching resources for evolution, as well as practical tips for dealing with classroom controversy about the teaching of evolution. The search for the activities to use in the unit mainly used the internet as a research tool. Accessing web-sites such as ENSI (Evolution and the Nature of Science Institute) and the PBS (Public Broadcasting Service) site devoted to evolution provided access to on-line versions of student activities as well as links to other resources. Science organizations such as the NSTA (National Science Teachers Association) and the NABT (National Association of Biology Teachers) have a variety of resource guides on evolution. The resources found during the course of this study are described in the annotated bibliography appendix.

To reach the goal of having a series of engaging lab experiences designed to overcome student misconceptions and provide better explanations for evolution, many different resources were utilized. Activities included in the unit were selected based on their connections to the guiding unit questions, and other factors such as practicality and appropriateness for the learners at Seaside High. In addition, activities were selected that represented the most up-to date information on evolution, and uses of technology that help engage students and provide real-life examples of evolution.

Assessments

Three types of assessments were used during the implementation of this curriculum. Pre-instructional, formative, and summative assessments provided data about what students knew before instruction, how new knowledge was being constructed during instructional activities, and what students' new understanding of the theory of evolution by natural selection became after the curriculum unit was implemented.

Pre-Instructional Assessments

Pre-instructional assessments provided vital information before instruction by identifying student misconceptions. One of the pre-instructional assessments was a survey based on MATE (Measure of Acceptance of the Theory of Evolution). The MATE survey, described in the literature review, was designed and tested with university students. For effective use with high school students, questions were re-written making sure they could be fully understood by all high school students. For example, the statement: Organisms existing today are the result of evolutionary processes that have occurred over millions of years was slightly revised to: Living things that exist today are the result of the processes of evolution that have occurred over millions of years. The purpose of administering this survey was to assess the student's pre-instructional knowledge of evolutionary theory, knowledge of the nature of science, and their acceptance of evolutionary theory.

Another pre-assessment used is based on the Robbins and Roy study referenced in the literature review, an un-announced pre-quiz that consists of two questions: 1. Explain the Theory of Evolution, and 2. Do you accept it? Why or why not? Students were told they received credit if they provided thoughtful answers to the two writing prompts, and they must spend ten full minutes writing. This assessment helped identify misconceptions that students have about evolution and the number of students who accept that evolution has occurred. In order to qualify as explaining the theory of evolution, student answers must state that individuals best adapted to their environment are best fit to reproduce, so their traits will be more prevalent in the next generation.

Formative Assessments

Student work samples were collected from key activities that provided evidence to link back to the research questions. For example, to demonstrate that students understand how DNA provides evidence for evolution, student work was collected and analyzed from activities designed to reach that goal. This might be a "quick write" prompt (warm-up question on the board), or a lab sheet. Each of these had a simple rubric to rate the level of student success in reaching the learning goal, and to determine which students had reached developing, proficient or advanced levels of understanding.

Sample Rubric: Lamarck vs. Darwin Evolutionary Scenarios

Developing	Proficient	Advanced
Able to identify the given Lamarck and Darwin scenarios	Able to identify and describe some parts of Lamarck and Darwin's scenarios	Able to identify and analyze the parts of Lamarck's and Darwin's explanations of evolution mechanisms
Partial completion of own Darwin/Lamarck scenarios	Completed own dual scenarios that somewhat illustrate Lamarck's and Darwin's mechanisms for evolution	Completed own dual scenarios that correctly illustrate the two mechanisms

Summative Assessments

The next step was to determine the acceptable evidence for student understanding of the guiding unit questions, and resolution of the research questions. Students were given a writing prompt or open response instrument (ORI) as a post unit assessment. This prompt described a situation in which evolution by the process of natural selection has occurred, and related to activities that students did during the unit. Students wrote a response explaining how evolution occurred. Student writing was assessed based on pre-identified indicators of understanding of the theory of evolution defined in a student writing rubric.

Writing prompts:

1. Pakicetus, the ancestral whale species, became extinct and was replaced by a new whale ancestor, Ambulocetus. Using the language of natural selection, explain how and why this happened.

2. There are thirteen species of finches on the Galapagos Islands. Each species has a different beak, ranging from a long thin beak for crushing cactus seeds, to a woodpecker like beak for digging insects out of wood. Using the language of natural selection explain how the common ground finch on Daphne Major came to have its particular beak shape.

A rubric was designed that assessed the various components of a response that indicates understanding of evolution and the degree of sophistication of that response:

Indicator	Level 2 Developing	Level 3 Proficient	Level 4 Advanced
Student defined and described variations as heritable traits	Brief description of variation	Uses scientific language describing variation	Uses scientific language defining and describing variations
Student describes environmental factors as reason for species' change	Brief mention of environmental factors or change	Describes possible environmental factors as reason for species change	Uses scientific language to describe possible environmental factors leading to species' evolution
Student describes possible adaptations	Describes adaptations	Describes adaptations and	Describes adaptations using scientific

		links to survival or "fitness"	language, i.e. selective advantage
Student describes a "struggle for existence" as a part of natural selection	Mentions factors such as lack of food	Defines struggle for existence as part of the process of natural selection	Uses scientific language to describe the struggle for existence in differential rate of survival
Student described a natural selection mechanism	Combination of Lamarkian and natural selection mechanism	Correctly describes natural selection as process of heritable change	Uses scientific language to describe the process of heritable change

In addition to a post unit writing prompt (ORI), the CINS assessment tool (Conceptual Inventory of Natural Selection) described in the literature review, was also administered. As with the MATE survey, this was developed for use with university students. Careful analysis and re-writing of the multiple choice questions about natural selection was done to assure that it is a valid assessment tool for high school students. The CINS consists of twenty questions based on scenarios presented about Galapagos finches, Venezuelan guppies, and Canary Island lizards. The questions are linked to seven different topics that students should have synthesized during the unit: biotic potential, population stability, natural resources, limited survival, variation within a population, inherited variation, differential survival, change in a population, origin of species, and origin of variation. Each question also has incorrect answers, distractors, which are linked to alternative conceptions.

Finally, students were asked to re-visit their initial writing assignments on: What is the theory of evolution? Do you accept it? Their initial writing pieces were given to the students, and they were asked to re-write their responses based on what they learned throughout the unit. Student responses were assessed using the same criteria used in the pre-assessment.

Data

Pre-Instructional Assessments

The MATE survey student responses consist of answers to questions along a continuum from strongly agree (A) to strongly disagree (E). The survey items address six different concepts: the process of evolution, scientific validity of evolutionary theory, the evolution of humans, evidence for evolution, scientific community's view of evolution, and the age of the Earth. Each survey item addresses one or more of these concepts. The survey includes scoring instructions that correlate the different responses to numbers (Rutledge and Sadler, 2007). To determine an individual's numerical score, the scorer follows the scoring instructions and finds the sum of the scaled responses to all twenty items. The individual scores are then assigned to categories of acceptance as follows (Rutledge and Sadler, 2007):

Very High Acceptance: 89-100

High Acceptance: 77-88

Moderate Acceptance: 65-76

Low Acceptance: 20-52

After scoring the student surveys, a table and accompanying graph were prepared showing the number of students in each category.

The other pre-assessment, the writing prompts, were evaluated by reading them, and determining the percentage of students who were able to explain the theory of evolution and who either accept it or don't. In order to qualify as explaining the theory of evolution by natural selection, student answers must state that individuals best adapted to their environment are best fit to reproduce, so their traits will be more prevalent in the next generation. This constitutes an operational definition of natural selection, the mechanism for evolution. Pie charts were prepared showing the percentages of students that can/can't explain evolution, and who accept/don't accept evolution.

Formative Assessments

Selected student activities had simple rubrics to rate the level of student success in reaching the learning goal, and to determine which students had reached developing, basic or proficient levels of understanding of the learning goal (based on the guiding unit questions). These results were represented in a table and accompanying graphs that identified the learning goal, the number of students at each level, and connections to the research questions.

Summative Assessments

The post unit writing prompt assessment was examined (using the aforementioned rubric) to determine whether students had achieved a new level of understanding at the end of the unit that shows they can explain the process of natural selection without relying on misconceptions. The results were compiled and displayed in a table and accompanying graph that shows the number of students that reached developing, proficient and advanced levels of understanding.

Analysis of the student results of the post-unit assessment, the CINS, involved determining the number of correct responses for each student taking the test. This data was displayed in a table showing the number of students at developing, proficient, and advanced levels of performance on the multiple choice test. In addition, key questions linked to the concept of natural selection were analyzed in terms of how many students answered correctly, and how many still had alternative conceptions. In this way, the CINS data provided an efficient method of measuring student knowledge of the key concepts of natural selection after the unit was presented.

To analyze data from the final post-unit assessment, the re-written responses to the questions: Explain the theory of evolution? Do you accept it? were assessed using the same criteria used in the pre-assessment. A new post-unit pie chart was constructed to show the percentage of students that can/can't explain evolution and the percentage of students who accept it/don't accept it.

Using three different post assessment tools provided a variety of data to be used in evaluating the effectiveness of the unit, and in the resolution of the research questions. Students who do not perform well on multiple choice tests had two other avenues in which to demonstrate their knowledge of the theory of evolution. Taken together, the data was analyzed to show the strengths and weaknesses of the unit, in terms of which concepts were understood, and which alternative conceptions were still commonly present in student explanations. Using these results, the unit was revised to include more focused instruction in particular areas in which student understanding was not satisfactorily developed.

Field Notes

Journaling to record observations of the teaching and student learning was done each day, and included student responses and anecdotes. The journaling protocol included prompts about whether or not the new materials being used were producing better levels of student understanding of evolution. Major headings in the journal pages were:

- What worked?
- What caused confusion?
- What questions did students have?
- What new understandings were demonstrated (based on the guiding unit question)?
- Student anecdotes/responses to warm-ups.

Holistic observations were made about the effectiveness of the lesson and whether or not students had reached the goal and demonstrated understanding.

Summary and Conclusion

The updated and expanded curriculum unit on the theory of evolution that was developed in this action research project involved a three week unit designed around the California state standards for biology combined with the project's research questions. The activities and assessments that were selected and designed for the curriculum followed the instructional theories of backward design and constructivism in order to develop new student understandings of the theory of evolution.

After the initial pilot of the updated curriculum unit, decisions on the effectiveness of the lessons and activities were made on what, if any, components needed to be adjusted. These decisions were made based on the student work collected during the unit, reflections recorded during the implementations of the lesson, and the results of the summative assessments. The curriculum unit, with its focused lesson plans and annotated bibliography of resources, is a valuable resource for any biology teacher seeking to help students understand the foundation of modern biology.

RESULTS

The data collected during the implementation of the updated curriculum unit on evolution was analyzed to provide resolution to the research questions:

- What are the challenges involved in developing student understanding of the theory of evolution?
- Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?
- Will an updated curriculum using new resources and technology result in better student understanding of biological evolution?
- How can different assessment instruments be used to measure student understanding of biological evolution?

Pre-assessments provided a baseline for research by revealing student misconceptions about the theory of evolution, and students' level of understanding of the basic concepts such as natural selection. Key lessons had formative assessments that provided evidence for student learning, and resolution of the research questions. Summative assessments provided data that showed new levels of student understanding of the concepts after instruction. All of the assessment data is displayed in tables and accompanying pie charts showing the number of students at developing, proficient or advanced levels of understanding of the concept being presented or assessed.

Field notes provided additional data for assessing the effectiveness of the curriculum. Journaling about each day's lesson recorded holistic impressions regarding what worked, what questions students had, what caused confusion and needed to be adjusted, and how new student understanding was being demonstrated. Field notes also included quotes from student work samples, and questions and statements from students during class discussion.

The results are presented in a chronological format, focusing on the key lessons and assessments from which data was collected and analyzed. Each analysis will combine the data from assessments with observations from the journaling to determine the success of the lesson or assessment in producing or determining new levels of student understanding. The research question linked to each lesson or assessment is identified and connected to the analysis of the data.

Days 1-2 Research Question:

What are the challenges involved in developing student understanding of the theory of evolution?

For this research question, the MATE, Measure of Acceptance of the Theory of Evolution, (literature review, page 18) and the essay prompts (literature review, page 19) were given to the students before any instruction on evolution.

The MATE is designed to measure the degree of acceptance of evolutionary theory. Statements are read by students, and they respond to them using a Likert scale continuum from strongly disagree to strongly agree. Students exhibiting a very high acceptance of evolution would strongly agree to a statement such as: Modern humans are the product of evolutionary processes that have occurred over millions of years. Students exhibiting a very low acceptance of evolution would strongly agree with the statement: Humans exist today in essentially the same form in which they always have.

All of the students were given this essay prompt before any instruction on evolution: **What is the theory of evolution? Do you accept it? Why or why not?** Since they have been introduced to the theory of evolution as part of their 7th grade life science course, students can write responses to the essay prompts based on their prior knowledge and or beliefs about the theory of evolution.

Data from student work

Table 1 MATE Survey Results 4th Period: 25 students

Category	Very High Acceptance 89-100	High Acceptance 77-88	Moderate Acceptance 65-76	Low Acceptance 53-64	Very Low Acceptance 20-52
Scaled Scores		80, 78, 78	76, 73, 73, 73, 72, 72, 72, 71, 71, 71, 71, 71, 71, 69, 68, 66, 66,	58, 58, 57, 55	50
Total	0	3	17	4	1

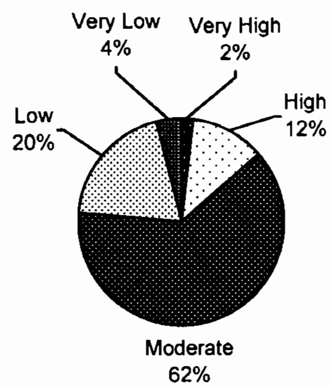
Table 2 **MATE Survey Results 5th Period: 26 students**

Category	Very High Acceptance 89-100	High Acceptance 77-88	Moderate Acceptance 65-76	Low Acceptance 53-64	Very Low Acceptance 20-52
Scaled Scores	94	84, 84, 80	75, 75, 75, 74, 74, 74, 72, 72, 72, 72, 71, 69, 69, 69, 68,	62, 61, 57, 56, 56, 56	48
Total	1	3	15	6	1

Table 3 **MATE Survey Results: All 50 Students**

Category	Very High Acceptance 89-100	High Acceptance 77-88	Moderate Acceptance 65-76	Low Acceptance 53-64	Very Low Acceptance 20-52
Total	1	6	32	10	2

Figure 1 Acceptance of the theory of evolution based on MATE



Pre-Assessment Data: Essays

Four of the fifty one students were able to explain evolution using the concept of natural selection, or inheritance of favorable traits by species over time. Forty seven students either relied on misconceptions or couldn't explain evolution.

Figure 2 Explanation of evolution based on student essays

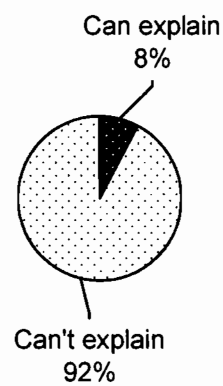
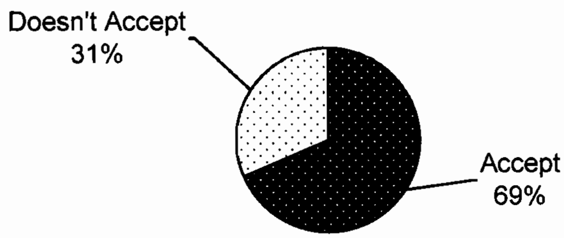


Figure 3 Acceptance of theory of evolution based on student essays.



Thirty five of the fifty one students stated they accepted the theory of evolution, sixteen students stated they did not. Misconceptions about the theory of evolution were revealed in their essay answers as they explained why they do or don't accept the theory of evolution. These misconceptions are listed here, followed by the number of students that wrote that particular misconception in their essay.

<u>Misconceptions about evolution from student essays</u>

- Evolution thought up by scientists that don't believe in God.-1
- Evolution theory includes the Big Bang: origins of Earth-4
- The theory of evolution explains how life began.-6
- Humans evolved from gorillas/monkeys.-14
- There's no proof for the evolution of humans.-1
- Evolution tries to prove the Bible wrong.-1
- Evolution is something people "believe".-2
- The theory of evolution goes against most religions-2
- Religion (Catholicism) says evolution isn't real.-3

- There is a “missing link” that can’t be found.-1
- Animals or plants "change" their characteristics to better suit their way of life.-1
- The evidence for the theory of evolution is just assumptions-2
- The theory of evolution says we came from one person named "Eve"-3

Data from field notes

During instructions for the essay pre-assessment, one student asked; “Can we talk about religion?” Students were engaged, and participation was high, in the whole-class discussion regarding what is science and what is non-science that took place as the misconceptions from the student essays were being reviewed.

Data Analysis

Based on the data collected from the pre-assessments, the majority of the students surveyed accept the theory of evolution. According to the MATE, 76% of students had a moderate to very high acceptance of evolution. According to the essay responses, 69% of students stated they accepted the theory of evolution. The data therefore indicates that 24 to 31% of the students do not accept the theory of evolution.

The data from the pre-assessment essay in which students explained evolution indicated that only 8% could correctly describe evolution as a process involving change in a species over time due to inheritance of favorable traits. The vast majority, 92%, were not able to explain evolution using the correct scientific concepts.

The essay questions in which students explained their acceptance level of evolution also revealed misconceptions about the theory of evolution. These common misconceptions fall into the three categories of misconceptions detailed in the literature review (page 8): philosophical, historical and cognitive. For example, eight students expressed the point of view that "belief" in evolution goes against their religion, a common philosophical misconception.

The data from the pre-assessments gives a baseline for instruction, as well as resolution for the research question. Since 94% of students could not explain the theory of evolution as a process of change over time due to inheritance of favorable traits, the obvious challenge is to develop lessons and activities that will enable them to understand and be able to explain evolution by natural selection. In addition, the other challenge is to focus instruction in order to help the 24-31% of students overcome their misconceptions so that they can accept the theory of evolution as a valid scientific theory.

Days 3-4 Research Question:

What are the challenges involved in developing student understanding of the theory of evolution?

For further data to resolve this research question, students participated in an activity on the development of theories of evolution throughout history. One of the common misconceptions revealed in the pre-assessments was that student understanding of the nature of scientific theories was low. This activity explores the concept that scientific theories, including evolution, are tentative, and based on the latest scientific evidence and testing. The data presented includes results from both group and individual work.

Data from student work

All students participated in ten groups of five students. The number of groups that produced work in each category is listed in the box for that category.

Table 4 **Theory Group Activity Rubric**

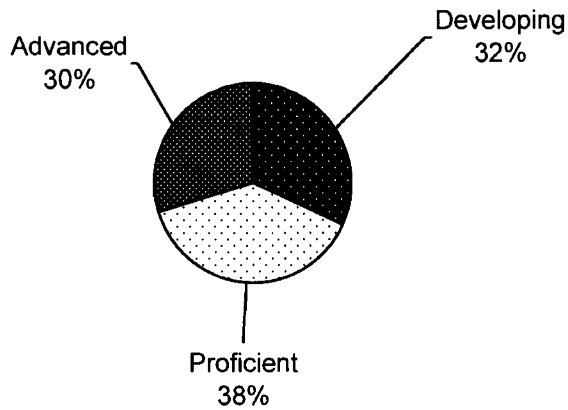
Developing	Proficient	Advanced
Evaluation form incompletely filled out 1	Evaluation form filled out, with strengths and weaknesses for most theories **3**	Evaluation form filled out thoroughly, with strengths and weaknesses for each theory **6**

Forty eight students completed the individual portion of this activity, responding to the question: What did you learn about scientific theories? A student who exhibited a developing level of understanding would not include the concept of evidence or testing as part of a scientific theory. A proficient level of understanding would include one or more of these concepts. An advanced level student would discuss evidence and testing as well as the tentative nature of scientific theories. The number of students who produced work at each level is listed in the box for that level

Table 5 **Individual Theory Evaluation Form Rubric**

Developing	Proficient	Advanced
Assessment questions do not show understanding of what is a scientific theory **15**	Assessment questions show partial understanding of what is a scientific theory **18**	Assessment questions show correct understanding of what is a scientific theory **14**

Figure 4 Understanding of scientific theory



Data from field notes

Quotes from student work, in response to the question: What did you learn about scientific theories?

- "I was surprised after all of this time those are still theories not proven facts."
- "A theory isn't just a guess; it's been tested many times."
- "Not all theories are always right, some of them you could scientifically prove. But some people wouldn't believe it anyways."
- "I learned a theory and a belief are two different things. It takes a lot of data and evidence to create a theory."

Student discussions regarding Theory E, the "scientific creationism" theory, generated some animated remarks such as:

- "You don't believe in God!"
- "Why can't we learn about the Bible in school?"
- "It basically says everything in the Bible is right and there is no science!"

Data Analysis

Data from the group work showed the majority of groups were able to work together, analyze the theories' strengths and weaknesses and rank them by date and "correctness". Data from the individual work indicated the majority, 68%, had a proficient to advanced understanding of scientific theory after instruction, with 32% still developing their understanding. Student quotes and anecdotes from field notes also indicated that student understanding of scientific theory is still developing in some students, with some common misconceptions still present.

The challenge identified in this lesson was that while some students were able to overcome misconceptions and construct new understanding of the concept, defining a scientific theory, some students needed more opportunities to overcome their misconceptions and construct a new understanding of the nature of scientific theories and how scientists work.

Day 5 Research Question:

Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?

New fossil evidence for the evolution of whales was used in this activity. Students, working in teams of two, analyzed pictures of fossils of ancestral whale species, predicted a transitional form, and summarized how whales changed over time as they adapted to different environments.

Data from student work

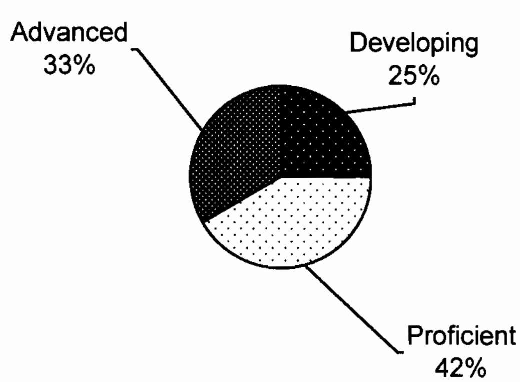
Discussion questions were assigned after students completed the activity, designed to help students explore the concepts of fossil evidence for the evolution of whales demonstrated in this lesson. Developing students did not provide detailed enough answers to determine their understanding of fossil evidence. Proficient students were able to apply what they learned in the activity to answer such questions as: What typical whale traits were the earliest to appear? Advanced students were able to answer such questions as: What age sediments, and in what region of the world, would you search now for whale ancestor fossils?

Twenty five student teams completed this activity. The number of teams that produced work at each level is indicated in the box for that category.

Table 6 "Becoming Whales": rubric for student work

Developing	Proficient	Advanced
Answers are incomplete, student understanding of the fossil evidence not determined **6**	Answers to discussion questions are complete, showing limited student understanding of fossil evidence for evolution **10**	Answers to discussion questions are thoughtful and complete, showing student understanding of fossil evidence for evolution. **8**

Figure 5 Understanding the fossil evidence for evolution



Data from field notes

Quote from student work (advanced level) in response to the question: Explain why the absence of transitional fossils is not a fair argument against evolution.

- "The absence of transitional fossils isn't a fair argument because even though they haven't been found doesn't mean they don't exist."

Students were engaged in comparing their drawing of the predicted transitional form with the actual picture of the ancestral whale species Ambulocetus. Using the timeline of the Cenozoic era was a concrete element to help students visualize the appearance of the different transitional species of whales throughout geologic time. Student teams were unable to complete all of the discussion questions in the time available for the activity.

Data Analysis

The majority of students participating in the activity were able to use new evidence regarding the evolution of whales, based on recent fossil evidence, to continue the development of their understanding of the theory of evolution. 75% of students demonstrated a proficient to advanced level of understanding of the fossil evidence for the theory of evolution. Students were engaged, and interest was generated in the hands-on activity as they reconstructed a timeline of whale evolution, and predicted a transitional form of ancestral whale.

Days 6-7 Research Question:

Will the updated curriculum using new resources and technology produce better student understanding of biological evolution?

A new resource for helping students understand the evidence for evolution are recently developed television series about evolution. These programs use animations and the latest field data to illustrate evolutionary processes. A new series broadcast on National Geographic Channel, "Morphed", was taped and shown to students in order to collect data for this research question. The "Whales" episode traces the evolution of whales from wolf-like terrestrial animals to streamlined ocean dwellers, and links directly to the Becoming Whales student activity done the previous day. High tech animations bring the fossils to life and show the adaptations for each transitional species encountered in the previous activity.

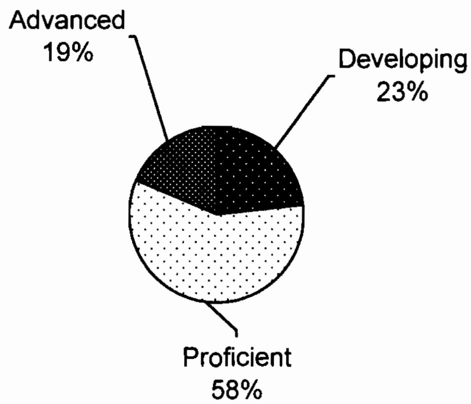
Data from student work

Forty three students completed and turned in the viewing guide with questions about the program and assessment questions regarding fossil evidence for evolution: **Explain some of the adaptations the different whale species had to their environment. Do you think the fossil evidence for evolution is a strong part of the theory of evolution? Why or why not?** The numbers in each box represent the number of individual students producing work at each level.

Table 7 **Morphed: Whales rubric for student work**

Developing	Proficient	Advanced
Answered some viewing guide questions 5	Answered most viewing guide questions thoroughly 23	Answered all viewing guide questions thoroughly 15
Demonstrated some understanding of adaptations and fossil evidence 10	Describes whales' adaptations, explains how fossil evidence supports the theory of evolution 25	Used scientific language to describe adaptations and how fossil evidence supports the theory of evolution 8

Figure 6 Understanding adaptations and fossil evidence



Data from field notes

Quotes from student work (proficient to advanced levels), in response to the questions:

What were some of the adaptations seen in the different whale ancestral species? Based on what you saw in the video, do you consider the fossil evidence a strong part of the theory of evolution? Why or why not?

- "Fossils show how animals change over time"
- "It's evidence that proves evolution"
- "The world keeps changing, like now Ambulocetus doesn't exist, it disappeared"
- "Fossil evidence is strong because it shows that they all have a s-shaped bone in the ear and shows slow change over millions of years"

Students were absorbed in the video presentation, and when the tape was stopped periodically, they were able to discuss the viewing guide questions. One student had a question regarding an ancestral species going extinct, or "becoming" the next species.

When asked, students agreed that they liked the video, and that it helped them visualize the species they had been working with in the previous activity.

Data analysis

The new curriculum resource using high-tech animations, the National Geographic video "Morphed-Whales", was effective in helping students understand the concept of adaptations and the fossil evidence for evolution. Student understanding of the fossil evidence for evolution and adaptations of species to changing environmental conditions was demonstrated at the proficient to advanced level by 77% of students that completed the activity. Students were engaged in the video presentation and agreed that it helped them visualize the adaptations of ancestral whales and fossil evidence for the evolution of whales that was begun in the previous activity, "Becoming Whales".

Day 8 Research Question:

Will the updated curriculum using new resources and technology produce better student understanding of biological evolution?

New resources for teaching students about evolution include books dedicated to providing classroom activities that allow students to model evolutionary processes. An activity on variation, a factor in natural selection, was selected from a newly obtained resource guide. This updated activity, in which students use data from actual field research to measure and compare finch beaks, was used to collect data for this research question.

Data from student work

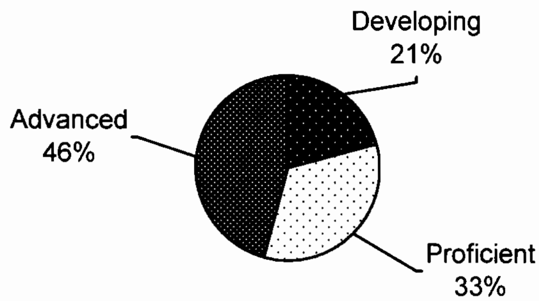
Students collected and analyzed data by measuring and recording six different finch beaks (from pictures). They then answered the assessment question: Do you think that tiny variations in beak size matter for survival? Why or why not? A developing students' answer would not include enough information to show understanding of variation and its connection to natural selection. A proficient student would link the tiny variations seen in the beaks to ability to eat different foods. Advanced students would use scientific language, such as references to adaptation, in connecting variation to natural selection.

Twenty four student teams participated in this activity. The number of teams that produced work at each level is listed in the box for that level.

Table 8 "Famous Beaks": rubric for student work

Developing	Proficient	Advanced
Collected data **5**	Collected complete data **8**	Collected complete, accurate data **11**
Shows understanding of variation **6**	Shows understanding of variation and role in survival **16**	Uses scientific language in describing the role of variation in survival **2**

Figure 7 Understanding of variation



Data from field notes

Quote from student after seeing the pictures of bird beaks (all of the common ground finch):

- "Are these all the same kind of bird?"

Quote from student analysis:

- "Variations in beaks are important for a bird's survival because their beaks have to be specific for their diet and if they can't eat they can't survive."

The lesson flowed well, and students appeared to be developing an understanding of variation within a population as they measured the finch beaks and recorded their data.

Data Analysis

This activity from the new curriculum resource guide, "The Virus and the Whale", was effective in developing student understanding of the concept of variation within populations, a key part of the mechanism of natural selection. The results from this activity show that 79% of students were at either proficient or advanced levels of understanding of natural variations within a population of common ground finch, and its role in survival in an environment. Students were engaged and successful in completing the activity.

Days 9-10 Research Question:

Will the updated curriculum using new resources and technology produce better student understanding of biological evolution?

To collect more data for this research question, a follow-up activity from the same recently obtained resource guide was selected to further explore the concepts of variation, environmental factors affecting survival, and natural selection.

Data from student work

Students, working in teams of two, built large and small "beaks" and tested their ability to gather food under two different environmental and food conditions, normal and drought years. Students collected and analyzed data from the two different years, then answered an assessment question designed to reveal their understanding of the concepts of variation and natural selection:

You tested two different variations of beaks, large and small. In the drought environment, which beak variation is favored and why?

Twenty four student teams completed the activity. The number of teams that produced work at each level is listed in the box for that category.

Table 9 Battle of the Beaks: Rubric for student work

Developing	**Proficient**	**Advanced**
Identifies environmental factor as reason for change in rates of survival **3**	Identifies environmental factor as reason for change in beak size **13**	Identifies environmental factor as reason for change in beak size, passed on to offspring **9**
Identifies beak size as a variation affecting survival **3**	Shows understanding of variation and its role in natural selection **16**	Uses scientific language to describe variation and natural selection as a result of differential reproductive success **5**

Figure 8 Understanding of environmental factors

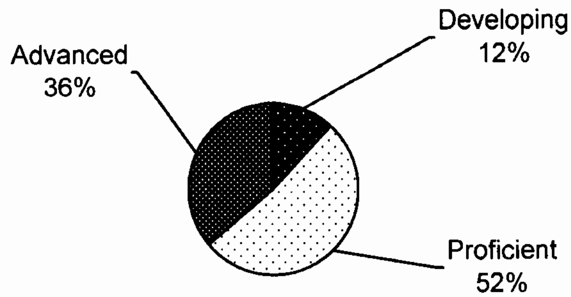
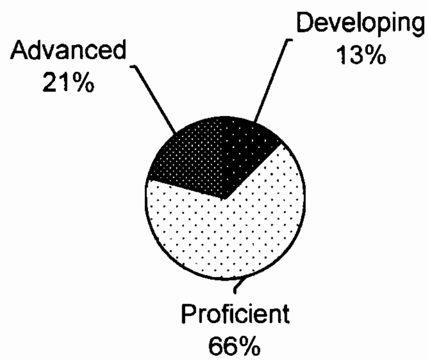


Figure 9 Understanding of variation & natural selection



Data from field notes

Quotes from student analysis questions:

- "The birds' parents passed their traits to the new birds…."
- "The large beak is favored because they are able to gather food more easily, while the little beaks died out. Large beaks have the selective advantage and were able to evolve to better fit in their environment due to natural selection."

Starting the lesson with a stuffed shore bird specimen and asking students what they thought the bird ate based on its beak was an engaging opener for the activity.

Student answers included: fish, crabs, snails, worms. Class discussed the relationship between bird beaks and their food supply.

Building the beaks was challenging for some students, however, kinesthetic learners were able to accomplish the task with ease. One student remarked, "We could make this into a video game and have different levels!" The activity provides a concrete example of small and large beak variation within a population and its effect on survival under differing environmental conditions. Student interest in the activity was high, and all teams successfully built the beaks and collected and analyzed the data.

Data Analysis

This activity, from the new resource guide Virus and the Whale, was effective in developing student understanding of the concepts of environmental factors, variation within populations, and how they affect the mechanism of natural selection. The data from student work shows 88% of students reaching either the proficient or advanced level of understanding of the concept of how environmental factors affect survival rates of different variants of bird beaks. The data also shows that 87% of students reached either proficient or advanced levels of understanding of the concept of variation and its role in natural selection, as evidenced in responses to analysis questions about the activity.

Day 11 Research Question:

How can different assessment instruments be used to measure student understanding of biological evolution?

Students were given the post-instruction essay test on natural selection, which consisted of a choice of two scenarios. The two scenarios were directly related to the activities on natural selection that students had participated in the previous ten days. They were allowed twenty minutes writing time, and could use their viewing guides from "Morphed: Whales", as reference. Vocabulary words for the unit (without definitions) were displayed on the overhead projector.

Scenarios for natural selection:

- Option 1_Pakicetus, the ancestral whale species, became extinct and was replaced by a new whale ancestor, Ambulocetus. Using the language of natural selection, (i.e., the vocabulary words) explain how and why this happened.
- Option 2: There are thirteen species of finches on the Galapagos Islands. Each species has a different beak. Using the language of natural selection, (i.e., the vocabulary words), explain how the common ground finch on Daphne Major came to have its particular beak shape.

Forty seven students completed the essays. The number in each box indicates the number of individual students that produced work at that level.

Table 10 **Natural Selection: rubric for essays**

Developing	Proficient	Advanced
Brief description of variation **29**	Describes variation **15**	Uses scientific language, such as adaptation. **3**
Brief mention environmental factors or change **12**	Describes possible environmental factors. **30**	Uses scientific language such as changes in climate and food supply. **5**
Mentions adaptations **9**	Describes adaptations. **30**	Uses scientific language to describe specific adaptations **8**

Mentions factors such as lack of food. **20**	Defines struggle for existence. **20**	Uses scientific language to describe struggle for food, shelter, mates. **7**
Combination of Lamarkian, i.e. "wants" or "needs" to change, and Darwinian natural selection mechanism **19**	Correctly describes natural selection as process of heritable change **19**	Uses scientific language to describe the process of heritable change, i.e. inheritance of genetic traits **9**

Figure 10 Understanding of variation

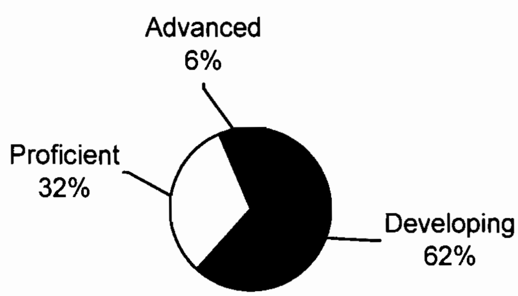


Figure 11 Understanding environmental factors

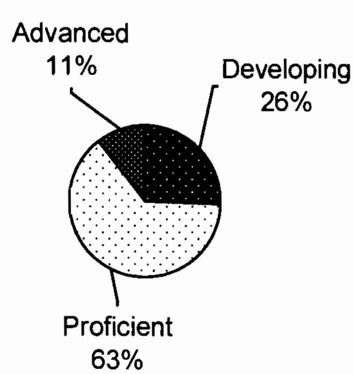


Figure 12 Understanding adaptations

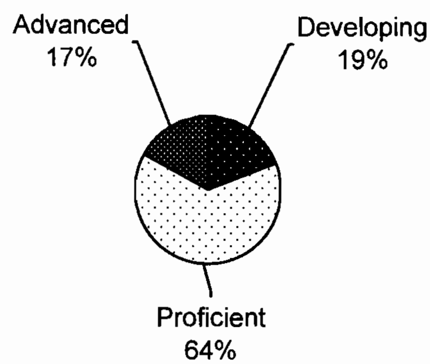


Figure 13 Understanding the struggle for existence

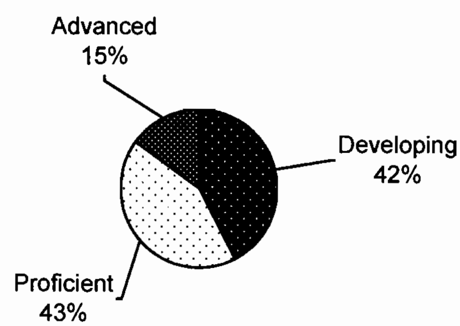
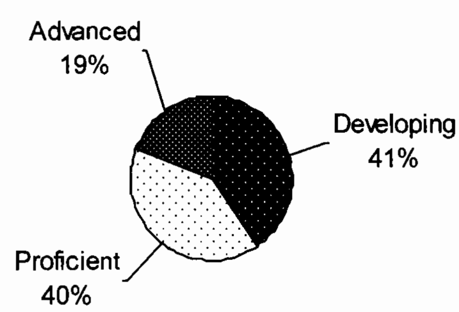


Figure 14 Natural Selection Explanation



Data from field notes

This student wrote an essay response about the transition from Pakicetus to Ambulocetus in the evolution of whales. Students had learned during the two whale evolution activities that Pakicetus was a land-based mammal, and that Ambulocetus lived in the sea. Although his response was rated advanced overall, there is some Lamarkian explanation present in his essay (underlined in the following quote).

"The reason for Pakicetus' extinction was that the environment around it was changing and Pakicetus was soon struggling for existence. In order for it to survive, Pakicetus **had to adapt** to its new environment. Time passed, and it was harder for Pakicetus to get food, it was forced to go into the water for food. After time a new species arose. This species was very similar to Pakicetus; however, it had slight variations that gave it a selective advantage. This new species was called Ambulocetus. This animal was very similar to Pakicetus. The only difference was that it had webbed feet which were better for swimming. Webbed feet gave Ambulocetus the advantage over Pakicetus, it was able to swim better in order to get food. Slowly over time heritable traits were passed from generation to generation. These traits slowly improved Ambulocetus' ability to survive. This is natural selection because over time animals adapt to the environment by being the fittest. If an animal is a better swimmer allowing it to survive then it will reproduce and soon there will be a new species of better swimmers. Some who struggle to survive die off and go extinct. Over time, animals have slight variations that help them survive."

Data analysis

The results from the essay test on natural selection were broken down into the five components of the process of natural selection. Student work was rated according to the level of understanding of each component as demonstrated in their written essay.

Only one component, variation, had a minority of students, 38%, demonstrating proficient to advanced understanding. Environmental factors leading to natural selection had 74% of students at the proficient to advanced level of understanding. Adaptations were understood at the proficient to advanced level by 81% of students. 58% of students showed understanding of the struggle for existence at the proficient to advanced level.

Lastly, the overall explanation of the mechanism of natural selection was proficient to advanced in 59% of the student essays, with the remaining 41% using a mixture of Lamarkian and Darwinian explanations. This indicates that misconceptions about the mechanism of evolution are still present in 41% of the students, evidence of the resilience of common misconceptions and the continuing challenge of helping students develop new understandings.

The results of the essay test show that the majority of students tested were able to explain natural selection without relying on misconceptions. This summative assessment provided data successful in evaluating my students' understanding of the theory of evolution by natural selection. The results of the summative assessment also indicated successful implementation of the curriculum to this point, in terms of student understanding of the guiding unit questions. The challenges identified helped focus instruction, and the new resources, evidence, and technology were effective in developing student understanding of the concepts of natural selection. The remaining week of the curriculum was designed to help the students continue to develop their new explanations of evolution by natural selection.

Days 12-13 Research Question:

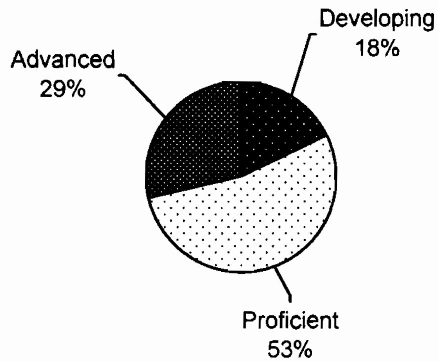
Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?

New evidence in the form of DNA comparisons between chimpanzees and humans was the focus of this activity. Student teams analyzed sequences of DNA to determine mutations and the time elapsed between ancestor and living DNA, then looked at actual sequences of chimp and human DNA and analyzed them for differences. Lastly, they wrote a "news story" about humans and chimpanzees that explains how they are related and could have a common ancestor.

Table 11 "It's Molecular Time and Mutations up Close" rubric for student work

Developing	**Proficient**	**Advanced**
Collected data and recorded it. 4	Collected accurate data, recorded and analyzed it 16	Collected accurate data, recorded, and completed thorough analysis. 5
Completed a short news story about chimps and humans 5	Completed a short news story that information about new DNA studies or a common ancestor 15	Completed a short story that included info about new DNA studies, and idea about a common ancestor 8

Figure 15 Understanding of DNA evidence and common ancestor



Data from field notes

Quotes from student written "news stories" about chimps and humans (advanced level):

""New science suggests that chimpanzees and humans might be closely related. In 2,700 DNA sequences, there are only 10 differences. This suggests that humans and chimps are closely related but not descended from one another. Also, that we evolved from a common ancestor."

"Did humans evolve from chimpanzees? The answer is a definite no. Humans did not evolve from chimps, but we are in the same family, which means that we have a common ancestor. New DNA studies have proved that chimp and human DNA have more in common than they have different, out of 2700 sequences only 10 are different."

Many students noted their surprise when only 10 differences were found between the human and chimp DNA. The DNA sequences, when arranged from living to distant ancestor, generated questions from students about "What is the common ancestor of humans and chimps?"

Data analysis

The new evidence from DNA studies was effective in helping students develop their understanding of evolution, and students' interest was captured by exploring the similarities and differences between humans and chimps.

Students were able to synthesize the data from the two activities in order to demonstrate understanding of the concept of descent with modification from a common ancestor, specifically chimps and humans. The DNA sequences with mutations and side by side comparison of human and chimp DNA were understood by students as evidence supporting the theory of evolution, and helped resolve a common misconception identified in the pre-assessment that humans are descended from chimps.

Day 14 Research Question:

How can different assessment instruments be used to measure student understanding of biological evolution?

The summative assessments for the unit were given to students at the end of instruction. Students completed the Conceptual Inventory of Natural Selection or CINS; (referenced in the literature review, page 23) a twenty question multiple choice test on natural selection. Secondly, students revised their original essay questions, using their class notes: **Explain the theory of evolution by natural selection. Do you accept it? Why or Why not?**

Data from student work

Table 12 Student responses to essay questions

Can explain evolution using concept of	Can't explain

natural selection	evolution
39	12

Accept theory of evolution	Doesn't accept
50	1

Figure 16 Explanation of evolution by natural selection

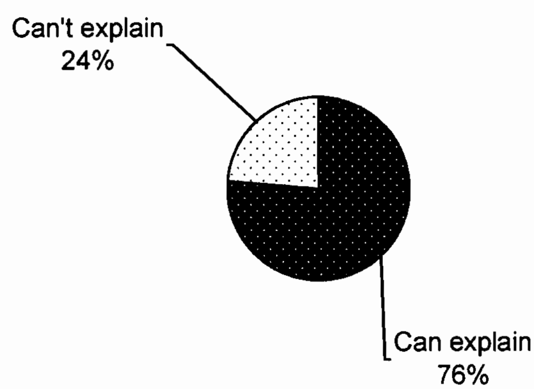


Table 12 Individual student scores on CINS Multiple Choice Test

Developing 0-13 correct	Proficient 14-16 correct	Advanced 17-20 correct
33	17	1

Figure 17 Individual scores on CINS multiple choice test

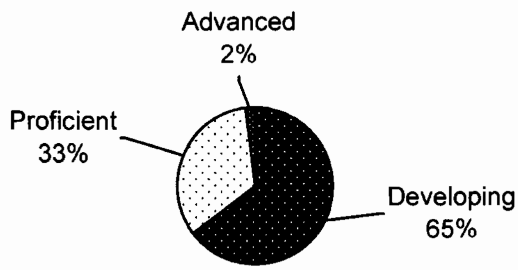


Table 13 Data from Conceptual Inventory of Natural Selection (CINS)

Item	Scientific concept	Percent correct	Alternative conceptions
4	Change in population	29.4	Mutations occur to meet the needs of the population-49% Changes in population occur through gradual change in all members- 20 %
5	Struggle for existence	59	Organisms work together and don't compete- 41%
6	Origin of variations	29.4	Mutations are adaptive responses to environmental conditions- 33% An organism tries, needs, or wants to change genetically- 27%
7	Heritable traits	69	Traits that are positively influenced by the environment will be inherited by offspring-20% When a trait is no longer beneficial for survival, the offspring will not inherit it-10%
9	Variation	49	Variations only affect outward appearance and don't affect survival-39% All members of a population are identical-12%
18	Differential survival-fitness	29.4	Fitness is equated with strength, speed, intelligence or longevity-70%
20	Origin of species	29.4	An organisms tries, wants, or needs to become a new species over time-70%

	(natural selection)		

Data from field notes

Quotes from student essays: Explain the theory of evolution. Do you accept it? Why or why not?

- "....every single living creature was originated from a single common ancestor, which split into several new species, which split into new species, and so on. This is called the tree of life..."
- "....everything came from one species or organism and over time developed variations to help them survive. For example, the finches on Daphne Major....ones with a big beak got more food because of its adaptations to its environment, while finches with smaller beaks ran out of food, so they couldn't survive and reproduce."
- "..the whales started inheriting a long tail, and then legs became flippers.....sometimes they have offspring that are better and they live longer...
- "I accept the theory of evolution because it makes sense. I have been exposed to enough evidence to believe it is true."
- "...the many explanations that have been given add up..."
- "...there's proof....DNA and fossil proof. That's what makes it a theory and not a hypothesis"

Data analysis

The two summative assessments used provided different avenues to assess student learning of the main concepts of evolution by natural selection. Each assessment tool draws on different skills and strengths that individual students have to varying degrees. The results of both can be combined to analyze how students developed a new understanding of evolution by natural selection, as well as to what extent alternative conceptions are still prevalent.

The essay test allowed students to synthesize information that was learned in the unit and provide their own explanation of evolution by natural selection. The data shows that a majority, 76%, wrote acceptable explanations explaining natural selection, and 24% either relied on misconceptions or couldn't explain evolution. Acceptance of evolution was expressed by 98% of students, with only 2% (one student) expressing not accepting the theory.

The multiple choice test, CINS, exposed students to varying scenarios of evolution, and asked them to choose the correct answer to a question while avoiding distractors that contained alternative conceptions. The majority of students, 65%, performed at the developing level of performance on the test, while 35% scored at proficient or advanced level. Of the five components of natural selection: 69% chose the correct answer for heritable traits, 59% chose the correct answer for the struggle for existence, and 30% chose the correct explanation of population change, fitness, and natural selection. Alternative conceptions (distractors) were selected as answers by 70% of students for questions regarding population change, fitness, and natural selection. The data from the CINS suggests that when alternative conceptions are presented as possible explanations for some components of natural selection, many students will choose that explanation over the correct one.

Summary

In this chapter the results of implementing the updated curriculum unit on evolution have been presented, and how the data helped to resolve the research questions. In the next chapter, I will revisit the purpose of my thesis project, and what the data indicates in terms of success in developing better student understanding of biological evolution. The overall strength of the curriculum unit will be evaluated and decisions made about how to adjust certain elements, and how it can be shared with other teachers.

DISCUSSION AND ACTION PLAN

Purpose

The teaching of the theory of evolution is challenging, both due to the sophisticated concepts being presented, and the many common misconceptions held by students. The purpose of this action research project was to develop an updated curriculum unit on the theory of evolution for high school biology classes. Since modern biology is based on the concepts of evolutionary theory, understanding evolution is an important goal for the biology curriculum, and it prepares our students for making informed decisions in the 21st century. The concepts presented in the unit also helped students to become better critical thinkers as they examined evidence and learned about the nature of the scientific thinking that led to the theory of evolution.

The curriculum was designed using the principles of constructivism. Students started with their prior knowledge and experience (including any misconceptions) about evolution, and constructed a "new" version of evolution by natural selection throughout the course of the unit. Specific strategies were put into place to identify student misconceptions, and then by taking students through a variety of intellectually challenging learning experiences, they came to a new level of understanding.

Creating a "community of learners" in the classroom is one of the keys to the successful implementation of this curriculum. Knowledge is "constructed" and modified by individuals within a group context, then shared with others through positive social interactions (Clark, 1996). In this curriculum unit on evolution, students collaborated in experimentation, innovation, discovery, and problem solving as they participated in a series of lab activities designed to help them gain an understanding of the theory of evolution.

The development of the curriculum was based around four research questions. Data was collected during the teaching of the unit to provide resolution to all of the research questions:

- What are the challenges involved in developing student understanding of the theory of evolution?
- Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?
- Will an updated curriculum using new resources and technology result in better student understanding of biological evolution?
- How can different assessment instruments be used to measure student understanding of biological evolution?

Summary of Results

What are the challenges involved in developing student understanding of the theory of evolution?

The pre-assessments given before the teaching of the unit on evolution provided the data to resolve this question. The main challenges identified were to help students understand: the development of the theory of evolution including what a theory is and how scientists work, what is the evidence to support the theory and how evolution by natural selection works.

The fact that the vast majority of students, 94%, were not able to explain evolution by natural selection was not surprising to me. Even though most students were exposed to evolution in their 7th grade life science course, their inability to retain information from middle school is a phenomenon with which I am familiar. Much of the 7th grade curriculum is "spiraled" and repeated again in high school biology. However, when these supposedly familiar concepts, such as cell biology, are presented a few years later it is my experience that they have to be re-taught from "scratch".

Evolution by natural selection is a sophisticated, cognitively challenging concept that is difficult for high school students to understand. This raises a question as to whether the concepts are too sophisticated for middle school; if students do not retain any of the information perhaps they were not developmentally ready for it. In addition, it can actually result in students coming away with misconceptions that will actually impede their learning in the future.

I was pleasantly surprised by the fact that, based on the student essays, 69% of students accepted evolution while 31% did not. Many of the students indicated that their non-acceptance was based on religious belief, and also a general feeling that the theory was "just guesses". This provided a starting point for the unit, as I wanted to help students understand that science and religion are two different ways of understanding the world.

The emphasis for the first few lessons became focused on what is the nature of scientific thinking, including theories and how they are developed. This proved to be a vitally important part of the curriculum, because I felt that once students had a new understanding of what is a theory, they were "ready" to learn about evolution. One of the major roadblocks had been removed, and some students appeared more comfortable with the topic as we moved on.

Another common misconception, that the theory of evolution says that humans descended from monkeys, was cited frequently (14 times) as a reason why students didn't accept evolution. This identified another challenge which actually became a goal for the unit: for students to understand the concept of descent with modification from a common ancestor. Human evolution was a controversial subject for Charles Darwin's work, and today much of the objection to the theory of evolution still centers on this part of the theory. If I could identify some lessons that would help students understand that the multitude of evidence for human evolution, from fossils to DNA, is not in direct conflict with religious teachings another roadblock for understanding and accepting evolution would be removed.

Does new evidence and information about evolution generate student interest in and understanding of the theory of evolution?

The development of this curriculum was necessary because the material provided by the textbook had proven inadequate, in my opinion, to generate student interest in and understanding of evolution. The information in the text included a chapter on Darwin's voyage and development of the theory, and a chapter on evolution of populations. It has been my experience in the past that student interest in the voyage of the Beagle is very low, and the second chapter, on evolution of populations, is too advanced for the majority of students to grasp. Although there is some good reference material in the textbook, what is missing is current, relevant information on evidence for the theory of evolution. One of the major goals of this project was to find lessons and hands-on activities that incorporated new evidence and information about evolution that would engage students' interest.

Whale evolution is fascinating to most people because it happened backwards, from the land to the sea. The fossil evidence for the evolution of whales is already extensive and growing rapidly. The activity, "Becoming Whales", helped students understand how scientists work and how fossils provide evidence for the theory of evolution. Students were engaged, and interest was generated in the hands-on activity as they reconstructed a timeline of whale evolution, and predicted a transitional form of ancestral whale. In addition to the understanding of the fossil evidence, they got some experience in "doing" science as they used the fossils on the timeline to predict what a newly discovered ancestral species of whales would look like, based on the species that came before and after it on the timeline.

The second activity that provided data for this research question also addressed the goal of helping students understand the evidence for human evolution. In "It's Molecular Time", and "Mutations up Close" students compared human and chimp DNA. This lesson is a perfect match for the rest of the biology curriculum which is heavily focused on genetics. Students were able to use what they already knew about DNA as they compared actual sequences of DNA code between humans and chimps. Students were engaged in this activity which produced some animated questions and discussion from students after they discovered the extreme similarities of the DNA. By the end of the lesson, I felt another roadblock was removed as students were discussing the idea that chimps and humans were part of the same family tree rather than humans descending from chimps.

The activities selected to help students discover both fossil evidence and molecular evidence for evolution were successful in engaging the students, and helping them understand the theory of evolution. Based not only on the data and the field notes, but from my holistic impressions of the implementation of the activities, the updated curriculum was much more effective than in previous years. Students seemed genuinely interested in the activities, based on not only their participation, but in the quality of the work produced and their level of interactions.

Will an updated curriculum using new resources and technology result in better student understanding of biological evolution?

Today's teenager is accustomed to using technology to obtain information and communicate. In the classroom, if we want to engage students, using technology should be an integral part of our teaching. The program "Morphed-Whales" used high technology animations to bring the fossil evidence for the evolution of whales to life. Also, the program recreated the environmental conditions that went along with the changes in the ancestral whale species. Overall, the program was perfectly tailored to help students visualize how the animals might have looked, and made the "Becoming Whales" activity even more effective. The written viewing guide tied the concepts being learned, such as adaptations and environmental change, to the content of the program. I felt it was highly effective based on student interest, the questions that were generated from the program, in addition to the overall quality of the answers to the viewing guide questions.

The newest resource books contain activities designed to help students understand the theory of evolution. Activities can be selected that allow students to investigate the main concepts of the theory of evolution by natural selection. As they progress through the activities, they can construct new understandings of the concepts based on the results of their investigations. The resource guide, the Virus and the Whale, provided many of the activities used in this updated curriculum unit. Although it was written for middle school students, the activities I selected were appropriate for the abilities of my students because they were able to do the investigations and discover the information on their own. In order for the community of learners to operate effectively, students need activities that are challenging, but accessible in terms of being able to do the work independently and discuss and synthesize the information together.

The series of activities from Virus and the Whale based on the field research work of Rosemary and Peter Grant on Daphne Major in the Galapagos Islands not only developed the concepts of variation and natural selection, but also illustrated that evolution can be seen to happen in our lifetime. A personal connection was also made as I was able to "show and tell" students about my own experiences as a tourist on the Galapagos Islands.

In "Famous Beaks", students did "real science" as they measured finch beaks based on illustrations and scale drawings of actual finch beaks. They were encouraged to come to their own conclusions as they considered the different beak sizes in relation to the available food on the island during the "Battle of the Beaks" normal and drought years. Data that showed the change in this species during a period of thirty years showed students that evolution by natural selection has been documented. This concrete example showed students "survival of the fittest" as the smaller beaked birds died out and the larger beaked birds survived and reproduced.

The finch activities provided students with experiences in which they were able to construct a new understanding of the concepts of variation and natural selection, as well as how scientists work. The data shows that most students were able to demonstrate understanding of these concepts after the activities, and based on my observations, all students participated and were engaged in them. I felt they were much more effective than methods used in previous years to develop student understanding of natural selection.

How can different assessment instruments be used to measure student understanding of biological evolution?

Constructivist teachers analyze student products and artifacts as benchmarks and gather information to use in developing future activities and to evaluate instructional practices (Mintzes, Wandersee and Novak, 2000). The formative assessments used during the implementation of the curriculum, rubrics designed to measure student understanding of the concepts of the lesson, consistently showed the majority of students at proficient levels of understanding. In the case of the formative assessments, the students were working collaboratively and sharing their ideas and conclusions as they worked together ton complete the activities. In other words, as a community of learners, the majority of students were reaching proficient levels of understanding of the concepts being presented throughout the unit.

What does it mean to understand? Students must be able to make sense of, and use, the knowledge they have learned and the principles underlying it (Wiggins and McTighe, 1998). The purpose of the first summative assessment, the open response instrument quiz on natural selection, was to see if individual students were able to explain natural selection. In order to reach proficient of advanced levels, according to the rubric, they had to be able to use scientific language (vocabulary terms) to explain either the evolution of whales or finches by natural selection. The five different components of natural selection had to be included and discussed in order to demonstrate understanding of natural selection. The majority of individual students were at proficient to advanced levels of understanding of four out of five components as measured by the rubric. I was pleased at this outcome, and the overall performance of students on this quiz. I also felt they displayed quite a bit of confidence as they approached the writing, and were absorbed in and serious about writing their responses.

The reason I decided to have students explain the evolution of whales or finches by natural selection is because I felt that students were more likely to be successful using the familiar examples we had discussed in class. Looking back, this decision was probably a good one in terms of whether or not students were able to actually complete the quiz. On the other hand, this assessment did not measure the students' ability to transfer the concepts of evolution by natural selection to a new situation. This is an assessment problem I have encountered frequently. Students are able to explain things they are familiar with, and that have been experienced and discussed in class, but are not confident or sophisticated enough to discuss or explain unfamiliar examples using the knowledge they have gained in class.

Researchers at Ohio State University concluded that a combination of open-ended response and selected response questions are the best way to assess student understanding of the theory of evolution (Nehm and Schonfeld, 2007). Selected response questions, or multiple choice, are also the preferred method of standardized testing that measure the success of our schools. Therefore, the decision to include a multiple choice test, the CINS, seemed to be another appropriate summative assessment. The CINS would also measure students' ability to evaluate unfamiliar situations of natural selection and whether or not they could choose the correct answer rather than distractors that included alternative conceptions.

The data from the CINS suggests that when alternative conceptions are presented as possible explanations for some components of natural selection, many students will choose that explanation over the correct one. Alternative conceptions (distractors) were selected as answers by 70% of students for questions regarding population change, fitness, and natural selection. In addition, only 35% of the students performed at the proficient to advanced level overall on the test. I was disappointed, but not surprised at these results. It is a result I have encountered in the past when I attempt to assess student learning using multiple choice tests, especially ones constructed and written by textbook writers. The results of the CST (California Standardized tests) are equally disappointing each year. For example, in the testing year 2007-2008, only 34% of my students scored at the proficient level on the end of course tests given in the spring.

There are several possible reasons for the disappointing scores on the CINS, and other multiple choice tests. In the case of the CINS, the distractors that students chose often sounded very similar to the correct answer. I felt that reading ability was definitely an issue, as it is in terms of performance on the CST. Students that aren't proficient readers often fail to discriminate fine differences between answers that are "almost" correct, and the "correct" answers. They tend to pick the first answer that seems right, which may be the distractor, rather than the correct explanation. In other words, these content area multiple choice tests are often a measure of students' reading ability, not necessarily their mastery of the content.

Another possible explanation for their poor performance on the CINS is because students hadn't overcome their initial misconceptions and therefore had not constructed a new explanation of evolution by natural selection. If this were true, other assessments should have shown that students weren't able to explain evolution using the correct scientific concepts. I feel that the other assessments, both formative and summative, showed that students were able to do this. For example, the essay test allowed students to synthesize information that was learned in the unit and provide their own explanation of evolution by natural selection. The data shows that a majority, 76%, wrote acceptable explanations explaining natural selection, and 24% either relied on misconceptions or couldn't explain evolution. Acceptance of evolution was expressed by 98% of students, with only 2% (one student) expressing not accepting the theory.

My opinion is that while poor performance on multiple choice tests indicates that students may have difficulty discriminating distractors from correct answers, the overall results of the assessments indicated that the curriculum was effective in developing student understanding of evolution by natural selection.

Students have everyday, common sense explanations that can interfere with their understanding of natural selection. These naive explanations can prove difficult to dislodge, even when students are presented with multiple opportunities to construct new understandings. Perhaps more time and activities can be included in the unit in the future, along with simplified explanations of natural selection, to help students develop the sophisticated concepts of how species change over time.

In conclusion, the curriculum was successful in terms of engaging students, and improving acceptance of evolution. The theory is a powerful tool that can be persuasive if carefully presented to students. Further study is needed to adjust some of the components of the curriculum to improve student understanding of the mechanism of evolution, natural selection.

Action Plan

The updated curriculum unit on evolution was successful in its first year of implementation, and a copy of it will be shared with other biology teachers at Seaside High. If other teachers choose to implement the lessons and activities used, their feedback will be helpful in terms of what works and what needs adjustment. This curriculum will continue to be refined and improved in each successive year, by continually evaluating the student results and looking for new and updated information and activities. Evolution involves rapidly changing scientific discoveries, so while the goals of the unit will remain the same, the curriculum itself has to remain fluid and open to change.

During the first years' implementation, several areas of possible improvement were identified based on data and field notes. For example, some of the activities either had too many discussion questions, or not enough in-depth critical thinking ones. These will be re-written and adjusted to fit the time frame and focused on the type of thinking students should be doing to understand and apply the concepts.

The assessments will be adjusted based on the results of the first year's implementation. More effort needs to be made to help students apply the concepts they have learned to new situations. For example, using an unfamiliar scenario of natural selection on the summative assessment might be a good way to do this. Allowing students to work together in teams or groups as they write their explanations would help with student anxiety generated with unfamiliar situations, and also help the overall construction of their new explanations of natural selection.

The multiple choice test, the CINS, will be re-written. I will leave some distractors in the possible answers, but attempt to make them sound distinctly different from the correct answers. I understand that students need practice with multiple choice tests, and that even though I feel it was not an accurate measure of the success of the unit, it will be included in successive years.

One of the issues raised during the research and implementation of this unit on evolution was the importance of student understanding of the nature of science, and the societal issue of scientific literacy. I now have a new appreciation for the importance of having students investigate and understand what science is and how scientists work. This provided another goal for my teaching in terms of setting the stage at the beginning of the year for scientific study. For example, a new unit will be designed for the beginning of the year, called the Nature of Science. Rather than teach students about the five steps of the scientific method, it will be concentrated effort to help students understand, through current events and historical examples, of what the rules of science are and how scientists have worked within those rules to make the world a better place.

Final Thoughts

This action research project was a culmination of my quest to improve my teaching practice by developing a comprehensive curriculum unit on the theory of evolution. The work that I have undertaken during the last year as I have worked on this project has also helped me refocus my career. By seeing the success of this project, I am motivated to use research to help improve other areas of the curriculum in both my biology and earth science classes. I have a renewed appreciation for the importance of what I do, and how I can make a difference in my students' lives.

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APPENDIX A: THE CURRICULUM

Guiding Unit Questions

Using the technique of backward design, guiding unit questions were defined before instruction. These questions provided the goals of the unit, and are based on the Biology State Standards combined with the research questions of this study.

- How was the theory of evolution developed?
- What is the fossil evidence for evolution (macroevolution)?
- How does variation within a species increase the likelihood that at least some members of a species will survive under changed environmental conditions?
- How does natural selection work to determine the differential survival of populations of organisms?
- How can evolution be directly observed to occur in our lifetime (microevolution)?
- What is the molecular evidence, including DNA, for the evolution of the different species existing today?
- How does descent with modification explain how natural selection produced the different species that exist today, including humans?

The Curriculum

Pre-assessments: before the unit on evolution begins

- Administer the MATE, or similar survey of acceptance of evolution.
- Administer the two question essay pre-test.

<u>Day One</u>

Guiding unit question: How was the theory of evolution developed?

- Review pre-assessments, discuss common misconceptions.
- Guided class discussion on what is science vs. non-science. To obtain a lesson plan and handouts for this lesson, CONPTT, go to http://www.indiana.edu/~ensiweb/lessons/conptt.html
- Guided class Discussion on what evolution is/is not. For handouts for this lesson, go to http://www.indiana.edu/~ensiweb/lessons/ev.not.s.pdf
- Homework: Practice Identifying data, inferences, and prior knowledge and beliefs. For handouts, go to www.wcer.wisc.edu/ncisla/muse/

Evolution by the Process of Natural Selection Pre-Quiz

Spend ten minutes writing about these two questions:

1. What is the theory of evolution?
2. Do you accept it? Why or why not?

Throughout the course of this unit you will be asked to complete written assignments. The goal of these assignments are to provide me with a chance to reflect on what you know, and to provide me with some insights for what you are thinking about particular topics.

The questions for the assignments are designed to make you think about what you know; therefore, your responses will not be graded on their "correctness". Instead they will be evaluated by looking for thoughtful answers that capture in writing, your ideas and some of the reasoning behind them. All thoughtful responses will earn full credit. There are no "right or wrong" answers.

The MATE Survey (Rutledge and Sadler, 2007)

For the following items, please indicate your agreement/disagreement with the statements using the following scale:

A	B	C	D	E
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

1. Living things existing today are the result of the processes of evolution occurring over millions of years.
2. The theory of evolution can't be tested scientifically.
3. Modern humans have evolved over millions of years.
4. The theory of evolution is based on guesses and not valid scientific observation and testing.
5. Most scientists accept evolution to be a scientifically acceptable theory.
6. The data available is unclear as to whether evolution actually occurs.
7. The age of the Earth is less than 20,000 years.
8. There is a large body of data that supports evolutionary theory.
9. Living things that exist today are basically the same as they have always been.
10. Evolution is not a scientifically proven theory.
11. The age of the Earth is at least 4 billion years.
12. Current evolutionary theory is the result of good scientific research and practices.
13. The theory of evolution creates predictions about the characteristics of life that can be tested.
14. The theory of evolution cannot be correct since it disagrees with the Biblical story of creation.
15. Humans today are basically the same form as they have always been.
16. The theory of evolution is supported by factual historical and laboratory data.
17. Many scientists doubt that evolution occurs.
18. The theory of evolution explains the different characteristics and behaviors observed in living things.
19. Most living things on Earth came into being at the same time.
20. Evolution is a scientifically proven theory.

Scoring Instructions for the MATE

To account for positively and negatively phrased items, the scaling of responses must be appropriately reversed so that responses indicative of a high acceptance of evolutionary theory receive a score of 5, while answers indicative of a low acceptance receive a score of 1 (Rutledge and Sadler, 2007).

Step 1 Scoring of Items 1,3,5,8,11,12,13,16,18, and 20 is as follows:

Strongly Agree = 5

Agree = 4

Undecided = 3

Disagree = 2

Strongly Disagree = 1

Step 2 Scoring of Items 2,4,6,7,9,10,14,15,17, and 19 is as follows:

Strongly Agree = 1

Agree = 2

Undecided = 3

Disagree = 4

Strongly Disagree = 5

Step 3 An individual's score on the MATE is equal to the sum of the scaled responses to all 20 items. Scaled scores are rated on the following categories of acceptance (Rutledge and Sadler, 2007).

Very High Acceptance: 89-100

High Acceptance: 77-88

Moderate Acceptance: 65-76

Low Acceptance: 53-64

Very Low Acceptance: 20-52

Day Two

Guiding unit question: How was the theory of evolution developed?

- Warm-up: Name two scientific theories (think, pair, share)
- Student Activity (groups) Theory, Theory Who's got the Theory? For detailed lesson plans and student handouts for this lesson, go to www.indiana.edu/~ensiweb.

Theory, Theory Who's got the theory?

"**A "theory"-evaluation activity.** A set of 5 scenarios (proposed explanations for how diverse life came into existence on Earth) is divided evenly throughout the class, so each student is asked to evaluate one "theory". Students then come together in groups of 5, so that all 5 "theories" are represented in each group, where the 5 "theories" are compared and evaluated. Each group reports out to the entire class for further discussion and clarifications." © 1999 ENSI (Evolution & the Nature of Science Institutes) Michael L. Kimmel

Individual Theory Evaluation Form Rubric

Advanced	Proficient	Developing
Analysis questions for individual theory thoroughly and thoughtfully completed	Analysis questions for individual theory completed	Analysis questions for individual theory not completed.
Assessment questions show correct understanding of what is a scientific theory	Assessment questions show partial understanding of what is a scientific theory	Assessment questions do not show understanding of what is a scientific theory

Theory Group Activity Rubric

Advanced	Proficient	Developing
Evaluation form filled out thoroughly, with strengths and weaknesses for each theory	Evaluation form filled out, with strengths and weaknesses for most theories	Evaluation form incompletely filled out
Group rankings filled out by all group members participating	Group rankings filled out by some group members	Group rankings completed

- Homework: Vocabulary terms: natural selection, selective advantage, variation, theory, fitness, adaptation, common ancestor, descent with modification.

Day Three

Guiding unit question: How was the theory of evolution developed?

- Debrief yesterday's activity and evaluate class results: whole class discussion.
- Reveal dates and authors of theories; discuss why Darwin's theory is the one studied in biology.

THE "THEORIES" USED

Theory A: Aristotle, *circa* 350 B.C.

Theory B: Jean Lamarck, 1809

Theory C: Empedocles *et al, circa* 500 B.C.

Theory D: Charles Darwin, in his *Origin of Species*, 1859

Theory E: "Scientific Creationism" a la Morris and the Institute for Creation Research, *circa* 1960

- Video presentation: PBS's "Darwin's Dangerous Idea" (available for purchase on pbs.org). Show selected scenes on introduction to Darwin's voyage. Students complete viewing guide questions for Part One (individual work)

Darwin's Dangerous Idea Viewing Guide

Part One

1. What were some of Darwin's discoveries in South America?

2. What did the ornithologist (bird expert) discover about the birds Darwin brought back from the Galapagos?

3. What was Darwin's idea to connect all life?

Part Two

1. What are the two very different environments in Ecuador?

2. What tool do biologists have today that Darwin didn't have"

3. How can DNA provide evidence for evolution?

4. What are some examples of "selective advantage"?

Part Three

1. Why did Darwin decide to finally publish On the Origin of Species?

2. How does human and chimp DNA compare?

Day Four

Guiding unit questions: What is the fossil evidence for evolution?

- Warm-up: What are some of the characteristics of whales? (think, pair, share)
- Student Activity (partners): "Becoming Whales", for detailed lesson plans and student handouts for this lesson go to www.indiana.edu/~ensiweb.

"BECOMING WHALES"

"Experiencing Discoveries of Whale Evolution OR..."The thrill of discovery...The loss of de feet" Students will experience the historical discovery of fossils that increasingly link whales to earlier land-dwelling mammals. This experience reveals how scientists can make predictions about past events, based on the theory and evidence that whales evolved. Such predictions suggest the age and location of sediments where fossils of early whales would most likely be found, and even their traits. This lesson also provides confirmation, with multiple independent lines of evidence, that there *is* a series of intermediate forms, showing gradual accumulation of changes, linking certain terrestrial mammal groups with modern whales." by Larry Flammer © 1999 ENSI (Evolution & the Nature of Science Institutes)

Becoming Whales: Rubric for Student Work

Advanced	Proficient	Developing
Completed the sketch of the transitional fossil showing all required features	Completed the sketch of the transitional fossil	Sketch of transitional fossil is incomplete
Answers to discussion questions are thoughtful and complete, showing student understanding of the activity	Answers to discussion questions are complete, showing limited student understanding of the activity	Answers are incomplete, student understanding of the activity not determined

Day Five

Guiding unit questions: How does variation within a species increase the likelihood that at least some members of a species will survive under changed environmental conditions? How does natural selection work to determine the differential survival of populations of organisms?

- Warm-up: Debrief "Becoming Whales"

- Video Presentation: "Morphed—Whales" (National Geographic Channel) with viewing guide questions/student discussion.

Morphed: Whales Viewing Guide

1. How did one bone help identify the Pakicetus fossil?
2. What kind of environment did Pakicetus live in?
3. What "environmental pressure" drove Pakicetus into the water?
4. What adapatations did Pakicetus have for better swimming?
5. How did scientists determine Ambulocetus drank fresh water?
6. What adaptations did Rhodocetus have for better swimming?
7. What single adaptation did Rhodocetus have that helped it survive in the ocean?
8. What adaptations did Basilosaurus have for swimming? Why did it die out?
9. Why did Durodon become the surviving whale ancestor?
10. How did Durodon adapt to living in cold polar water?
11. What were some of the adaptations seen in the different whale ancestral species?
12. Based on what you saw in the video, do you consider the fossil evidence a strong part of the theory of evolution? Why/why not?

Morphed: Whales Rubric

Developing	Proficient	Advanced
Answer some viewing guide questions	Answered most viewing guide questions thoroughly	Answered all viewing guide questions thoroughly
Showed some understanding of adaptations and fossil evidence	Showed understanding of adaptations and fossil evidence	Used scientific language to demonstrate understanding of adaptations and fossil evidence

Day 6

Guiding Unit Question: How does natural selection work to determine the differential survival of populations of organisms?

- Video Clip:" Darwin's Dangerous Idea"(part 2); selected scenes about natural selection. Students complete Part Two of the viewing guide.
- Natural Selection: Operational Definition. Students take notes from the overhead and discuss the definition of the mechanism of evolution.
- Homework: Comparison of Evolution Mechanisms. Students compare and contrast Lamarckian and Darwinian evolution, and write sample scenarios of evolution using both mechanisms. For detailed lesson plans and student handouts, go to http://www.indiana.edu/~ensiweb

Evolution by the process of natural selection:

- All organisms show considerable natural variation within each species.
- Much of this variation is heritable.
- In nature, organisms tend to produce more offspring than can survive.
- Because of this, there is a "struggle for existence", the result of which is that not all offspring (and their genes) will be able to survive and reproduce.
- Some variants have a better chance of surviving and thus reproducing than others. These survivors live to produce offspring that are more like them than those individuals that died off.

Day 7

Guiding Unit Question: How does variation within a species increase the likelihood that at least some members of a species will survive under changed environmental conditions?

- Warm-up: What are traits that vary in birds? (think, pair, share)

- Student Activity (groups) "Famous Beaks" Students measure and compare ground finch beaks, based on actual data from research done on the island of Daphne Major in the Galapagos. Lesson plan and handouts for this activity are available from the resource guide "Virus and the Whale, Exploring Evolution in Creatures Small and Large", Judy Diamond, editor. Published by NSTA Press, 2006.

"Famous Beaks" Rubric

Developing	Proficient	Advanced
Collected data	Collected complete data	Collected complete, accurate data
Shows understanding of variation	Shows understanding of variation and role in survival	Uses scientific language in describing the role of variation in survival

Days 8-9

Guiding Unit Question: How does variation within a species increase the likelihood that at least some members of a species will survive under changed environmental conditions? How can evolution be directly observed to occur in our lifetime (microevolution)?

- Warm-up: (Display bird specimen – shore bird) What type of food do you think this bird eats, based on its beak? (think, pair, share)
- Activity (partners): "Battle of the Beaks". Lesson plan and handouts for this activity are available from the resource guide "Virus and the Whale, Exploring Evolution in Creatures Small and Large, Judy Diamond, editor. Published by NSTA Press, 2006

"Battle of the Beaks"

Developing	Proficient	Advanced
Identifies environmental factor as reason for change in rates of survival	Identifies environmental factor as reason for change in beak size	Identifies environmental factor as reason for change in beak size, passed on to offspring
Identifies beak size as a variation affecting survival	Shows understanding of variation and its role in natural selection	Uses scientific language to describe natural selection as a result of differential reproductive success

Day 10

Summative Assessment Day: Quiz on Natural Selection

Students write for at least twenty minutes on one of two options. They are instructed to use the vocabulary terms for the unit, which are listed on the overhead. They may use their "Morphed: Whales" Viewing guides to use as a reference.

Option 1 (based on the whale activities)

Pakicetus, the ancestral whale species, became extinct and was replaced by a new whale ancestor, Ambulocetus. Using the language of natural selection, (i.e., the vocabulary words) explain how and why this happened.

Option 2 (based on the finch activities)

There are thirteen species of finches on the Galapagos Islands. Each species has a different beak, ranging from a long thin beak for crushing cactus seeds, to a woodpecker like beak for digging insects out of wood. Using the language of natural selection (i.e., the vocabulary words), explain how the common ground finch on Daphne Major came to have its particular beak shape.

Day 11

Guiding unit Question: How does descent with modification explain how natural selection produced the different species that exist today?

- Direct Instruction: "Descent with Modification". Students copy notes from overhead. Whole group discussion on descent with modification referencing prior weeks' activities.
- Direct Instruction: "Evolutionary Tree". Teacher displays/explains tree on overhead. For handout for this lesson, go to: www.indiana.edu/~ensiweb/phylo.%20tree.html
- Activity: Students analyze current events article in teams or groups: "Research gives teeth to hypothesis that birds descended from dinosaurs", or similar article regarding current research. For student friendly information about this topic, go to http://www.enchantedlearning.com/subjects/dinosaurs/Dinobirds.

Descent with Modification

1. All life evolved from one simple kind of organism.

2. Each species, fossil or living, arose from another species that preceded it in time.

3. Evolutionary changes were gradual and of long duration.

4. Each species originated in a single geographic location.

5. Over long periods of time, new genera, families, classes and phyla arose by a continuation of the kind of evolution that produced new species (adaptive radiation).

6. The greater the similarity between organisms, the closer is their relationship and the closer in geologic time is their common ancestral group.

7. Extinction of old forms is a consequence of the production of new forms or of environmental change.

8. Once a group or species has become extinct, it never reappears.

9. Evolution continues today in generally the same manner as during preceding geologic eras.

10. The geologic record is incomplete.

Day 12

Guiding Unit Question: How does descent with modification explain how natural selection produced the different species that exist today, including humans?

- Warm-up: True or False? Humans are descended from chimpanzees? (think, pair, share)
- Teacher shows a "primate family tree". See www.whyevolution.com/eotree.jpg
- Activity (partners) "Chimps vs. Humans" Students analyze similarities/differences between chimps and humans. Lesson plan and handouts for this activity are available from the resource guide "Virus and the Whale, Exploring Evolution in Creatures Small and Large", Judy Diamond, editor. Published by NSTA Press, 2006.

Day 13

Guiding Unit Question: What is the molecular evidence, including DNA, for the evolution of the different species existing today?

- Debrief "Chimps vs. Humans"
- Activity, students work in teams: "It's Molecular Time" and "Mutations up Close". Lesson plan and handouts for this activity are available from the resource guide "Virus and the Whale, Exploring Evolution in Creatures Small and Large", Judy Diamond, editor. Published by NSTA Press, 2006.

Day 14

Guiding Unit Questions: How does descent with modification explain how natural selection produced the different species that exist today, including humans? What is the molecular evidence, including DNA, for the evolution of the different species existing today?

- Debrief: "It's Molecular Time, Mutations up Close"
- Documentary: "Becoming Human" (Institute of Human Origins www.**becominghuman**.org/). Whole class discussion about the evidence for human evolution.
- Review for test

Day 15

Summative Assessment Day

Students complete the CINS (multiple choice test on natural selection). For a PDF file of this test, go to www.biologylessons.sdsu.edu/CINS6_03.pdf To access the full directions and scoring guide: Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching, 39*, 952-978, Anderson, D.L., Fisher, K.M., & Norman, G.J. (2002)

Students also revise their original essay questions: Explain the theory of evolution by natural selection. Do you accept it? Why or Why not? They are allowed to use their notes.

APPENDIX B: ANNOTATED BIBLIOGRAPHY

This annotated bibliography reviews all of the resources that were examined and used in the course of the research and development of the curriculum. The first section details the print and web-based resources that were actually used, and the second section examines the ones that were not used.

Recommended Resources

Diamond, J. editor (2006) ***The virus and the whale: exploring evolution in creatures small and large.*** **Arlington VA: NSTA Press.**

This resource guide was used for several of the activities in the curriculum unit. It has activities and background information that explore seven current evolution research projects. The activities use easy to obtain materials, and students are able to understand and follow directions for the activities with very little teacher support. The topics of the activities include: HIV, diatoms, leaf-cutter ants (co-evolution), finch beaks, humans and chimps, Hawaiian flies, and whales.

Evolution and the Nature of Science Institute www.indiana.edu/~ensiweb/

This website also was the source of several activities used in the curriculum unit. This easy to navigate site has lesson plans, teaching tips and background information on the teaching of evolution and the nature of science. The activities have detailed instructions, and contain PDF files of student handouts and overheads. There are a large number of activities that use easy to obtain materials.

PBS Evolution: www.pbs.org/wgbh/evolution

The PBS website has several different parts that can be used in a unit on evolution. There is an online class for teachers about how to teach evolution, an evolution library with online links on various topics, online lessons for students, and online video segments. The student activities are inquiry based, include PDF files of worksheets, and rubrics for grading. Many activities use websites to get information. The online video segments are excellent and help illustrate such concepts as natural selection using footage of scientists gathering data in the field.

Project MUSE at the University of Wisconsin: ncisla.wceruw.org/muse

Project MUSE (Modeling for Understanding in Science Education) presents an extensive website that encompasses a nine-week course on the teaching of evolution. There are four main sections: the Nature of Scientific Arguments, Comparing Explanatory Models, Using Darwin's Model of Natural Selection, and Extending Darwin's Model to Anomalous Phenomena. The activities from the first two sections were the best in terms of developing student understanding of the nature of science and natural selection. The latter sections were too advanced for my students, and involved purchasing and growing plants.

University of California at Berkeley Understanding Evolution: evolution.berkeley.edu

This site is one of the best in terms of providing information about how to teach evolution. The Teaching Evolution page has three sections: Focus on the fundamentals, What would you like your students to know?, and Find resources to support their learning. It provides a straightforward road map to constructing a unit on evolution. The "Finding resources" section is a search engine that allows users to type in their grade level, topic and keyword. Articles, classroom activities, lectures, web activities and tutorials are included in the results of the search.

McComas, W. editor (2006) *Investigating Evolutionary Biology in the Laboratory.* Dubuque, IA: Kendall Hunt.

This book provided excellent background information about misconceptions about evolution and teaching using constructivist strategies. There are plans for activities, but no student handouts or lab sheets. The activities were mostly too advanced for my students, and needed lots of materials such as chemicals and skeletons. This was used extensively for the research and literature review, but did not provide any of the activities for the unit.

Jensen, J. (2008) *NSTA tool kit for teaching evolution.* Arlington, VA: NSTA Press.

This is a small but very useful guide for anyone just starting out to develop a unit on evolution. The book contains good lists of up to date resources, concise background information, and ideas for inquiry based lessons.

OTHER RESOURCES

Bybee, R. editor (2004) *Evolution in perspective: The science teacher's compendium,* Arlington, VA: NSTA Press.

There was nothing in this book to make it worth purchasing, as it mostly contains articles about the rationale for teaching evolution. Although the articles were well written, current and interesting, the lesson plans included were not unique, and similar ones can be found free online at the previously mentioned websites.

BSCS, (2005) The Nature of Science and the Study of Biological Evolution, Colorado Springs, CO: BSCS

Although this mini-text book contains up to date information on such topics as: Evidence of Evolution, The Genetic Basis of Evolution and Evolution in Action, it is mainly just a reference book. There are no student activities, although the included CD does have some good video clips.

Stebbins, R., Ipsen, D., Gillfilan, G. (2006) ***Animal coloration: Activities on the evolution of concealment. Arlington, VA: NSTA Press.***

The idea of using a concrete example such as animal coloration for illustrating natural selection seemed like a good idea. However, the activities provided in this book involve a lot of preparation of complicated models used in unrealistic sounding lessons.

National Health Museum: accessexcellence.com

Although I have used this website frequently in the past, the search engine that is the main part of this site did not prove particularly useful for finding lessons on evolution.

National Academy of Sciences Teaching About Evolution and the Nature of Science: www.nap.edu

This free online book contains lots of information about teaching evolution. There is also a section of activities for teaching evolution, although no student handouts are provided, just lesson plans. Although it contains lots of useful information, it seems outdated (published in 1998) and some of activities required lots of materials that would need to be purchased. It is not as user-friendly as the other web based resources.