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A new model of evolution education for middle school science

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A NEW MODEL OF EVOLUTION EDUCATION FOR
MIDDLE SCHOOL SCIENCE

A Project
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Education:
Science Education

by
Walter Lee Owen, Jr.
March 2006
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ABSTRACT

Inquiry education is currently under-emphasized in our middle school science classrooms. At the same time, evolution education is being de-emphasized or even eliminated in many states. Students in states that provide for evolution education may still lack the critical thinking skills to make sense of the evidence for evolution, and are therefore at risk of not understanding evolution’s significance as the central theme of modern biology. This project proposes a new model for teaching inquiry and critical thinking in the middle school science classroom. This model will assist students in learning the evidence for evolution for themselves, as well as assisting them in developing skills in critical thinking and inquiry. Utilizing this model can therefore create a more scientifically literate student body who can go on to pursue even greater understanding of the nature of science.
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CHAPTER ONE

EVOLUTION EDUCATION IN THE UNITED STATES

Statement of the Problem

In 1909, John Dewey addressed the American Association for the Advancement of Science, stating "Science teaching gives too much emphasis to the accumulation of information and not enough to science as a way of thinking. Science is more than a body of knowledge to be learned, there is a process or method to learn as well" (Dewey, 1997). In the ninety-six years that have passed since his speech, remarkably little has changed in science education. Much of the activity in science classrooms today is still focused on rote memorization or accumulating facts, while relatively little time is spent on teaching students to think critically or to use the strategies that scientists themselves use.

The lack of higher-level thinking skills can severely impede a student's understanding of the nature of science, and leave him or her insufficiently prepared for true scientific problem-solving. In order for students to gain a full appreciation for the power of science, students must be skilled in both critical thinking and inquiry. Both critical thinking and inquiry are intimately related
to scientific exploration, and students, acting in the science classroom as scientists, must be able to use both effectively.

In addition to the seeming lack of adequate inquiry-based science education, there is the additional problem, in the United States and elsewhere, of the controversy surrounding evolution education. Currently, evolution is a subject viewed with suspicion by many school districts, as well as states, politicians and the general public. This fact is borne out by the large amount of anti-evolution legislation and school board policies that are currently circulating in many areas. This is also supported by a March 8, 2005, Gallup poll results that shows only 18% of all Americans ages 13 to 17 believe that evolution accounts for the current state of human development, with no supernatural interference of any kind. The remainder of this group maintain that some sort of supernatural involvement is needed to explain our current place in the world (Gallup.com, 2006). Much of this suspicion comes from a lack of scientific understanding on the part of the individuals involved. The remainder comes from a religious perspective that cannot be addressed fully in this context. It must be noted, however, this lack of critical thinking and inquiry
education has been capitalized upon by the forces behind Some fundamentalist religious perspectives, and therefore those perspectives do play a role that can be addressed in educating about evolution.

The general public’s lack of scientific understanding can be connected with the lack of inquiry and critical thinking on part of the general public. It is the author’s hypothesis that an increase in both inquiry and critical thinking instruction in the science classroom will increase the students’ understanding of the nature of science, specifically evolution. This will, in turn, create a body of individuals who can pass on their understanding and can effectively voice their views on the subject of science in general and evolution in particular. This will create a greater understanding in the general population of the nature of evolution, which will reduce the controversial nature of the subject.

As is often the case in society, controversial topics tend to be misrepresented to the general public and/or misunderstood by the same population. High-quality science education, including inquiry and critical thinking, will help people gain a firmer grasp of the real problems underlying controversial topics, as well as the topics themselves. This will also allow the general population to
make better-informed choices that affect not only the individual, but also society in general.

Historical Perspectives on Evolution Education

The concept of biological evolution has been around for centuries. While most people think that the concept started with Charles Darwin, this is not the case. Darwin undoubtedly heard the idea from his grandfather, Erasmus Darwin. The elder Darwin was a member of "The Lunar Society of Birmingham." The Lunar Society was a group of thinkers, inventors and scientists who originally met in the mid-1760's to discuss ideas affecting society. These discussions were wide ranging, covering virtually all areas of "modern thought." Scientific ideas were a common theme at the meetings, which happened during the full moon (Uglow, 2002; Darwin, 1958, 2003).

The idea of biological evolution was discussed at society meetings on many occasions, and there is little doubt that his grandson Charles learned of Erasmus' musings. Erasmus and the Lunar Society were not the only ones to discuss biological evolution. Many individuals across Europe and in the United States were considering the possibility. However, none of these groups developed a cohesive mechanism for the evolutionary process, and
without this mechanism, biological evolution remained nothing more than an intellectual exercise.

What Charles Darwin did was provide the mechanism by which evolution could occur. This mechanism, known as "Natural Selection" became the basis for the Darwinian theory of evolution, as laid out in his book, *On the Origin of Species*. This book was published in 1859, and became an instant and controversial best-seller. However, the idea of evolution did not become established in the scientific community for more than a decade. After sufficient investigation, discussion and debate, the scientific community came to accept the idea of evolution, and it became, and remains, the central unifying theory in biology. However, this did not translate instantly into a change in public school biology curricula. That change did not begin until the new generation of scientists began writing textbooks (Fletcher, 2003).

While not always the case today, science textbooks in the past were generally written by scientists. Textbooks written before the turn of the 20th century were most likely written by scientists who were trained at a time before Darwin's theory was fully accepted by the scientific community. This meant that any discussion of evolution in the text would likely have been cursory,
derogatory, or more likely, nonexistent. It was only when scientists who trained after the acceptance of evolution by the scientific community and began writing textbooks that this changed; positive accounts of biological evolution began appearing in high school textbooks. Soon, public controversy began.

Put simply, natural selection states that living things will evolve due to the process of natural selection. Organisms generally produce far more offspring than can possibly survive. Since each offspring is genetically unique, all the offspring will have different combinations of traits that create advantages or disadvantages for each individual, based on the environment. Those organisms whose genetic make-ups are best suited to the environment are the ones that generally survive, while those whose make-ups are less suited to the environment tend to die out. Thus, each generation provides for slight “course corrections” that slowly cause the population to change and become better adapted to their environment. If the environment changes, then new pressures cause the population to continue genetic modification in a new direction. This process can eventually lead to entirely new species and greater
diversification. It is this process that is responsible for the vast diversity of life on Earth.

This accounting for the diversity of life goes directly against a literal reading of the opening chapter in the biblical book of Genesis. Fundamentalist Christians did not appreciate what they viewed as a direct attack upon their belief structure and their desire to impose it upon others. Natural Selection became the enemy, and the people who supported Natural Selection were viewed as an army whose goal was the destruction of western society as the Fundamentalist Christians saw it. Fundamentalists began formulating plans to fight off their perceived scourge of anti-religious activity (Dolphin, 1983; McGowan, 1984).

According to the Fundamentalist religious leaders in the early 20th century, the teaching of evolution was one of the greatest threats to the development of young people of the country. Evolution went against the direct teachings of the bible, as interpreted by some religious leaders. As a result, they managed to introduce and pass anti-evolution legislation in many states, predominantly in the southeast and midwest. This legislation banned the teaching of evolution in the public schools. Since the vast majority of private schools at the time were
religious, this meant that it was effectively impossible for a student to attend a class where evolution was taught (Larson, 1997; Moran, 2002).

The most notable of all early anti-evolution legislation is the Butler law, passed in 1925 in the state of Tennessee. The law itself was unremarkable, being yet another law against the teaching of evolution. Within days of the law's passage, the American Civil Liberties Union decided to challenge the law. Legally, however, the ACLU could not simply challenge, it needed to defend somebody being prosecuted under the law. The ACLU issued a press release stating it would defend any teacher arrested for violating the Butler law. A Dayton, Tennessee resident, George Rappelyea, read the press release and decided that a trial of this sort might "put Dayton on the map."

Discussion between the ACLU and civic leaders led to the decision to find a teacher who was teaching evolution, have him arrested and begin the trial. Since all the high school teachers in Dayton used the same text, Hunter's *Civic Biology*, which included a section on evolution, it would be easy to find a teacher. However, finding a teacher who was willing to be arrested and put his career on the line might be more difficult. Eventually John Scopes was persuaded by the civic leaders to participate.
He was arrested and stood trial in what became known as the “Trial of the Century,” the media circus of its day. For two weeks in 1925, the town of Dayton became the focus of attention for the entire country, and the subject of evolution became the dinner-table topic of the nation. Scopes was found guilty of teaching evolution and fined $100. The fine was reversed two years later by the Tennessee Supreme Court. However, they reversed the fine based on a technicality, leaving the Butler law untouched. It was not repealed for more than forty years (Moran, 2002; Larson, 1997, 2003; Scott, 2003).

The Scopes Trial serves as an example of the general attitude in the United States at that time. The teaching of evolution was considered to be wrong by the majority of Americans. Over the years since its introduction by Darwin, vast amounts of evidence had built up in support of evolution, but little of this reached the mainstream American population in any significant way. The scientific evidence was generally disparaged by the fundamentalists who made their case more vociferously than the scientific community. A weakness of the scientific community, then as now, is its expectation that scientific evidence would be influential to a population with little or no understanding of the nature and process of science. As a
result, science made very little progress with the public, while fundamentalists held the perceived moral high ground and maintained the exclusion of evolution from the science curriculum. Again, the reason behind this lack of public support for science in general, and evolution specifically, can be traced to a lack of understanding of the nature of science on the part of the public.

It must be noted that not all states and school districts were anti-evolution. Many students did receive a science education which included evolution. However, evolution was excluded in the majority of states and districts. Part of the reason for this rests not with the schools and states, but with the textbook publishers. So many states banned any mention of evolution that most publishers simply left it out of their texts, to avoid losing business. Thus, even if a district or state did not have an anti-evolution law, the textbooks they selected still might lack a chapter or section on evolution, simply because it was also marketed in anti-evolution states. If the material was not covered in the textbook, few teachers would give any great detail to it during classroom instruction (Fletcher, 2003).

Teachers in anti-evolution states stopped teaching evolution (or, at least were no longer being arrested for
it), and others made due by ignoring evolution or supplementing the text on their own. After about 1930, no new anti-evolution legislation appeared, and the situation quieted down. No new legal challenges were issued, and for a time no significant changes occurred. However, in 1947 a new challenge to the fundamentalist movement and anti-evolutionary tactics appeared.

In later years, the Cold War had caused an increased interest in science. Competition between the United States and the Soviet Union took on many forms, many of which were based on science in one way or another. This perception that the Soviets were gaining or surpassing the United States in technology and scientific knowledge led Americans to emphasize science education. This included the biological sciences, which included evolution. Scientists were encouraged to write new textbooks, covering topics in greater depth and detail.

The next major step came in 1968, when the Supreme Court heard the case of Epperson v. Arkansas, where a teacher held that the anti-evolution laws on the books in the state of Arkansas were a violation of the first amendment to the Constitution. The court agreed and the law was struck down (Epperson, 1968). Over the next few years more challenges occurred and more laws were struck
down. In this new time of scientific inquiry, evolution education began to flourish. At the same time, fundamentalists began looking for a new way to reintroduce creationism, which was the only thing that could be taught in the anti-evolution states, into the science classrooms across the country.

In the 1970’s Fundamentalist organizations were formed with the express purpose of promoting what they called “Scientific Creationism”. These organizations attempted to remove the overtly religious aspects of their beliefs and introduce their freshly sanitized ideas back into the curriculum, as an alternative theory to evolution. These organizations met with some success, particularly in the southern states and the in Midwest, just as they did in the 1920’s. Many states passed laws stating that creationism must be taught if evolution was taught. These laws were often called “Equal Time” laws, intimating that both evolution and creationism were intellectually and scientifically on the same level. This allowed the fundamentalists the foothold in the public schools that they desired (Scott, 2004).

Creationism is nothing more than a literal reading of the Biblical book of Genesis, from a Fundamentalist Christian point of view. Creationists take Genesis as a
literal description of historical events, up to and including the origin of the Universe, the Earth and life on it. They believe that the Universe and everything in it was created by divine fiat over the course of 6 days, no more than 10,000 years ago. These are exactly the religious views that were excluded from the public classroom under the first amendment (Scott, 2004).

To lend an air of science (and therefore academic respectability) to their religious beliefs, creationists developed Scientific Creationism, with which they attempted to meld scientific evidence into their belief structure. They have also questioned the validity of those discoveries of science that do not fit into creationism's scheme. The vast majority of evolutionary theory, and the evidence that supports it, cannot be used to support their ideas, so the vast majority of creationist effort is directed at discrediting evolution. Creationists often seem to assume that anything that questions an aspect of evolution is automatically evidence for creationism, thus demonstrating their lack of understanding of the methodology of science, or their intellectual insufficiency (McGowan, 1984). With little or no evidence to back their claims, fundamentalists managed to convince some states and districts that their religious doctrine
had scientific merit and that "Scientific Creationism" should be taught alongside evolution.

Another victory for the fundamentalists came when several states proposed and enacted laws that evolution must be taught as merely a theory, thus removing the scientific meaning of the word theory, which means a set of principals which are used to explain observed phenomena, can be used to make predictions and is widely accepted by the scientific community as generally correct. These legislative activities by fundamentalists caused resurgence in the teaching of creationism and a drop off in the teaching of evolution in any substantive manner. However, many teachers ignored the laws and continued to teach evolution as the only scientifically valid explanation of the diversity of life (Fletcher, 2003).

This condition persisted in education into the 1980's when challenges began mounting as the ACLU and the National Center For Science Education (NCSE) began championing the teachers caught under these equal-time laws. Since then, there have been many challenges, both pro- and anti-evolution. Generally, until the beginning of the 21st century, the pro-evolution forces won out, and the teaching of creationism dropped away. However, in the late 1990's and into the 21st century, two new
developments again threaten the teaching of evolution. Fundamentalist Christians, having failed with "Scientific Creationism" have again repackaged it, now calling it "Intelligent Design," also known as ID (Forrest & Gross, 2004; Perakh, 2004)

"Intelligent Design" basically states that life is so complicated that it could not possibly have evolved on its own, and must have had some sort of Intelligent Designer to create it. The fundamentalists careful and purposefully omit who or what they feel this Intelligent Designer really is. They have learned that any religious overtone means an automatic violation of the First Amendment, and thus avoid such difficulties. In this way, the fundamentalists have managed to make advances into the science curriculum of some districts and states, but vigorous opposition by the ACLU, the NCSE, and by science teachers themselves has managed to keep the ID proponents from infiltrating the science curriculum in most regions. However, the fundamentalists have found that the current political climate is now leaning their way, and they are feeling empowered to try again.

Recently, new district proposals and legislative bills have been introduced and aimed specifically at introducing ID into the public science curriculum, or in
reinforcing the old "evolution is just a theory" ploy. These bills and school board policies are currently being challenged again, but the Federal and some state and local governments are overtly aligning themselves with the fundamentalists, making the fight for a scientific curriculum more difficult. Elected officials are more willing to introduce anti-evolution legislation, and fundamentalists are more likely to lodge complaints about evolution with school boards and other elected bodies. This climate is becoming increasingly hostile to evolution education, despite the fact that many state education standards contain specific language about evolution, as do the national standards, and standards created by organizations such as the American Association for the Advancement of Science (AAAS) Project 2061 (Project 2061, 1989; AAAS, 1993).

It is due to these increasingly difficult circumstances that this master's project has been created. In addition to the difficult political climate, there has been a massive increase in scientific data regarding evolution, primarily from the fields of paleontology and genetics. The new field of cladistics provides additional powerful new tools for the study of relationships between species, genera, families, etc. This project will provide
the classroom teacher with a model as well as the understandings to help students learn the fundamentals of the scientific biological evolutionary theory.
CHAPTER TWO

INQUIRY, CRITICAL THINKING AND EVOLUTION EDUCATION

Introduction

Even though Humans are naturally inquisitive, they must still learn how to do science. It is not an innate characteristic of our species. Traditionally, the method of teaching most material is simple rote memorization. This method is relatively fast, easy and produces results easily measurable with a simple test. However, it does little to encourage real learning and thinking. A child can regurgitate information memorized without actually understanding anything he or she has memorized. However, there are deeper levels of understanding beyond mere memorizing.

While this idea of levels of understanding has been around for quite some time it was not formalized until Benjamin Bloom, in his work Taxonomy of Educational Objectives: Handbook 1, The Cognitive Domain (Bloom et al., 1956). His work delineated six levels of increasing complexity from a cognitive standing. Bloom maintains that true learning and understanding occurs at the higher levels of cognitive involvement. He set up a hierarchy, commonly referred to as “Bloom’s Taxonomy,” to encourage
teachers to consider how to create questions and situations to encourage higher-level thinking.

The levels he created are:

1. Knowledge - basic recall of facts and figures
2. Comprehension - understanding of the information, including describing and stating main ideas
3. Application - using information in new ways, applying it to new situations
4. Analysis - Using information to make inferences as supportive evidence
5. Synthesis - Using information to create new knowledge, deeper understanding
6. Evaluation - Judging the validity of information, defend ideas and conclusions

Bloom's Taxonomy is not directly taught as a part of the scientific method, yet it is inherent in the Scientific Method. There are as many subtly different interpretations of the scientific method as there are scientists, but they all follow a process involving the same basic pattern.

- Develop a research problem or question
- Optional, depending upon end goal: develop of a tentative answer to the question (hypothesis)
• Develop and conduct an experiment to obtain data related to the research question and possible hypothesis

• Analyze the date from the experiment to determine and answer to the research question and/or if the hypothesis is supported or not

• Come to a conclusion about the hypothesis or research questions, based on the data obtained

While Critical Thinking and Inquiry are not expressly delineated in any portion of the Scientific Method, they are part of the very nature of science. If students are to fully understand the nature of science and how science operates, they will need to understand the nature of Inquiry and Critical Thinking. As with most other things, students learn best by doing. By teaching students Inquiry and Critical Thinking skills, they can apply what they have learned to their science research, as well as their everyday thinking and their lives.

Inquiry
1. The act or an instance of seeking truth, information, or knowledge about something: Examination into facts or principles: Research, investigations (Webster’s, 1993).
In its simplest form, inquiry is nothing more than asking questions. In the science classroom, however, inquiry is a method that goes far beyond merely asking questions. It is an approach to learning where asking questions is the central focus. While questioning is central, inquiry also involves learning to answer those questions in a rigorous manner.

Inquiry and the National Science Education Standards, (NRC, 2000) the authority on inquiry science education, points out that inquiry has more than one meaning:

"The term 'inquiry' is used in two different ways in the Standards. First it refers to the abilities students should develop to be able to design and conduct scientific investigations and the understandings they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. In this way, the Standards draw connections between learning science, learning to do science and learning about science."

This differentiation is important, but equally important is the relationship between the two. "...the Standards draw connections between learning science, learning to do science and learning about science" (NRC, 1996). This relationship is something that the vast majority of students seem to lack, and it poses a major hindrance to learning. Learning from the lowest levels of
Bloom's Taxonomy can contribute a little to each of these, but to truly do both of these well, students must have tasks more challenging than mere memorization. Designing a curriculum to do this will be the major challenge facing most science teachers.

The first thing to consider when designing such a curriculum is that inquiry is a process that mimics actual scientific investigation. "Students who use inquiry to learn science engage in many of the same thinking processes as scientists who are seeking to expand human knowledge of the natural world" (NRC, 1996). Any curriculum that is designed to teach inquiry will have to be rich in opportunities for students to learn by using inquiry. Inquiry is not something to be taught through lecture and memorization. Students must learn by doing. The greater the opportunities to use inquiry, the greater the success of the students in learning how to understand and apply inquiry, not just in science class, but to all aspects of their lives.

Inquiry is nothing new to students. Humans use inquiry from birth. Early attempts are tentative at best, using a trial-and-error approach. As we gain skill and reinforcement, we are able to examine a situation, make predictions of various outcomes based on differing
actions, then assess the actual outcome based on the action taken and the results (NRC, 2000). Psychologists point out that the reason children make many poor choices is because they lack experience in the process of evaluating possible outcomes of these choices. The poor choices and their results are points along the way, where children gain experience with the evaluation process, albeit sometimes painfully.

If inquiry is something that is not new to children, why does it pose such a challenge for the science teacher? There are several reasons why it might. First, although the process is well known to children, it is not a conscious process, for the most part. Therefore the first challenge is for the teacher to convert a subconscious activity into a conscious, metacognitive activity. Once a student understands the process he or she has been using all along, it becomes easier for him or her to use it in the classroom setting, and to refine the process into a workable system.

Second, the process of inquiry is not one simple recipe to follow for success. While guidelines for the conducting of inquiry investigations do exist, there are always variables to consider. Each inquiry experience will be different, and students must learn to modify their
ideas and processes to fit the situation. Students and
some teachers often expect a one-size-fits-all approach to
lab activities, and inquiry may have to take different
paths than expected. This becomes even more apparent as
students take on a greater role in their own learning. As
the teacher scaffolds, or provides active support for
student learning activities, the students less and less,
proceeding with inquiry becomes more and more of a
challenge for the student. In a perfect inquiry driven
system, the teacher will inform the students what they are
to learn, based on the science standards, and allow the
students to work on their own to explore what they can.
Students would be expected to form hypotheses, perform
research, presenting their findings to the class in some
manner. In this scenario, the teacher acts as a
facilitator and resource, helping students find
information, design investigations and make sense of
findings.

More realistically, students generally need much more
guidance than this. Most students, because of the current
religious/political influences on education in most
states, have received inadequate science education.
Currently most school districts are emphasizing math and
language arts in the elementary grades, and other
subjects, including science, are suffering as a result. Since science is given less attention in most elementary classrooms, there is likely little time or motivation to encourage inquiry in science. The first time many students get intensive science education is in middle school or junior high school.

This means that the secondary science teacher is the first teacher with a real opportunity to expose students to scientific inquiry. Elementary teachers, pressured as they are by district administration for improved standardized test scores in language arts and math, cannot afford the time to teach with and about inquiry. In a perfect system, teachers, beginning with Kindergarten, would teach with and about inquiry in an age-appropriate manner. By the time students reached 7th grade, they would be proficient in inquiry as a process and would be able to perform their own independent investigations into whatever subject was assigned to them. As it is, due to the strictures of time, curriculum and district pressure, students come to 7th grade with very little in the way of inquiry experience.

One of the most direct and common ways of teaching the skills of inquiry is a process known as the "Five E" method. This is a way of learning based upon elements of
constructivism. Constructivism is the educational theory that holds that students learn best when engaged in lessons designed to construct their own meaning and knowledge, rather than learning by rote memorization. Constructivism is closely related to the scientific method in its approach, and is thus well-suited for use in the science classroom.

The Biological Science Curriculum Study (BSCS) has done extensive research into constructivist techniques. Rodger Bybee, working with BSCS, developed the Five E lesson cycle. The Five E’s, as outlined by Bybee are:

- Engage
- Explore
- Explain
- Extend
- Evaluate

**Phase I, Engage** The teacher uses a "hook" to pique the interest of the students. This could be something as simple as stating a leading question or making a statement that seems odd to the students, but whatever it is, it must be designed to catch the interest and attention of the students. It must create an interest in the students to learn more about the topic.
For example, when the students come into class, there could be a display of different animal skulls sitting on the teacher's desk. After suitable time for students to look at the skulls and wonder about them, the teacher could ask, "What do these skulls have in common?" "How do they differ from each other?" and "Why are they different from each other?" These questions will cause the students to consider the skulls more closely, and to begin the process of investigation and inquiry.

Phase II, Explore In this phase, students perform hands-on inquiry into the problem presented. Working directly with materials and each other, they cooperatively attempt to make sense of the situation and create an understanding of what is happening. The teacher acts as a guide or facilitator, helping only by observing, prompting, listening and providing references that will aid the students as they proceed through the investigation process. Here also, the students would begin to explain the relationships between form and function. They might look at they types of teeth and infer the diet of the animals. They might look at the structure of the mandible and determine the relative power of the bite for each animal. By performing investigations like this, the students begin formulating basic explanations and can
possibly determine evolutionary relationships between the skulls. If the teacher supplies information in the form of "Skull A is geologically older than skull B."

In the case of the skulls, students might make detailed examinations of the skulls, noting the structures of the component bones, the various dimensions of the skulls and bones, and the relative sizes of structures among the skulls. This would lead to a detailed quantification of the similarities and differences among the skulls.

Phase III, Explain Students make connections from their explorations to the concepts and vocabulary they have learned in class. The teacher can assist by asking leading questions and providing additional information about the topic. The students may also refer to information they have learned earlier in class, or that they will be learning in the future.

In the case of the skull activity, students could possibly connect this activity to the discussion of Darwin’s work on Natural Selection, allowing them to explain what had influenced the forms of the skulls. They might also look at the climates in which each animal species lives or lived and propose how that could have influenced the evolution of the species.
Once the students have made their explanations, the teacher must also provide further explanation, to help clarify and correct student understanding, and to help clarify and draw out more information from the students. This will help the students make further connections with previous learning.

Phase IV, Extend Once a basic understanding is achieved, the students must go beyond what they have discovered to apply this knowledge in new ways. A simple method may be for the teacher to ask questions which relate to the topic and lead to new insights on the parts of the students. This causes understanding of the concept to expand and deepen, which causes students to take greater ownership of the information.

Students might propose intermediate forms between the skulls, project into the future of the lineage, in a sort of "if this goes on" scenario. They may also propose hypothetical related species and alternate lineages, based on proposed alterations to environment. For example, they may look at a coyote skull and propose how it might be different, if over the millennia the source of prey animals were to slowly be eliminated and the coyote had to evolve to eat plants.
While the students evaluate their own work, and the work of their peers, it is also necessary for the teacher to perform an evaluation. This will provide a valuable check on the progress of the students, as well as allowing the teacher to insure the students have learned all they need from the activity.

Phase V, Evaluate In the evaluation phase, the teacher assesses the understanding of the students. Typically, formative and summative assessments are provided for the students in the form of tests and quizzes. Authentic assessments can be also be used summatively. This allows the teacher to get a good understanding of what the students really gained from the activity. In addition, authentic assessment makes the students think again about what they have accomplished, turning an assessment into yet another metacognitive device.

In this instance the students may produce a report of some sort, where they evaluate what they did in the exercise, and also teach others what they have learned. They may produce a paper in which they compare and contrast two skulls. Perhaps they make a poster showing the lineages as they have determined them. Another student (Or student team) might make a presentation for the class
where they use a PowerPoint presentation to teach other student about skulls that they have researched, and how they would fit into the lineage. The greater the freedom provided to the students, the wider the range of projects that will be created by the students. However, the students will require careful scaffolding to achieve a high-quality product.

The first time an inquiry lesson is presented to the students, their attempts will be tentative, as they learn their strengths and weaknesses. Some students will not be comfortable with so much freedom, and will fall back on familiar projects and products, creating something that looks similar to past projects. Other students may be too ambitious, attempting to create a project that is beyond them, which will generally lead to failure. Help from the teacher may help both groups of students work at a higher level and not extend themselves too far. Ultimately, what should be seen is the students taking greater and greater risks with their projects, as their skill and confidence increases (NRC, 2000).

By working through the 5E lesson cycle, the students will develop a greater understanding of the material than they would if all they had done is read about it in the textbook. They have become actively involved in a process
of discovery, and they have created knowledge for themselves, rather than absorbing information passively. The students then not only have information, but are also able to apply it in new and unusual situations. With enough practice, students will naturally fall into the inquiry mindset, where they automatically begin the 5E process when it is

While this is the most common form of inquiry, which owes much of its success to the influence that BSCS has had over several decades it is not the only form. The Miami Museum of Science (MMS) has a slightly modified version that it uses, the Seven E lesson cycle. They arrange it as follows:

- **Excite** - Stimulate the learner’s curiosity
- **Explore** - To satisfy curiosity
- **Explain** - The concept and define the terms
- **Expand** - Discovering new applications
- **Extend** - The concept into other content areas
- **Exchange** - Ideas, lesson plans or experiences
- **Examine** - The student’s understanding

(www.miamisci.org, 2001)

The MMS model can be viewed as a variation of the 5E cycle, but it does provide an expansion that can be very
useful to students. The "extend to other content areas" can provide mental linkages to seemingly disparate information that make the learning more real to the students. This can be particularly effective when placing science into an historical perspective. Many discoveries had a profound influence on history and were the basis for later discoveries. If students can discover this, they will develop a deeper understanding of the role science and technology have played in the formation of modern society.

This linkage between science, technology and society is important for student understanding, because of the profound influences of science in our history. The theory of evolution has had a profound effect on western culture and how it views the history of life on earth. Not always perceived as profound an effect as implementation of sanitation or computer technology, evolution has managed to affect a large rift in our society, which is part of the reason that evolution education is lacking in the United States.

Critical Thinking
Involving or exercising careful judgment or observation: Nice, exact, accurate, precise, punctual (Simpson, 1989).
The mental process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and evaluating information to reach an answer or conclusion (www.dictionary.com).

Critical thinking is intimately linked with science and inquiry. Like inquiry, it is an active, metacognitive task. The student takes information and puts it through a rigorous review process to test its validity and usefulness. As with inquiry, the term critical thinking involves two separate assertions. The first is the possession of the cognitive skills needed to actually think in a critical manner. Second, is the actual ability to use these skills to influence personal behavior and decisions. Again, as with inquiry, we see that the two ideas are linked and can be used simultaneously.

The process of critical thinking, whether in the science classroom or outside, is, in theory, practical and straightforward. In the science classroom, the steps would follow as outlined below:

1. Make observations about a phenomenon.
2. Develop a possible answer that explains the observations (Hypothesis).
3. Conduct observations, perform experiments and collect data about the phenomenon, to test the validity of the hypothesis.

4. Review the data and the arguments used to support the hypothesis.

5. Assess the data in light of the hypothesis, determining how much weight the data carry, and how thoroughly they support the hypothesis, or if they can be used to support other hypotheses as well.

6. Determine if the data support the hypothesis to the degree that the hypothesis can be tentatively accepted, must be rejected, or if further research is required.

Upon examination, this would appear to be nothing more than a re-statement of the scientific method. However, Critical Thinking goes beyond the scientific method and adds one component that is often lacking in science education: the critical review of the information. Oftentimes students merely accept data without question, simply believing the information to be valid without stopping to determine whether or not it supports the hypothesis.
The *National Science Education Standards* mention the concept of critical thinking in several places. The most significant passage explains that the purpose of critical thinking is to explore the relationship between evidence and explanations, as well as determining which evidence is valid in a particular circumstance. Dealing with discrepant events will also require the use of critical thinking skills (NRC, 1996).

One goal of inquiry education is to stimulate critical thinking, providing opportunities for students to use critical thinking skills to come up with an answer. In fact, critical thinking is absolutely necessary for successful inquiry. Students must be able to look at their data and ask "Does this make sense?" They must review their findings and determine if the data support their hypotheses, or if they must develop new ideas. To do this requires the ability to examine, in an unbiased manner, the merits of the evidence and the hypothesis. Insufficient or contradictory data must be dealt with. Inquiry education fits in perfectly with critical thinking education.

While critical thinking would seem to be a natural result of science education, this is not the case. Like nearly everything else, critical thinking must be learned.
Understanding how critical thinking works and applying this knowledge will make learning science far easier and will reduce errors caused by poor thinking and erroneous preconceptions. Teaching critical thinking as an independent activity is not the best method, however. To think critically and, therefore, scientifically, students should be taught in a structure that encourages critical thinking while covering other material, relevant to curriculum (Hiler & Paul, 2002; Paul & Elder, 2003).

The basic structure of the traditional science class -lecture, notes and the occasional lab experience are not enough to bring about critical thinking in students. Occasionally, something may, in the lecture, cause students to stop and ask a critical question, but this experience is generally limited. In order to truly help students to think critically, it is necessary to do several things. First, the students must be made to think in the higher realms of Bloom's Taxonomy. Secondly, the students must be presented with information that somehow challenges their points of view. Such information does not have to be world-shattering; all it needs to be is something that is unexpected. This unexpected event will have to be analyzed, and, coupled with the higher-level of
Bloom’s taxonomy, this will create a situation where critical thinking can begin.

Any discrepant event is a good example of presenting students with an unexpected challenge. When students expect one outcome, and something different happens (especially if it is wildly different), there is cognitive dissonance. Critical thinking is just the thing for dealing with the dissonance. The better the critical thinking skills of the student, the more effectively the dissonance can be dealt with (Piaget, 1971).

One example that can cause this dissonance among the student is the relationship between dinosaurs and birds. Many children think of dinosaurs as huge, lumbering beasts, and naturally would think that anything related to dinosaurs would also be huge and lumbering. To cause the dissonance by way of a discrepant event all the teacher needs to do is announce that a dinosaur has recently been found living in this country. The students will either become interested or skeptical. The teacher then announces that he or she has a picture of this dinosaur. At this point the teacher reveals a photo of a bird of some sort, such as a Budgerigar (commonly referred to as a Parakeet by many people). The smaller and less-dinosaurlike the
bird, the better. If the teacher can bring in a real bird, so much the better.

Many students will laugh at this, and most will not accept this picture as a dinosaur. However, if the teacher insists the picture (or animal) is in fact a dinosaur, the students will begin to experience some confusion. This confusion will generally lead to students wondering why the teacher would make such a claim. After a few moments, either a student will ask what the teacher means, or the teacher can ask the students what would lead him or her to make such a statement. This is when students will begin to analyze the situation, to see if they can find some reason for such a wild claim.

The teacher can then begin to ask probing questions that will cause the students to think about the situation. These questions should be leading, forcing the students to consider possibilities they may not have imagined before.

"What sort of evidence could we look for that would prove to us that birds are some sort of dinosaur?"

"If birds are related to other dinosaurs, such as Compsognathus, what would the intermediate animal look like?"

"This bird has feathers, but dinosaurs are usually shown with scales, like reptiles. Is it possible that
dinosaurs had feathers? Why would they need them if they could not fly?"

"Why am I saying birds are related to dinosaurs, when dinosaurs can’t fly. Pterosaurs could fly, wouldn’t birds be closer to them?"

These examples are just a few of the possibilities. There are any number of questions that students could consider. The goal of an exercise like this is to attract the interest of the students and make them think about a situation in a novel way. Doing this will begin the critical thinking process and can be the start of inquiry. Thinking about previously unconsidered situations or possibilities is an effective way of starting these processes (NRC, 2000). Simply observing a discrepant situation like this event is not enough. The students must be guided to actively think about the issue, rather than sit passively and receive information as in the lecture method. They must be encouraged to consider possible questions about the situation, to explore it through research and observation, and modify the circumstances to create new information.

Perhaps a student would recall seeing a picture of a dinosaur that looked like it was bird-like. Another might remember seeing a show about Harris’ hawks working
together to capture prey, and it reminded them of reading about how some theropods might have hunted in packs. By encouraging students to make such connections, and by asking leading questions about these events, the teacher helps the students think about the situation in a critical and evaluative manner. Taken to the logical conclusion, the students would eventually determine if and how birds might be related to dinosaurs. At the least, the students should be encouraged to come up with a working hypothesis about how to continue their research (NRC, 2000).

Critical thinking is a method of problem-solving. It is one more tool that a person can use to deal with difficult or challenging situations. Problem-solving is a learning process that involves the transfer of knowledge learned in one situation to a new situation. The knowledge involved is usually experiential in nature, and transferring it involves the determination of whether the knowledge is relevant to the new situation. Thus, the student must learn to think critically, in order to solve the problem in the most effective manner possible (Paul & Elder, 2003; Elder & Paul, 2002).

Teaching critical thinking, therefore, is inextricably linked with high quality science education, as is teaching inquiry and the scientific method. Science
teachers must be mindful of this fact and make certain they are providing ample opportunities for students to develop critical thinking skills. By planning appropriate classroom activities, the students will be provided with these opportunities, and the teacher will be ready to guide the students through the process. The ultimate goal, of course, is to create a learning environment in which the students will recognize situations where critical thinking, problem solving and inquiry are required, and utilize the appropriate skills in the appropriate manner.

Evolution Education

The state of evolution education across the United States is highly varied. Much controversy surrounds the teaching of evolution. The media coverage caused by the recent Kansas Board of Education decisions and the electoral removal of the Dover, Pennsylvania School Board members illustrate this quite clearly. School boards at the local and state level are dealing with controversies surrounding the teaching of evolution. The Federal Government is also facing this problem, President George W. Bush has recently weighed in on the topic, stating his support for the teaching of Intelligent Design in the science classroom. This political climate creates
difficulties for the classroom teacher when dealing with the topic of evolution.

At its best, evolution education is treated as any other scientific topic, with no controversy, and with an in-depth study of the concepts and evidence behind the theory. At its worst, evolution is denied, ignored, or misinformation is taught in its place or as an Alternative theory. A study released by the Thomas B. Fordham Foundation in 2000 took an in-depth look at evolution education as it stood and determined that only ten states address evolution in their education standards in what could be called a superior manner. Thirteen states received a failing grades in the same study, indicating that they did an extremely poor job of teaching evolution, if it was covered at all. The study found that the educational standards of nearly two-thirds of the states did at least a satisfactory job of covering evolution and the theory behind it. However, that leaves one third of the nation with students who receive inadequate or worse education when it comes to evolution (Lerner, 2000).

One may wonder why controversy exists regarding evolution? To understand why there is a controversy surrounding evolution education, one must understand the religious and social nature of the arguments against
evolution. In the past, the idea that the earth orbited the sun was considered a very controversial topic. The findings of Galileo, Bruno and others completely altered the understanding of the organization of the solar system. Despite the powerful evidence discovered by these scientists, the Catholic Church declared such ideas to be anathema. Many people were punished and even killed for holding this heliocentric view of the universe. The people who were in power had determined that the earth was in the center, and any other idea was not only incorrect, but also dangerous. Eventually, however, the heliocentric model became accepted.

This acceptance occurred for several reasons. First, the evidence became overwhelming in support of heliocentrism. Second, the original beliefs that went against heliocentrism were realigned with reality as the people in power were replaced over the years with more open-minded individuals who determined that the question of planet and star positions were not a matter that would damage the faith of their followers. Third, at the same time, the general public became aware of the controversy, and it became a non-issue as more and more people accepted the heliocentric view. The public acceptance created a
pressure for people in power to alter their views, so as not to alienate their followers.

While this acceptance was a slow process, it did happen. Lerner states that this happened because "As the frontiers advance, the body of noncontroversial, consensual knowledge grow apace. Scientists pursuing such fields are no longer divided into warring schools" (Lerner, 2000). This consensus by the scientific community meant that the general public heard a single voice from science, which lent greater authority to the ideas in question. The general public, generally illiterate in terms of scientific understanding, came to accept what scientists theorized without question. This scientific illiteracy within the general public led to problems, as well.

Most people do not think about evolution and its implications very often. It is simply something that does not affect their lives directly, as far as they can see. However, much like the people who opposed the findings of Galileo, many will rise up against evolution as a challenge to their fundamental beliefs. Evolution clashes directly with a small but vocal portion of the general population’s belief structure. They feel that evolution and its proponents are attempting to unseat them from
their central place in the universe, just as Galileo attempted nearly 400 years ago. These are the same kinds of people who would have gone against Galileo in his time, and for much the same reasons. Genetics has been around for about the same amount of time as evolution, but holds no real controversy for the general public, since there are no perceived threats regarding genetics to the religious beliefs of the general public and their leaders.

The controversy exists solely because of a particular interpretation of the creation story found in the biblical book of Genesis. Virtually every person who opposes evolution holds this position due to his or her interpretation of these passages, which seem counter to the discoveries made by evolutionary biologists. Areas of the United States where conservative, fundamentalist beliefs have strong public support are areas that generally have low-quality science instruction in general, and evolution in specific (Gross, 2000). This is supported by Lerner’s study, which shows that the states with the lower science scores for evolution education standards, are those states traditionally labeled as conservative. The people in these states generally support church leaders and politicians who are anti-evolution (Lerner, 2000).
The people who go against evolution either have a fundamental misunderstanding of the nature of science, or are willfully ignorant of the centrality of evolution as it relates to biology and other scientific topics. If they are willfully avoiding the evidence for evolution, there is little that can be done. However, if they lack a deep understanding of the nature of science in general, and evolution in specific, then science teachers can help correct the situation. The better the teaching of science, the more likely people are to understand the nature of science and evolution.

The State of California has earned very high marks in the Lerner study because of its in-depth inclusion of evolution in the state education standards. The state framework is only the beginning of the process. Regardless of how detailed the framework is in relation to evolution education, the standards will come to nothing without proper implementation. In order to achieve a true high level of understanding among the students with regards to evolution, it is necessary to have a highly trained, well-informed teaching staff and administration, from the local level on up, who are willing to support the teaching of evolution. With these in place, the effective teaching
of evolution, critical thinking and inquiry can take place in any science classroom.

In a perfect situation, evolution would be just one more subject being taught, without controversy, and critical thinking and inquiry would be used with all science subjects. This is as it should be, as evolution is just one more topic in science. Granted, it is considered the central, unifying topic in biology, but this should rate no higher than any other topic. It should be taught as a part of biology, just as atomic theory should be part of chemistry. To teach evolution, as well as all other topics in science, both inquiry and critical thinking skills are valuable, if not indispensable.

Teaching these skills, which will ultimately lead students to becoming independent learners, is the main job of the teacher. If a teacher can successfully teach a student to learn on his or her own, and to critically examine the evidence to determine what makes sense, then the teacher has accomplished the job. In the past, teachers were often viewed as the font of knowledge, pouring what they know into the brains of the students. The view today is rather different. Teachers are guides, helping students figure out how to learn for themselves. When students become independent, their learning takes on
personal significance and becomes more personally relevant. This personal relevance will lead to a deeper and more significant understanding of the material on the part of the student, as well as a desire to learn more.
CHAPTER THREE

A NEW MODEL FOR TEACHING EVOLUTION

What do Inquiry and Critical Thinking Mean in the Science Classroom?

Critical thinking and inquiry are intimately linked. While either may be taught and learned in isolation, they are counterpoints to each other. Both are high-level tasks in Bloom’s Taxonomy, which are often underutilized in science classes. Inquiry will stimulate critical thinking and vice versa. Both critical thinking and inquiry can be thought of as implicit aspects of the scientific method. They both can also be thought of as clarifications of higher-level thinking skills, a process by which higher-level thinking can take place. While they are not the only methods, they are particularly effective in the science classroom, because of their relationship to science and the scientific method (Bybee, 2002; Paul & Elder, 2002).

To “think like a scientist,” students will need to learn inquiry skills as well as how to think critically. They will need to design learning activities, collect evidence appropriate to the subject at hand, analyze and judge this evidence, and apply what they have discovered in a rational manner. This is what science does, and
encouraging both inquiry critical thinking in the science classroom will produce a truly scientific atmosphere in the classroom (Paul & Elder, 2003).

The National Science Standards (NRC, 1996) explain what inquiry should look like in the science classroom:

Students formulate questions and devise ways to answer them, they collect data and decide how to represent it, they organize data and generate knowledge, and they test the reliability of the knowledge they have generated. As they proceed, students explain and justify their work to themselves and one another, learn to cope with problems such as the limitations of equipment, and react to the challenge posed by the teacher and by classmates. Students assess the efficacy of their efforts - they evaluate the data they have collected, re-examining or collecting more if necessary, and making statement about the generalizability of their findings. They plan and make presentations to the rest of the class about their work and accept and react to the constructive criticism of others.

A New Model For the Teaching of Evolution in Middle School Science

If a science teacher is to effectively teach science, he or she must encourage students to use science and its tools in the ways that scientists use them. This includes critical thinking and inquiry. Students must be able to look at their questions, problems and ideas and ask, "Does this make sense?" The concepts surrounding evolution are especially well-suited to this, as critical thinking and
inquiry provide powerful tools to help students understand the nature of the evidence that supports evolution.

Modern evolutionary theory is a combination of work from many areas of research and the work of hundreds of scientists over the past century and a half. To fully understand evolution the students must not only understand the workings of evolution, but how evolution interconnects with other areas of biology (Project 2061, 2001). Evolution is central to biology. As a result, students should learn about evolution and its interrelationship to other areas of biology whenever practical. In order to truly learn not only the facts of evolution, but the science behind it, students should use inquiry and critical thinking in their learning of evolution. To better accomplish this, the author puts forth a new model for the teaching of evolution. This model is based upon Bybee's 5E lesson cycle, the 7E lesson cycle created by the Miami Museum of Science, and the principals of critical thinking.

This model actively incorporates critical thinking skills into the lesson cycle, to create a situation where students will not only use critical thinking, but understand how it is used and its power when used. Students are also made aware of the model itself, so that
the activities become metacognitive, as they analyze their performance against steps of the model. This provides further feedback for them, as they work towards their goal.

The Model

The new model is divided into seven steps or phases. These steps are student-driven and flexible to accommodate the needs of students. Some steps may take a significant amount of time, while others take less. This chapter will address guidelines of the model as it should be implemented, while chapter five will provide more specific examples.

1. Engage

The teacher introduces the topic to the student by some method. This can be as simple as showing the students a picture or as elaborate as setting up a display or experimental condition. The goal of this step is merely to get the students thinking about the topic. When choosing an introduction to a science topic, the teacher should make sure that the material will be something that will generate interest and questions on the part of the students.
2. Question Generation:

The students now begin to formulate a list of questions generated from observing the introduction. These questions should be ones that can be investigated at a later time by the students. This list should also contain both low-level and high-level questions. Students should be encouraged to focus on the higher-order questions. Students will often concentrate on the lower level questions, assuming that quantity is better than quality. The ultimate purpose of generating the questions is to have a list of things to learn for the lesson. Once students can answer the questions, the outcome should be a thorough understanding of the lesson and the scientific content.

When questions have been generated, there are several options. The students work together in groups to develop a master list of critical questions and submit the questions to the teacher for compilation into a single class-generated list. Generally, this process should be a cooperative effort between the teacher and students, especially in the early stages, until students have developed skills to work with large numbers of questions.

The point of this phase is to generate a large body of questions for the students to use for their own
research, to guide their learning. They can suggest low-level questions that can be answered simply by looking up a single fact, or higher-level questions that are more comprehensive and take more time and effort to answer. The teacher can model good questioning and encourage the student to come up with creative, thought-provoking questions. How many questions the students develop should be determined by the level and skill of the students. In early lessons the number should be lower. As the students gain skill with the method, the number and quality of the questions should increase. By the end of this phase, the students should have a list of questions for them to base their research upon in the next phase of the lesson.

3. Question prioritization

The teacher now presents the compiled list of questions to the students who cooperatively determine the priority of the questions, which questions are redundant or unnecessary, and whether there are other questions that need to be included. The teacher can add questions to the list if the students seem to be missing an important aspect of questioning. This can be done simply by adding it to the original lists submitted by the student groups, or by saying, “Have you considered this?” As students gain experience with the method they will require less and less
assistance from the teacher. The students must determine the importance of each question. The list should generally be arranged into lowest-to-highest level order in Bloom’s taxonomy. Examining the lists will allow the teacher to see where the students’ minds are at when it comes to their level of understanding.

The teacher can also emphasize the critical thinking aspect at this point by asking the students to study the list and re-categorize the list of questions. The list could be divided into 1) questions we are likely to answer, and 2) questions we are unlikely to answer completely. The students would also provide reasons for the divisions they have chosen. Thus creating a list becomes a metacognitive activity, where the students must analyze their own capabilities and the extent of the knowledge they feel exists.

4. Explore and search:

Now the students have basic questions to work with. It is time for them to explore the questions and determine which can be easily answered and which will need further research. Finding answers may take the form of book or Internet research, or physical experimentation, depending heavily on the material being studied and the questions generated by the students.
Regardless of the exploration performed, the goal is to collect information that will allow the students to answer the questions they have created. Once they have searched through resources or performed experiments to gather the data they need, the students are ready to move onto phase five, where they will use this information to answer the questions. If students need extra assistance, the teacher can help by asking deeper, more leading questions, which can help them see trends and connections they may not have considered themselves.

Students who are exploring and searching must also think critically about the explorations they are conducting. They must determine if the questions they are asking are relevant to their explorations, if better questions exist, and if the explorations will truly answer the questions they have posed. The author's experience shows that students will often develop an exploration that does not relate to their question, but is merely something they are interested in doing. By encouraging the students to think critically about their work, they can evaluate the process and determine whether or not what they are doing is the most effective way of reaching a final answer.
5. Explain, Analyze and Connect:

At this point, students have information that they need to answer the questions. They now begin to compile their evidence in ways that will allow them to create answers for the questions they developed in phase 2. This is more than simply answering the questions. The students must also develop relationships between the questions, based on threads of data discovered in the last phase. They take the information they gathered in phase 4 and use it to make coherent, communicable explanations for what they have discovered. They will also create a list of new questions that have emerged as a result of their research.

Also in this phase the students will extend their knowledge into other scientific or curricular areas, relating what they have learned in this lesson to something previously learned. The number of connections is also something that will expand based on the experience of the students. The first time they work with this model, they will likely have few connections between other lessons and units. As their experience and confidence expands, so will the number of connections they are willing to make. The teacher should allow even tenuous connections to other fields, as these may prove to be rich areas of research in the future. If the connections are
listed as questions, they become powerful tools for further research. Questions like, "Does evolution relate to how a cell works?" can lead to fertile areas of study.

At the same time, they should analyze their conclusions by asking questions such as, "Does this make sense based on the evidence I have collected?" or "If someone says I am wrong, what evidence can I provide to support my answer?" By using this method, students think critically about their answers, and begin to develop a defense for their conclusions. Since being able to defend a conclusion is critical in science, the students must have skills in this area if they are to think like scientists.

6. Evaluate and Assess:

Now that the students, in groups or individually, have created questions and answered those same questions, they must now evaluate their performance. The students will create a product that both teaches others what they have learned and acts as a self-evaluation of their own work. Just as students create the questions for investigation, they are responsible for evaluating how effectively they have completed the task of investigating those questions. Each student or group should revisit the list of questions generated in phase 2 to determine if the
questions they selected have been addressed. If they have addressed the question, then the students must decide if they have adequately answered those questions, or if further work is needed to give a sufficient answer. And, just as before, the teacher may need to scaffold the students in early attempts at evaluating their own work. In the early phases, the students may not truly understand the nature of this evaluation and may only judge the quality of their artwork, or the length of the essay they have created, ignoring the quality of the content they have generated. The teacher can provide feedback and assistance for the students to use to improve their evaluation skills.

As a secondary exercise, students can evaluate the work of others, judging the quality of their responses. This will give each student insight into what other sort of projects were possible, including recognizing what worked and what did not. In addition, each student can develop a list of questions from each project, which allows for further extension of the task. Students should be able to determine whether or not they have been successful. If so, they are ready to move on to new, possibly more advanced subject matter. If not, more study in this area is advisable.
7. Expanded Thinking

In the final phase of this method, students again visit phase 5, where they look for links to other areas of understanding. The students will determine how their research relates to other fields of study, and which sort of subjects can be connected. At the same time, the students finalize a list of questions that have arisen during the activity that can be fuel for further research. The teacher should not initially limit the range of either connections or questions, as this activity will require the students to delve into other areas regardless of plans that may exist for future units. Once the students have developed the questions for further research, the teacher can then pick the questions that relate to future lessons. Posting these questions in the classroom can be a valuable tool, reminding the students of the connections they themselves have made, which will help them recall earlier learning when they reach the later units.

Giving the students a wide path and not limiting them will allow for expanded creativity and divergent thinking. It may take some practice on the part of the students as well as the teacher to allow for this expanded thinking, but with practice, it is possible, and can be profitable for the students. Perhaps the student would ask a question
such as "How do you think this might relate to how vertebrates first emerged onto land?" or "What would be different if Neanderthals had not gone extinct and we had two species of humans today?" The student might need a bit of guidance at the beginning, and the teacher can provide help in the form of exemplar questions for the students, which give them the chance to think in new and different way about the topic. By creating opportunities to think and consider possibilities, the teacher allows students to go beyond what they have learned and extend their learning into new areas.

In a student-driven classroom, the students will have a very strong influence on the sequence of what is learned in class. Even when limited by standards, the students should have quite a bit of leeway in determining what they will be learning and, more importantly, how they will be learning the material. This model is an effective way of allowing students to learn the material, but it must have some flexibility. The students should be able to move from one phase to another as needed. Students who have developed the questions and are exploring the answers may have to go back to the question phase if they discover their questions are inadequate. By the same token, students in the evaluation phase may discover their answer
is inadequate and they must go back to the explore phase to discover more information.

This method must therefore be flexible and have adequate time available for students to accomplish all phases and return to revisit previous phases as needed. The teacher must be ready to assist students at any phase. However, the teacher must also be cognizant of the need for students to discover their own answers. The teacher should therefore not provide answers, but should be ready with leading questions. The teacher should be ready to ask if the student has thought about X or considered Y when doing their research. In this way the teacher can lead the students to discover the answer for themselves, thus reinforcing their own learning.

When evaluating the products, the teacher must be ready to examine many different kinds of products. In student-driven assessments, it is expected that each student will play to his or her own strengths and create a product that will best showcase what he or she can do and what he or she has learned. Determining how well the student has addressed the original issue should be the criterion used to measure the success of the project, not the format the student has chosen. The teacher should encourage students to try new things as they gain
experience with the method, but should be careful about denying a student a particular form of assessment without good reason. With practice, student will create some products that are unexpected by the teacher, and that will show remarkable insight on the part of their creators.
CHAPTER FOUR
USING THE MODEL IN THE CLASSROOM

What are we Currently Seeing in Classrooms with Regards to Evolution Education?

There are a great number of techniques that can be used in the science classroom to teach evolution. Some are inquiry-based, and many others are not. Regardless of which techniques the teacher chooses to use, there are many topics under the umbrella of evolution that students must learn if they are to understand the nature of evolution and its impact to life on earth. In the author's view, the following topics are the most critical:

1. The historical context of evolutionary theory:
   Darwin and the voyage of the Beagle
2. Natural selection as the force behind evolution, including artificial selection as an analog of natural selection
3. Genetics and its role in evolution
4. Fossils and their relationship to evolutionary theory
5. Supporting evidence for evolution
6. Evidence for the age of the earth and universe
7. Evolution as it relates to other topics in biology
Assuming students are skilled in using inquiry and critical thinking, they would be able to begin investigations to test questions related to evolution, either developed by themselves or posed by the teacher. These same skills would allow them to develop working hypotheses, explore possible answers and develop conclusions consistent with the evidence that they discover. A student who studies the evolutionary relationship between different groups of vertebrates may then formulate a tentative hypothesis regarding specific aspects of this relationship.

For example, the students may determine that dinosaurs are significantly different from reptiles and should be considered a separate group. At the same time, the student may determine that birds are close enough to dinosaurs to be included in the same category. More importantly, the students will be able to explain the logic behind the classification decision, and not just that the relationships exist. If the students have not yet developed these skills, careful scaffolding by the teacher will create an environment where the students not only learn about evolution, but also develop skills in critical thinking and inquiry (Etheredge, 2003).
Much depends on what kinds of educational materials the teacher relies upon, and to what extent. There are some materials that encourage inquiry, while others fail to utilize the processes of inquiry or critical thinking. Many people are familiar with the stereotypical teachers who only use worksheets or textbooks. On the other side of the continuum would be the teacher who utilizes inquiry and critical thinking wherever possible, always encouraging students to use advanced skills and techniques. Most teachers fall in-between on this continuum, ranging from those who rely heavily on book- and ditto-work to those who readily and frequently involve inquiry.

While the average science teacher does not solely rely upon the textbook provided by the school district, the textbook often does play an overly-important role in many science classes, both during the evolution unit and others. Reviews of several textbooks that include evolution indicate that the outline of topics shown previously is covered, but the information is presented in a basic manner. The textbooks are strong in some areas, such as basic knowledge, but weaker in the promotion of higher-level thinking. Textbooks published more recently do a better job, generally, than older textbooks when
dealing with higher levels of Bloom's Taxonomy. However, they do not cover them to the extent that is recommended by the National Science Education Standards (NRC, 1996). Most science textbooks today are sold as kits, with pre-made labs, assessments, and other supplemental materials readily available for the classroom teacher. These materials do a fair job of creating critical thinking situations, and a few suggested activities are somewhat inquiry-based, but they are no substitute for a sound-inquiry-based unit designed by the teacher with the specific needs of his or her students in mind. In addition, these books do not cover the relationships between the various subjects of biology in great detail. Relying solely on the textbook would not be advisable, as this cannot promote the deeper understanding that critical thinking and inquiry will produce (Padilla, 2001; Madrazo, 2001; Todd, 2001).

As noted, the evolution sections of these recent textbooks more sufficiently address evolution than many earlier texts. One major improvement is the use of the word "evolution." Many earlier texts ignored this word in place of the less specific, but also less inflammatory phrase "change over time." Newer chapters on evolution tend to be more detailed, carrying more information than
the older books, but they still need to be supplemented by any teacher who wishes to create an inquiry-based science class. Many sections of evolution units are often taught as simple recall of names and dates, and details of discoveries. For example, students might be asked to repeat what Charles Darwin discovered on the Galapagos Islands. The teacher would then expect a litany of names of animals and how they differ from mainland species. In general, the teaching of evolution at the current time is focused on the lower end of Bloom's taxonomy, as is much of science education. While improvements have been made in recent years, there is still a great distance to go before all students experience the high-level science that has been designated as optimal by the AAAS and the NAS (NAS, 1996; Project 2061, 1989; Collins, 2002).

As stated earlier, the current texts do a much better job of including higher-level than do earlier ones, especially in the units on evolution, but they generally include higher-level materials only as an adjunct to the text, rather than something that should be incorporated into the core of the curriculum. Informal conversations with other teachers by the author have indicated that many teachers ignore the non-text portions of the textbook. If they choose to do higher-level activities, they do not
come from the text or the supplemental materials supplied with the text. Many teachers appear to be incorporating little in the way of higher-level materials, and these are used only as occasional add-ons to the curriculum.

Labs are a routine part of science classes, but many labs are not designed to encourage inquiry or critical thinking. In fact, many labs are the antithesis of inquiry, being nothing more than recipe-based activities with little or no doubt as to the outcome. This kind of activity can be used to excite some critical thinking, if the teacher asks leading questions, such as, "How do you explain this outcome?" or, "What would happen if we altered the activity in this manner?" Generally, however, this is not done, and the activity remains low-level (NRC, 2000).

Additionally, the National Research Council (NRC) notes that, despite the widespread availability of supplemental materials from organizations such as Biological Sciences Curriculum Study (BSCS) and the Intermediate Science Curriculum Study (ISCS), many science teachers are still relying upon traditional teaching methodologies such as lecture and notes. Often school supply budgets are insufficient, leaving teachers who want supplemental materials to purchase them using their own
funds. The report does note that improvements are being seen, but that there is still much room for advancement in most classrooms.

An Example Lesson in Evolution, Using the Proposed Model

The model proposed in this project will take planning to properly implement. However, once mastered, it is relatively simple for the teacher to use, and the students will understand what is required of them and be able to do their job with little difficulty. Scaffolding and guidance on the part of the teacher will be required from the outset. Early attempts to use the model should be scaled down until the students gain skills and can be given increasingly challenging tasks. For this example, the author has selected a poster for the students to analyze.

1. Engage

Rudy Zallinger's classic poster of human evolution, made famous by the Time-Life book Early Man, shows fifteen different stages of human evolution, as it was understood in 1966. This picture has become the basis for hundreds of imitators, yet it remains the stereotypical poster of evolution, beginning with the Gibbon-like Pliopithecus, moving through various ape-like animals including Oreopithecus and Ramapithecus, then through the
Australopithecines, Homo erectus, and finally six creatures, all described as various forms of Homo sapiens. This poster should engage students and elicit reactions from them. It is likely that they will naturally move into the second phase. When seeing such examples, students often begin asking the teacher questions immediately. The teacher can tell the students to write these questions in preparation for the second step.

2. Question Generation:

Once the students have been introduced to, and engaged by, the subject, they will begin the question-generation process. This happens naturally, as humans are generally curious and freely ask questions. In this case, the students should begin to create a list of questions. They should not take a lot of time to think in detail about the questions. The goal is to create a large bank of questions to work with later. It does not matter if the questions are scientifically worded or not. Students should feel free to ask whatever questions, related to the topic, that they see fit. There will be time later to evaluate each question and determine whether it should be pursued.

Examples of questions, based on the Zallinger poster, include:
“How tall was Proconsul?”

“How long ago did Proconsul live?”

“How do we know that these were our ancestors?”

“What caused these animals to evolve this way?”

“If monkeys evolved into humans, how come we still have monkeys?”

“Are humans the end of the line, or will we change into something else?”

“If we do evolve into something else, what will it look like?”

“How many teeth did Ramapithecus have?”

“How do the teeth of Ramapithecus compare to human teeth?”

“Did Ramapithecus use its teeth differently than we do?”

“Did all of these have the same diseases we do, or did they have monkey diseases?”

“Did these all live in trees?”

“How can you tell when Oreopithecus turns into Ramapithecus?”

3. Question prioritization

Once the students have developed their questions about the poster, they can now prioritize them. This can be done in many different ways. One method is to have
students work in groups to examine each list and make a master list for their group of the questions they have created. Then, this list can be prioritized. Prioritization can take one of several forms, including easiest-to-hardest, lowest level to highest level, most interesting to most uninteresting, or any other priority form the teacher feels is appropriate to the ability level of the students.

Another option is for the teacher to collect the questions generated by each student group and create a master list. Once the list is created, the teacher can present it to the entire class, along with the criteria for prioritization, and together they can develop the final list of questions. At the same time, students can determine if any question should be eliminated if the students deem it redundant or superfluous. The teacher may also decide, for one reason or another, that a particular question should be eliminated. Ultimately, regardless of the method used, a final, prioritized list is created and all students receive a copy to study.

4. Explore and search:

Having received their questions, the students must decide how to pursue answers. Some questions may be more challenging than others. It might be possible to assign a
group of students a single question or a small number of
related questions to work with. This is particularly
effective if the students are skilled in inquiry and
research methods, and if the questions are sufficiently
high-level enough to stimulate in-depth research. The
students may do library or Internet research to determine
the current state of our scientific understanding and
compare it to our understanding when the poster was
created, four decades ago. They may examine two members of
the lineage and attempt to determine how an intermediate
form might have appeared, or examined the branching that
occurred in the human lineage, rather than the straight
line depicted in the poster. Whatever they choose to do,
it should both reflect the question they are answering,
and the original topic to which their research is related.

As an example of experimental research, unrelated to
the poster example but still in the evolution unit,
students learn about the role of mutation in evolution.
Perhaps some student asks if it is possible to induce
mutations, and what the result would be. After some
research, the students determine that radioactive material
may be a strong mutation-inducer and design an experiment
to grow three groups of Drosophila fruit flies; one group
exposed to a low-level radiation source, such as Cobalt$^{57}$,
another receiving a higher level dose, and the third, a control group with no radiation exposure. The students then grow the flies in these conditions, obtaining results that will help them answer the question that they themselves have posed.

The students should now have information to work with, to determine the answers to the questions they were posed. Students should begin to develop these answers through research or experimentation: It is not necessary to have perfect answers at this point, but the students should have a good working hypothesis, based on the data collected.

5. Explain, Analyze and Connect:

In this phase the students will explain what they have discovered, determine its usefulness or validity and extend their knowledge into other areas, relating what they have learned in this lesson to what they have previously learned in science or another content area. In the case of the Zallinger Poster, the students may take what they have learned about human evolution and extend it into the evolution of other organisms. They may determine how the understanding of the human family tree differed at the time the poster was produced to the present day. They may have to go though the data and determine which data
are authoritative, and which are not. This is especially important if they use unregulated sources, such as the Internet. Students may need assistance from the teacher to make this determination, especially if they are only beginning to use critical thinking.

As for making connections, the students may relate evolution to genetics, or discuss the role of mutation in both evolution and genetics. The connections are virtually limitless, based on the efforts of the students in phase 2. At this point any connection the students attempt to make should be encouraged. As they work through the process it will generally become apparent to the student whether there is enough evidence to make such a connection. At this point students may ask more questions of the teacher, asking how the answers they have developed may relate to other areas. The teacher should encourage the student to save such questions as a starting point for future research.

The final result of this phase is that the students have developed an answer to their initial question or questions, and have evidence to support their conclusions. Students should be aware that they may have to defend their assertions, and evidence and careful reasoning will be needed if anyone should challenge their conclusions.
6. Evaluate and Assess:

In this phase of the process, the students must evaluate their answers and determine how well and completely they have responded to the original questions, and present their findings. There are many ways they may do this. One group of students may choose to write an essay that explains the evidence relating one particular species to another. Another student might deconstruct the poster, creating a new one that explains our current view of human evolution, complete with a branching tree, rather than a lineage, and the evolutionary dead ends of species such as Homo neanderthalensis. Still another student might create a presentation comparing the old ideas of human evolution to the new. Each student would then go back to the questions generated in phase 2 and determine if they addressed the question or questions they have been working with. If they have addressed the question, then they must decide if they have adequately answered it, or if further work is needed to give a sufficient answer.

An important part of the evaluation process is the opportunity for students to assess their own work. This is more than simply assigning a grade. They must critically examine their work and determine how thoroughly and successfully they have answered the questions, and if
there is anything they have left out. Students should create a brief reflection in which they evaluate their work and determine what grade they feel they should earn. Another method that can be used is to have all the students evaluate each other’s work and assign a grade. Each project can be evaluated based on a rubric developed by the teacher, or collaboratively developed by the teacher and students.

7. Expanded Thinking

Although evaluation is generally considered the end of the lesson, in this model, it can be an extension to further learning. Here, having discovered the answer to the questions they were assigned, the students are given the opportunity to relate what they learned to that of the other students and to expand their thinking even farther. This expansion does not need to be limited to the subject at hand. It can go beyond the current unit to include other units the students have learned or will learn. It could even relate to topics not covered in science.

Again, there should be as little restriction as possible to the connections made by the students. Many of these connections may be highly relevant, while others may not seem related. This does not mean the irrelevant connections are without value. Any connection may be
highly fertile grounds for developing future learning. This can be quite successfully done if the students use what they have learned as a start for asking more questions. In the end, the student may make statement-question pairs like:

"I discovered that Raymond Dart, the scientist who studied many Australopithecines, was born in Australia during the reign of Queen Victoria. How did his social background affect his views of Australopithecines?"

"I learned that scientists have determined that early human diets were different from our own. How did this affect the structure of their digestive systems?"

"At one time many species were considered part of Homo sapiens that are now separate species. Why did we change this? Was it because of new discoveries, or did we not like the idea of being the same as these 'primitive' humans?"

"I learned that Homo neanderthalensis had a larger brain than us. Does this mean that the size of the brain is not all that important?"

Many of these questions might be useful later on, if they relate in one way or another to future units in the class. The teacher should make a note to revisit them in
the future at the appropriate time. Even those that are not directly related may be of value, as they can be used as idea starters for the students later on. It is theoretically possible to begin the school year with one lesson that will ultimately lead to and relate in one way or another to every other lesson. This web of learning would be exactly what Project 2061 outlines in *Atlas of Science Literacy* (2001).

The lesson illustrated in this section is just an example of the power of the proposed model. With practice, both teacher and students can master and use it to create powerful learning on the part of the students. It may not be possible, or advisable, to replace all lessons with this model, but including inquiry-based lessons will improve student understanding of the nature and methodology of science, and not just its discoveries.
CHAPTER FIVE

HOW DO WE GET THERE?

The model proposed here is not a wholly-new breakthrough in teaching. It is simply the logical application of the scientific method, inquiry and critical thinking in the science classroom. The method outlined in the model may be different in some respects from other models, but the scientific approach behind the model is nothing new.

Evolution is one of the most contentious issues in science education today. Much of this is due to the fact that the public does not understand the evidence for and nature of evolution. By using critical thinking and inquiry during the evolution unit, the teacher can assist the students in gaining not only an understanding of the evidence behind evolution, but also skills to begin to critically analyze the evidence and understand its strength. Given time and enough dedicated teachers, a change in the American population can come about. When enough citizens understand the nature of science in general, and evolution in particular, the furor surrounding evolution should subside, and evolution will
become just another factual subject taught in the science classroom.

Most science teachers strive to have high-quality programs in their classrooms. Some may have difficulties enacting the program they envision, either because of time constraints, district, state or federal educational mandates or any other number of causes. However, teachers can adapt to these circumstances and make alterations that will benefit the students. It is the author's assertion that the model will provide significant help in teaching evolution to students in the middle grades.

While the lesson demonstrated previously was an evolution lesson and this model was originally designed to emphasize inquiry and critical thinking in the evolution unit, these methods are equally effective in all areas of science education. The teacher will have to adapt the method to each situation. In addition, the teacher will have to provide scaffolding, especially in the early stages. Eventually, if the method is used often, the students will become adept at its use and can build their own lesson, once presented with the engaging activity. Theoretically, the students can become fully independent, designing their own lessons, based on an aspect of the curriculum that engages them personally.
This method will also assist the teacher in achieving the goals set forth in the National Science Education Standards (NRC, 1996). The Changing Emphasis Summary lists current emphases seen in most programs and the new emphases under NSES. The following is an abbreviated version of the list, demonstrating the increased emphasis on inquiry and critical thinking.

Table 1. Changing Emphases for Teaching

<table>
<thead>
<tr>
<th>Less emphasis on...</th>
<th>More emphasis on...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focusing on student acquisition of information</td>
<td>Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes</td>
</tr>
<tr>
<td>Presenting scientific knowledge through lecture, text and demonstration</td>
<td>Guiding students in active and extended scientific inquiry</td>
</tr>
<tr>
<td>Maintaining responsibility and authority</td>
<td>Sharing responsibility for learning with students</td>
</tr>
</tbody>
</table>

Adapted from (NRC, 1996)
Table 2. Changing Emphases for Programs

<table>
<thead>
<tr>
<th>Less emphasis on...</th>
<th>More emphasis on...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textbook- and lecture-driven curriculum</td>
<td>Curriculum that supports the Standards and includes a variety of components, such as laboratories emphasizing inquiry and field trips</td>
</tr>
</tbody>
</table>

Adapted from (NRC, 1996)

Table 3. Changing Emphases for Assessment

<table>
<thead>
<tr>
<th>Less emphasis on...</th>
<th>More emphasis on...</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-of-term assessment by teachers</td>
<td>Students engaged in ongoing assessment of their work and that of others</td>
</tr>
<tr>
<td>Assessing discrete knowledge</td>
<td>Assessing rich, well-structured knowledge</td>
</tr>
</tbody>
</table>

Adapted from (NRC, 1996)
Table 4. Changing Emphases for Contents

<table>
<thead>
<tr>
<th>Less emphasis on...</th>
<th>More emphasis on...</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowing scientific facts and information</td>
<td>Understanding scientific concepts and developing abilities of inquiry</td>
</tr>
<tr>
<td>Activities that demonstrate and verify science content</td>
<td>Activities that investigate science questions</td>
</tr>
<tr>
<td>Investigations confined to one class period</td>
<td>Investigations over extended periods of time</td>
</tr>
</tbody>
</table>

Adapted from (NRC, 1996)

The NSES Changing Emphases are an ideal, showing what teachers should be aspiring to do in their own classes. A class that is conducted using the "more emphasis" side will be more like a scientific research laboratory and less like a classroom. Students will become scientists, investigating scientific questions and creating knowledge for themselves. It does not matter that the knowledge is not new to the scientific community. What matters is that the knowledge is new to the students, and they have discovered it for themselves.

A class like this may be the ideal, and has been written about before, but it is far from the norm in the United States (NRC, 1996, 2000, 2005). Therefore, the question becomes, "How do teachers move from where we currently are to where we should be?" To achieve this, the teacher must analyze his or her program as it currently
exists. Once the teacher has established where the program is, he or she can begin to move toward the ideal. A progress inventory may assist teachers in determining where they lie upon the continuum of progress. An inventory based on the NSES table on the previous pages can provide guidance to the teacher wanting to incorporate the proposed model into his or her classroom.

This inventory is straightforward. The teacher notes the number that represents the current status of the teacher, the students or the program. This will provide a gauge for where the program is currently located, and how far the teacher has to go to achieve the ideal. Once the current status is known to the teacher, he or she can begin to make adjustments to the program that will lead to a more inquiry-based classroom.
Progress Inventory
1= Strongly disagree
2= Disagree
3= Neutral
4= Agree
5= Strongly agree

1. I understand the elements of an inquiry-driven lesson.
   1   2   3   4   5

2. I routinely use inquiry-based lesson with my students
   1   2   3   4   5

3. My students understand what is required of them in inquiry-based lessons.
   1   2   3   4   5

4. I routinely discuss the elements of inquiry with my students.
   1   2   3   4   5

5. I understand the principals of critical thinking.
   1   2   3   4   5

6. I routinely provide opportunities for students to use critical thinking skills.
   1   2   3   4   5

7. I routinely discuss the elements of critical thinking with my students.
   1   2   3   4   5
8. My students understand what is required of them in critical thinking situations.

9. I encourage students to discuss new ideas among themselves and with me.

10. I encourage students to “think like scientists.”

11. I routinely create situations for student-driven learning and discovery.

12. I understand the significance of the scientific method.

13. My students understand the significance of the scientific method.


15. I routinely examine my program and look for ways to improve it.
16. I feel confident in my level of understanding of the science supporting evolution.
1 2 3 4 5

17. I feel confident in my teaching of evolution.
1 2 3 4 5

18. When teaching evolution, I routinely provide high-quality lessons which includes inquiry and critical thinking.
1 2 3 4 5

Any teacher who has decided to make the change to an inquiry-based classroom will have to make deliberate changes to his or her program. This will require time and effort on the part of the teacher. How the teacher proceeds will be based upon his or her perception of the distance from the "ideal" program as well as the individual situation in which he or she is placed.

This survey was given informally to the science teachers at the author's school. The results indicate that many teachers feel ready to teach inquiry-based units, but have not yet implemented them. They indicated that they use inquiry from time to time, but not as regularly as they feel they should. While it varies from teacher to teacher, and from GATE to Special Education, the teachers generally feel their student need greater understanding of
inquiry, critical thinking and evolution. Implementing this model may help in all these areas.

Some teachers may find that their district or state has created a situation that makes shifting to an inquiry-based system difficult. Scripted programs are becoming increasingly common, particularly in elementary schools for language arts and math. The same may be occurring in some districts for science programs. Other teachers may encounter roadblocks in their state standards, or the requirements placed upon them by administrators who are attempting to adhere to the No Child Left Behind Act. Still others may encounter trouble from pacing requirements that limit time spent on the evolution unit. Finally, the misperceptions of the general public toward evolution adds constraint to many science teachers. In addition to these external difficulties, individual classes may also prove challenging. Students with discipline problems can interfere with the plans of the teacher, making the transition to an inquiry-based classroom a challenge.

Regardless of the problems faced by the teacher, it should be possible for him or her to make at least some progress toward creating an inquiry-based class. It may involve efforts to change the minds of colleagues, school
or district administration. Once the teacher begins the change process with a single lesson, his or her confidence should increase. From that point it should become easier to make the same transition in other lessons and in other units of the curriculum. Given adequate time and resources, it should be possible to transition from a traditional classroom to an inquiry-based room where students engage in student-driven research and critical thinking.

The teacher will have to begin slowly. A lesson designed to use the proposed model, but set up to be somewhat limited in scope would be a good starting point. Incorporating the model into the existing program would be effective and less frustrating to the students than attempting to scrap the old program entirely and begin anew. Slowly incorporating new inquiry-based lessons will also give the teacher a chance to analyze the progress of the students and the efficacy of the new lesson. This will allow the teacher time to make adjustments to planned lessons and assist with scaffolding the students as needed.

The proposed model does not only apply to evolution education, but can be used on other units, and can also be used by the teacher to develop those units. The
modification process for many teachers may be slow and difficult. Some attempts may be unsuccessful. However, if the teacher applies the model to his or her own process of lesson development, he or she should be able to determine which processes work best, and which need to be modified.

It is hoped that the science teacher studying this model will be able to use it to improve his or her own science program, creating a generation of students who can think critically, ask questions, analyze information, defend findings, and use inquiry as a regular part of their lives. This is science at its purest. When this occurs consistently in the classroom, students will be far better prepared for further study into the nature of science and how it affects their lives.
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