UNDERSTANDING EVOLUTION:

INFLUENCES ON THE TEACHING AND STUDENT UNDERSTANDING OF EVOLUTIONARY CONCEPTS

by

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I dedicate this review to all teachers who struggle with the question of whether to teach or not to teach evolution.

Abstract

This paper reviewed 30 qualititative research articles on the effects of science teacher beliefs and understanding of biological evolution on the teaching of evolutionary concepts and student understanding. Its goal was to explore the various factors that may play a role in how evolution is taught in high school biology or science classes. Chapter Two provides some background about the conflict between biological evolution and creationism as taught by Christianity. Chapter Three reviews research focused on several factors. It was found that most teachers currently cover evolution in their science or biology course but to a minimal extent and some teach creationism alongside evolution as an alternative explanation to the origins of life. Some practices such as using inquiry-based learning and higher-level questioning along with teaching about the nature of science and using examples show that students have a greater understanding of evolution. Teachers' personal beliefs and understanding of the nature of science and evolution also determines the extent to which evolution is taught in their classroom. Students' prior knowledge also plays a role in their own motivation to learn about evolutionary concepts. Other factors that may affect the teaching and learning of evolution is how well teachers are able to implement innovative learning practices taught in professional development lessons that include using inquiry based-learning and higher-level questioning along with how well textbooks present evolution. More studies should be done that involve specific practices that are oriented towards high school teachers and students. Chapter Four suggests practices that may improve student understanding of evolutionary

concepts and what factors affect the propensity for the teaching of evolution in high school. These practices can improve student understanding of evolution and if studied based upon high school students' understanding, may shed more light on ways to constructively teach the importance of understanding evolution.

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Chapter One: Introduction

Introduction

In a nation that recently has put more emphasis upon standardized testing especially in science, it is increasingly important to look at what factors affect students' understanding of various science concepts, more specifically, evolution a culturally controversial topic. Because the National Science Teachers Association (2003) believes that evolution is an important concept in biology and a major unifying piece of science, evolution is used to link various science topics together and applicable to all sciences. Students who have a strong understanding of evolutionary concepts can use that knowledge in other areas of science and may have an academic advantage over students who do not possess the same understanding (Scott, 2005). Unfortunately, poor teaching strategies are not the only obstacle teachers and students face when learning about evolution. Teachers and students are pitted against religious beliefs and values that may not agree with the teaching of evolution in a school that requires the understanding of evolution for testing purposes and success in higher level science courses. Because of the significance of evolution to science in an age where technology and medicine is more present than ever, it is important to look at what factors affect how a teacher teaches evolution and how evolution can be successfully presented and taught to students from various cultural and religious affiliations.

Rationale

The teaching of evolution has historically been very controversial. The theory of evolution conflicts most with conservative Christian religious beliefs on the origins of life and can contradict some of the most basic human instincts and assumptions about our origins and place among other organisms on this earth. Understanding what the reviewed literature says about how students learn evolutionary concepts and what personal factors affect the probability for teaching evolution is important for teachers to take into consideration when teaching such a controversial topic. The knowledge gained from this study can be carried over into other academic areas where prior knowledge and beliefs directly interfere with the concepts taught. It is important to challenge students' prior knowledge and create a safe space for students to question, test, and examine their beliefs, and provide them with enough evidence for them to create their own conclusion without forcing them to believe in something they wish not to.

Definition of Key Terms

Biology is the study of living organisms. Evolution is a part of biology that explains the origins of all living organisms and purports that they are all descended from a common ancestor that may have lived more than 4 million years ago. The first living organisms were single-celled bacteria. Through evolution, organisms adapt and change genetically through small genetic mutations and those who are more fit will survive and pass their traits on to their

progeny. Organisms usually evolve and change because of a change in environment. Evolution is frequently described as descent with modification.

Evolution is a scientific theory. A scientific theory must have the following characteristics: it is guided by natural law, it must be explained by reference to natural law, it is testable against the empirical world, its conclusions are tentative, and it is falsifiable (Scott, 2005). Theories are the most important and tested scientific explanations. The theory of evolution meets all of these criteria.

The Christian fundamentalist belief of creationism explains how the earth and all its living things came to be. Creationism states that God created the Earth and its organisms in about 4004 B.C. in six days. People who believe in this fundamentalist view of creationism may believe that dinosaurs and people once lived together side-by-side. There are different levels to which Christian fundamentalists may accept Creationism, Young Earth Creationists and Old Earth Creationists are the most common along side those who believe in Intelligent Design.

Young Earth Creationists typically reject modern physics, astronomy, chemistry, and geology when it concerns the age of the Earth and do not accept biological decent with modification (Scott, 2005). They adhere to the literal interpretation of the bible in that the Earth is only 6,000-10,000 years old and all organisms essentially appeared in their present form.

Old Earth Creationists typically accept the idea that the Earth is ancient based on scientific evidence but still believe that God is the reason for all

observed biological changes and created all organisms as they appear in their present form (Scott, 2005).

To oppose evolutionary theory, some fundamentalist sects of Christianity use Intelligent Design. It states that there are irreducibly complex parts of life that are too complex to have evolved so they must have been created in full form by some sort of unnamed intelligent being such as God (Discovery Institute, 2008). Some groups believe that Intelligent Design should be taught along side evolution since it does not use the name of God or any religious organization (Humes, 2007).

The Political Context

In the United States, biology is typically taught for a complete year in high school grades 9, 10, or 11. It covers such topics but is not limited to cell biology, reproduction, genetics, DNA, ecology, and evolution (OSPI, 2008). Many states teach integrated science in lower grades, which may briefly introduce biological concepts to students to be reexamined at length in a biology course. Many teachers are required to teach certain topics and adhere to a standard curriculum due to state testing standards that cover specific concepts and topics to a specified level of understanding.

Evolution questions are common in many state standardized tests. It is advantageous for students to understand evolution and how scientists came to call evolution a scientific theory. These concepts are widely used in college science courses and are crucial for students who want to pursue careers in medicine or biological science especially in the study of emerging diseases.

However, some students or their parents may discourage the teaching of evolution because they find it offensive and conflicting with the teachings of their religion and a negative influence. This makes science concepts based around evolution difficult and controversial. A public school does not serve to tell a student what religious values to believe or not to believe but it is important for parents and students to understand why evolution is an important concept and what science research has achieved based on these concepts.

Creationist beliefs cannot be taught in public schools in the United States because it would infringe on students' rights as outlined in the First Amendment. Parents reserve the right to guide their children's religious views and since attendance in public schools is mandatory, courts have restricted teachers from proselytizing students (Scott, 2005). Strict Christian Young Earth Creation beliefs state the Earth is only about 6,000 years old and that the Earth was created in 6 days. Currently 46% of Americans believe in strict Creationism despite the scientific evidence to support evolution (Gallup, 2006).

Biology teachers may also be subject to Creation beliefs regardless of having an advanced science education with courses focused around evolution (Deckard, 1997). Many have their own reservations about teaching evolution because it does not parallel what the Bible says. Sometimes teachers' religious beliefs obstruct a fair or complete representation and teaching of the theory of evolution in their own classrooms (Chuang, 2003). Each state is responsible for their own teaching standards and some states do not require the teaching of biological diversity and the origins of the universe; sometimes leaving it up to the

teacher's discretion (Scott, 2005). Due to increasingly strict content demands, states that do not require the teaching of evolution may be more inclined to allow teachers to skip over this topic. Either way, this important biological concept is not fairly represented for students to create an understanding about the origins of life through the scientific theory of evolution. It is very difficult to separate the controversy from the importance of knowledge.

In America, Conservative Christians typically have conflict with evolution and disprove of the teaching of evolution in public classrooms (Humes, 2007). Christian beliefs about the origins of life are told in the Old Testament, Book of Genesis, and express that the Earth was created in 4004 BC and that all animals, plants, and humans were created in full form over the course of seven days.

Scientific study and theory believes that the Earth is about 4.55 billion years old with life forming in the water about 3.5 billion years ago as microscopic heterotrophes that consumed organic material from reactions happening inside the Earth, with humans first appearing only about 2 million years ago (Scott, 2005). Science believes these dates based on carbon dating of rocks and fossils. This scientific belief does not correlate with the beliefs as written in the Book of Genesis. At a closer look, evolution, the process by which all living things developed from more primitive organisms through changes occurring over billions of years since the first sign of life, shows the possibility to trace all living organisms back to their most primitive and common ancestor.

Biology teachers may find this subject difficult to teach and very controversial because it may not fit into some student's current views or beliefs about how the earth and life has formed. Students enter each classroom with preconceived ideas and images about how certain things in the world work (Zull, 2002). Many students have only been exposed to the origins idea of creationism as described by a Christian faith, before they enter high school biology, as opposed to evolution (Webb, 1994). Teachers of biology have been called "Godless" or "amoral" because they teach a topic that does not fit into the Christian faith (Humes, 2007). Over a century of conflict has fed the debate between evolution and creation with teachers taking on a responsibility to teach correct science and to not make judgments about their students' personal values or religion.

Various religious faiths have attempted to allow the teaching of creationism in public schools alongside evolution or as an alternative to evolution. Most attempts at incorporating creationism have failed because it violates student's rights in the First Amendment of the United States Constitution. In this amendment, the Establishment Clause prohibits the organizing of a national religion by Congress and/or the preference of one religion over another or the support of a religious idea with no identifiable secular purpose. Since public schools are supported and funded by the government, religious ideas cannot be taught to students. Evolution is not a secular religious belief but based in scientific theory and research where a majority of scientists find it to be a plausible scientific explanation for the origin of life (Scott, 2005).

Many people in the United States value religion. Religion can instill values and encourage moral behavior, provide answers about uncertainties, and offer the promise of something after life (Scott, 2005). Certain religious communities blame the theory of evolution for steering people away from moral behavior. Some religious authorities blame crime and unethical behavior on the teaching of evolution because they see it as a large proponent and reason for people to not trust or believe in creationism and Christian religion, and presently a cultural war wages between America's religious faith and the rationality of scientific progress.

Many students enter a biology class with some exposure to and ideas about the origins of life. Whether the knowledge that the student has is scientific or non-science based, when teachers interact with students they need to know that the student already has some engrained knowledge about how the world works (Zull, 2002). Whether about evolution or how the sun gives off light, students have already formed ideas about subjects based on other experiences they have had either in or out of class, what a parent or friend has told them, what they have seen on television, or even what they have heard or read about in church. Jensen (2005) and Zull described the connections that the brain makes to different pieces of information and how that information is stored and used. In their descriptions, they propose that if information presented by the teacher does not fit the student's current view of that topic, they can loose motivation to learn more about that topic. If it directly conflicts with strongly held beliefs the student may chose to not to actively engage their brain or may

become angry with the teacher for presenting conflicting information that they believe to be wrong.

As a religious belief, the information students already have is very strong and engrained because they have been taught that to believe anything different than what their religion may tell them, is to condemn themselves to misery or sin (Sinclair & Pendarvis, 1998). This one major reason has caused the conflict between religion and evolution to continue so strongly and why 46% of Americans only accept creationism as explained in the Book of Genesis as opposed to evolution (Gallup, 2006). When a teacher challenges these strongly held beliefs, it can frighten and challenge the adolescent student when confronting their life inside and outside of school.

Some teachers believe that if they can teach evolution well enough and provide the students with tangible and reasonable examples, that every student will learn, understand, and accept evolution and its concepts despite previous beliefs or knowledge but this does not happen in classrooms across America. High school textbooks have taught evolution regularly for the past 25 years. A survey of views about evolution (Gallup, 2006) showed that in 1982 approximately 44% of Americans believed in creationism and 47% supported evolution. Another survey on evolution 24 years later (Gallup, 2006) showed that 46% of Americans believed in creationism and 43% supported evolution. If teachers successfully taught students to understand and accept evolution, then the American's who believe in evolution should increase and creationism should decrease. These results reveal little change between polls and reveal instead

that even after instruction about evolution students retained their nonscientific beliefs about the origins of organisms and the Earth.

Education in America started with religious and creationist teachings. Spring (2008) explained that many schools in colonial America were created for children to learn how to read in order to follow the teachings of the Bible and obey the government. Currently, Christian fundamentalists use the term Intelligent Design to wedge creationism into schools and teach as an alternative to evolution. The creation versus evolution war in school continues to this day with the increased teaching of evolution showing little to no effect upon the acceptance of this scientific theory.

Statement of Purpose

All students deserve access to information and an equal opportunity to understand concepts that may be on standardized tests that could affect their future education. Although a controversial subject, the evolution controversy has persisted over several years without compromise from either side. This paper will explore the effects of teachers' attitudes and approach towards nonscientific beliefs such as creationism and other factors along with student preconceptions, on student understanding and acceptance of biological evolution. The research reviewed provides explanation to assist in the teaching of evolution in order for a more complete, fair, and balanced understanding. Teachers might be able to provide a better explanation and teaching of evolution that may interfere less with students' personal and religious beliefs for a broader understanding of scientific concepts for educational purposes.

Limitations

To keep this paper relevant to future teaching practices, this paper uses articles from research on both high school and college students because the research base was fairly limited. Not all of the articles reviewed were unbiased. It was difficult to find articles that specifically relate to evolution practices at a high school level but many studies using college biology courses could translate over to a high school biology class with some alterations. One limitation showed that some college courses used and studied many different creation beliefs to compare to evolution and build a strong background about the various beliefs on origins of life. At a high school level, some may view an in depth study of other creation beliefs as a form of proselytizing. This paper will identify the factors that affect how students learn about evolution but will not mention factors that effect how strongly students hold onto their religious beliefs. The goal of this paper is to not force students to question their religious beliefs but to show ways in which all students can understand evolution and its importance to science regardless of the factors that may inhibit their desire to learn about or accept evolution.

Summary

This chapter explained the topic of evolutionary biology that is usually taught in 9, 10, or 11th grade. It is a controversial subject to teach because the theory that states that all organisms descended from a common ancestor possibly a single-celled bacterium about 3.5 billion years ago. Many fundamental sects of Christianity believe in Creationism that claims God created the Earth and all its organisms only 6,000 years ago. These two very contrasting views about

the origins of life create emotional and psychological controversy for some. According to a 2006 Gallup poll, 46% of Americans believe in Creationism and reject the scientific theory of evolution.

The teaching of evolution in the classroom caused problems because it is a strongly held and tested scientific theory but about half of all students going to public schools came from families who do not accept evolution as the origins of life. Some parents believed that if evolution is taught in schools so should creation. Due to the Establishment Clause of the First Amendment schools cannot teach or promote any religious ideas including creation. Some parents and religious groups have tried to use Intelligent Design to oppose evolution in schools but it has been found unconstitutional because it stems from a religious base.

Evolution is an important concept because it is used in many college science courses and in many occupations in the science field. Many state high school science tests contain questions about evolution and students who do not receive a fair teaching of evolution may be at a disadvantage. Some states do not require the teaching of evolution and due to increasing content demands teachers may chose to not teach evolution. The Gallup poll (2006) showed that the teaching practices of evolution today were not affecting current beliefs about the creation of life on earth. Some teachers believe that if they teach evolution well enough and with many tangible examples that all students will understand and accept evolution.

This paper will explore the effects of teachers' attitudes and approach towards non scientific beliefs, such as creationism, and other factors, on student understanding and acceptance of biological evolution.

Chapter Two: Historical Background

Introduction

Religious beliefs have conflicted with scientific findings for hundreds, possibly even thousands of years. Without the aid of the scientific method and tools to make scientific observations and inferences various religions held beliefs to explain some of life's phenomena. Many religions had written laws of the natural world based upon simple observations of what they saw and what they wanted to followers to believe (Humes, 2007). Although most religious natural laws have been tested and turned into theories of science or proven inaccurate, today, several religions still have specific explanations for the origins of life and the Earth, the purpose of life, and what happens after life. Most religious proclamations cannot explain research performed by scientists, and the origins of life specifically evolution, has been one of the most widely controversial of all scientific discoveries that challenge some religious beliefs. This paper has limited discussion to the teaching factors that affect student understanding and acceptance of evolution and poses the question: How do teachers' attitudes and approaches toward nonscientific beliefs such as creationism and other factors effect student understanding and acceptance of biological evolution?

Chapter One introduced the importance of science in the present world and how various scientific groups believe that evolution plays an significant roll in many scientific fields. Evolution and creationism has conflicted for many years and schools still struggle to teach or not to teach this controversial topic that science experts find a central and unifying concept in science.

This chapter reviews the historical timeline of the science and religion controversy starting in Europe in the 1500s with scientific observations about heliocentrism to the present in the United States. It addresses how certain religions have accepted or dealt with various scientific theories and how public schools in the United States have managed the evolution-creation controversy in the classroom and through legal battle in the 1900s to the present.

Beginning of the Religious and Science Controversy in Europe

Controversy between religion and certain scientific beliefs have existed even before 1514 when Nicolaus Copernicus a Polish astronomer hypothesized about heliocentrism—belief that all of the planets including the Earth revolve around the sun. Before this hypothesis, Roman Catholics mainly held the belief that everything revolved around the Earth because Earth was the center of the universe. The theory of heliocentrism opposed the Holy Scripture and Copernicus' was censured in many countries.

In 1610 Galileo Galilei an Italian physicist, mathematician, and astronomer, built upon Copernicus' hypothesis of heliocentrism. The Roman Catholic Church received his ideas similarly to Copernicus'. Heliocentrism was one of the most influential scientific discoveries of the time and it had a major effect on the Catholic Church because it opposed the idea that the Earth was the center of the universe (Ruse, 2005). Before Copernicus, the Catholic Church believed that all the stars and sun revolved around the Earth. Heliocentrism caused followers to truly question this strongly held belief.

Early European Christian views saw the Earth and its organisms as stable and unchanging where the age of the Earth did not matter because everything had been the same since the beginning of time (Scott, 2005). As societies changed and grew the advent of new technology such as the microscope in the early 1600s with the discovery of microorganisms, people began to make more observations that conflicted with previous beliefs of a stable and unchanging world. Through various new tools that Europeans could gain knowledge about the natural world, and through travel, discoveries of land features, animals, and plants that were not mentioned in the Bible created conflict and questioning. Fossils of large animals were discovered that no longer existed that were unexplained in the Bible and did not fit into the story that the Earth has remained unchanged since its creation showing that the Bible did not contain all knowledge (Scott, 2005).

Religion, Darwin, and the Origin of Species

Over the course of history, religious beliefs have been repeatedly questioned as new scientific theories arose and were tested. The main controversy that is still contested today is that of evolutionary theory. Historically, evolution has searched for "what happened" and religious creationism has searched for "who done it" (Scott, 2005). In 1859 Charles Darwin, a respected English scholar and naturalist published a book titled *On the Origin of Species* which hypothesized that populations evolve over the course of generations through a process called he called "natural selection." Darwin created the hypothesis of evolution by studying birds on isolated islands of the Galapagos.

He noted that there were many different birds that appeared to be of different species because of their different beak sizes. Some birds looked like warblers while others looked like woodpeckers. He noted that the distribution of the birds varied depending on the types and size of the seeds available on the island. Larger beaked birds ate larger seeds and smaller beaked birds ate smaller seeds.

Darwin collected animals and plant life that he found on these islands and brought them back to England where he showed the birds to an ornithologist who studied birds. He was very surprised to find that all of the birds he collected from the islands were finches. As Darwin studied his written observations of the birds he wondered why he found so many different looking finches in one area and he hypothesized that these birds compete with limited resources on the islands such as food and that birds with slightly larger beaks may have an advantage on an island where the seeds are larger. The birds with the larger beaks are more likely to survive and reproduce since they have access to those larger seeds; in comparison to birds with smaller beaks who may not survive because they are unable to get to the larger seeds as well as the larger-beaked birds. Over time, the population of the birds on the island will have larger beaks than the previous populations because the larger beaked birds are surviving more than the smaller beaked birds.

Again, this scientific theory conflicted very strongly with Christian beliefs. The idea that species could change over time was not what was written in the Bible. The Bible states that the Earth and all plants, animals, and humans were

created fully formed in six days with no mention in the Bible that species evolved or changed over time but Darwin recognized that it was very possible that there was a common ancestry for every living organism on the planet. The Christian religion became concerned at the implications of this theory because it opposed the teachings of the Bible and could cause people to question the religious teachings of Christianity. Darwin's hypotheses were controversial during his lifetime and he was aware of the tension between Christianity and his new discoveries.

The United States Constitution and the First Amendment

Spring (2008) pointed out that the original schools in America were deeply intertwined with religion and faith along with the skills of reading and writing. Eventually public schools prohibited proselytizing and teacher/faculty-lead prayer due to the First Amendment of the Constitution which mandates the separation of church and state and that the government will not create a national religion or overtly support one religion over another. This includes public schools, where required teacher or faculty lead daily prayer has been ruled unconstitutional as a violation of students' rights.

Although Darwin wrote *The Origin of Species* in 1859, evolution was absent from American schools for most of the first half of the twentieth century. Scott (2005) purported the reason for a lack of evolution in schools was due to the decentralized educational system in America. As an establishing country, America constantly grew and moved. Frontier communities were in charge of setting up their own school systems along with hiring teachers and deciding what

should be taught to their children. Even today the federal government does not have as much control over local schools as the state and local school district have. School boards are made up of members of the community who typically express their religious and moral values that they wish to see passed down to students in their school and community and typically since the teaching evolution does not play a religious or moral roll for various community members, it did not enter the curriculum or was fought against.

The Scopes Monkey Trial

The famous Scopes Monkey Trial of 1925 as depicted in the 1960s movie *Inherit the Wind* (Kramer, 1960), showed the impact of one teacher's introduction of the scientific theory of evolution and common ancestry to a classroom at a time when evolution was not accepted by the state because of the controversy it caused with local religions. The Tennessee teacher John Scopes violated a law called the Butler Act, which stated that in any state-funded school, the teaching of any theory that opposed the story of Divine Creation as told by the Bible, was forbidden. The courts found the teacher guilty of a misdemeanor and fined $100. The Butler Act remained until 1967 when it was repealed after a teacher argued that it violated his First Amendment rights to freedom of speech (Humes, 2007).

Many religious groups have argued that evolution supports atheists and immoral and irrational values. Religious groups claim to support moral values and prove that there is a higher purpose for man. When evolution entered the picture, the notion of a higher purpose and that "man's ascendance was nothing more than a happy accident," (Humes, 2007) frightened churches and religious

groups who believed in this higher purpose. They believed that man was not just another organism working to survive to reproduce like all of the other organisms on this planet but had a larger purpose as told in the Bible.

Organized religion serves many people in the United States. A 2006 Gallup Poll showed that 40% of Americans attend some sort of religious service on a regular basis. The same Gallup Poll showed that 46% of Americans believe in creationism as the explanation of how the earth and its organisms came to be. It also revealed that only 43% of Americans accept the scientific theory of evolution as the primary explanation of how living organisms, including humans, came to be.

Biology teachers who may be required to teach evolution to America's children should be aware of possible pre-existing beliefs about the origins of the Earth and its organisms. Treating the scientific theory of evolution as the only true answer to how life formed on Earth may not be an effect way to teach students who have previously learned that God created the Earth, animals, plants, and man in six days only 6000-10000 years ago.

Dover, Pennsylvania and Intelligent Design

The trials and controversy of evolution and religion in the classroom are still evident in courtrooms around America. In 2004 in the town of Dover, Pennsylvania, parents and school board officials went to court about an alternative teaching to evolution called Intelligent Design. Some of the school board officials wanted to bring morals and values back to the schools through adherence to religious beliefs (Humes, 2007). The main proposal of change was

for the teaching of evolution. One school board official stated that they wanted creationism taught along side evolution but the board realized this that this would not happen due to the First Amendment of the Constitution.

A large religious based conservative think tank in Seattle, Washington known as the Discovery Institute developed a more acceptable and less secular explanation of creationism called Intelligent Design. This explanation states that certain features of the universe and living organisms are best explained by stating that there was some sort of "designer" that created these structures with a purpose rather than an undirected process of natural selection (Discovery Institute, 2008). The scientific community criticized the Intelligent Design theory because the supporters of the theory called it a "scientific theory" that had equal standing to the way that evolution is a scientific theory implying that it is based on scientific data. Parents of several students in Dover became angry because although Intelligent Design never states anything about God or creationism, they saw it as just another form of creationism that was being taught to students in public government funded school that violated the students' First Amendment rights (Humes, 2007).

Humes (2007) stated that in the courtroom, the parents had to prove to the judge that Intelligent Design was not a scientific theory and that bringing Intelligent Design into the classroom was a religiously motivated action by the current school board members. Scientific theory requires a mathematical or logical explanation, or a model testable through the interaction of natural occurrences and able to predict future events of the same kind. It must be

testable through experimentation and is capable of being falsified through observation. Scientific theories are always tentative and are subject to corrections or to include a wider theory and they can be tested over and over through scientific experimentation and will remain a theory until an experiment contradicts the theory.

Darwin's theory of natural selection formed the foundation for the theory of evolution. Science has studied and built upon Darwin's findings through revision and addition to previous evidence. In all the experimentation done since Darwin's *On the Origin of Species*, the theory of evolution has never been found to be false. Some hypotheses based on evolutionary theory proved false but in those findings more evidence to support evolution was discovered that was not explained before (Humes, 2007). Supporters of Intelligent Design claimed that it was a scientific theory even though a higher being or "designer" of some sorts that has not yet been seen. In science, if something is not observable, it cannot be tested which was a major pitfall for the supporters of Intelligent Design who still claim that Intelligent Design falls under a scientific theory even after members of the scientific community claimed that Intelligent Design was not science.

During the Dover trial, a lawyer for the prosecution requested copies of the drafts of the Intelligent Design book titled *Of Pandas and People* in order to research the defense's claim that Intelligent Design was not based off of creationism. After examination of the first draft of the book the lawyers found

direct statements where “Intelligent Design” was added to replace the word “Creationism” in the final draft (Humes, 2007).

In court, the argument for the defense of Intelligent Design in school science did not succeed and the judge ruled in favor of the Dover parents fighting to keep creationism and Intelligent Design out of the school. Although this is a recently documented case and widely publicized, arguments such as this happen yearly in some schools (Humes, 2007 & Scott, 2005).

Teaching Evolution Today

Science teachers have struggled to teach evolution and provide students with the knowledge base that they need for state testing and to understand how evolution fits into medicine and other science fields. In some states where evolution is not covered in standardized tests, teachers skip over the chapter of evolution in the textbook and avoid the controversy it may cause (Scott, 2005). Teachers make these decisions that may effect whether or not a student receives an education that is equal and will prepare them for success in future careers. Most college level biology courses teach evolution along with many other science courses because it is such as central part of biology and science. Students that have the pre-exposure to evolution in high school could have a better understanding and be able to advance more than students who had not (Scott, 2005). Science careers especially those based around biology may be less accessible to students without equal exposure to evolution in high school.

When faced with the controversy of parents asking for “fairness” for the balanced teaching approach of evolution and creationism, some teachers will

allow the equal time although against laws and the First Amendment, and some teachers will completely skip evolution to avoid having this battle with parents and students. The quality with which textbooks cover evolution varies and many come with disclaimers about evolution stating that "it is only a theory not a proven fact" (Scott, 2005). The "fairness" to teach creationism alongside evolution has the potential to create more problems than it solves, because not everyone in the United States or in a public classroom has Christian beliefs. Although the dominant culture may be Christian, it would not be fair to expect students from other faiths to learn about and be tested on the beliefs of another religion when their own would have no representation (Scott, 2005).

Summary

Science has had many conflicts with religious groups for hundreds of years starting with Copernicus and Galileo's hypothesis of heliocentrism. In more recent years including today, conservative Christian groups have opposed any teaching of evolution because it conflicts with their belief in Creationism. These religious groups believe that since evolution is only a theory that it cannot be taught as fact and that other theories about the origins of life must be taught in school too. The First Amendment of the Constitution does not allow for the teaching of religious ideas in a public school and has created controversies such as the Scopes monkey trial and in Dover, Pennsylvania. Public school teachers struggle with the responsibility to teach students knowledge that will assist them in their future lives and with religious beliefs of their own or their community. The

struggle to find a balance of the acceptance of evolution and religious values continues all across America.

Chapter Three reviews the literature that examines the factors that affect student understanding and acceptance of biological evolution within the public school.

Chapter Three: Critical Review of the Literature

Introduction

How does the professional literature in science education discuss the factors that affect student acceptance and understanding of biological evolution? Chapters One and Two discussed societal, cultural, and educational issues that have historically influenced student acceptance and understanding of biological evolution. Chapter One concluded that science has encountered many disagreements with several religions and science education has battled with the religious controversy surrounding the teaching of evolution since Charles Darwin published his book *On the Origin of Species* in 1859. Chapter Two outlined how the evolution controversy has played out in American schools and why it continues today.

Chapter Three reviews articles that examine the educational context and the factors that influence the teaching of and student understanding of biological evolution. The teaching of evolution is affected by a number of factors including, teachers' religious beliefs, student religious beliefs, teacher understanding of evolution and the nature of science, misconceptions held by students and teachers, state teaching standards, legal issues, and perceived level of difficulty.

These studies are organized into five major sections. Section one discusses the current evolution teaching practices of biology teachers. Section two reviews innovative teaching practices toward the teaching of evolution and their effects on student understanding of evolution. Section three outlines teachers' personal beliefs and how they affect their teaching practices around

evolution. Section four takes into account students' prior knowledge about evolution and the origins of life and how it affects their learning, understanding, and acceptance of evolutionary biology. Section five discusses other factors that influence how evolution is taught in public high school biology classes including state standards, laws, professional development, and stress. In general, all the studies found evidence that personal beliefs played a major roll in attitudes about the teaching of evolution.

Current Teaching Practices

This section reviews studies that have identified how current high school biology teachers teach evolution and evolution related concepts. These practices are currently in use and showed that not all teachers use the same methods or devote the same amount of curriculum time to evolutionary concepts.

Moore (2007) conducted a quantitative survey of 1441 undergraduate students who attended the Twin Cities campus of the University of Minnesota taking a large introductory biology course to determine what students have been taught about evolution in public and private high school biology courses. Moore was interested in what percentages of teachers teach evolution, creationism, both evolution and creationism, do not teach either, and to compare the teaching of evolution in public and private high schools.

Male and females were represented approximately equal, and the ethnic diversity was 53% Caucasian, 19% African American, 2% American Indian, 19% Asian American, 4% Hispanic, and 3% undeclared.

The survey was administered at the beginning of the first class of the semester and was anonymous, voluntary, and had no impact upon student grades. The findings of the survey showed that 95% attended public high schools and most were taught evolution and not creationism (54%). The 5% that attended private high schools, 90% were associated with religious organizations and were mostly taught both evolution and creationism (51%) and 34% were only taught evolution. In public high school when creationism was taught, teachers presented it as a scientific alternative to evolution and in private schools it was mainly taught as an idea “equal” to evolution. The most commonly creation story for both public and private high school biology was the Judeo-Christian story. It is fair to say that most high school biology teachers teach evolution as mandated by the state educational standards of Minnesota but many still teach creationism or do not teach evolution at all.

Strengths of this study include the large population size for this survey and in the reliability of the study to produce similar results from students over different semesters. The demographics of the students reported a strong diversity fairly representative of the overall ethnic population in the United States. The research results are comparable to other similar studies along with teacher self-reported studies of the teaching of evolution.

This study has three weaknesses starting with the lack of statistical analysis of the data. The second weakness stems from the research sample coming from the same university that may not be truly a random sample. Some students in the study also attended the same high school and may have reported

the same results. Students may also not be able to accurately recall their high school biology experience or may not understand creationism to the extent warranted by the questions asked in the study affecting the mortality of the research conclusions. Due to the fact that this study did not include a random sample of a larger population, it may not be generalized.

While Moore's (2007) first study sought to identify the percentage of public and private high school biology teachers that teach evolution, creationism, both evolution and creationism, or neither evolution or creationism, Moore's (2008) following study was to determine what creation stories are taught if teachers do teach creationism in their public high school biology class.

Moore (2008) conducted a quantitative research survey on freshman college students to identify what versions of creationism public high school biology teachers teach and how they present it to students. This study comes from knowing that about 15-30% of high school biology teachers teach creationism (Moore, 2008).

Participants in this study were freshmen attending the Twin Cities campus of the University of Minnesota in a large non-majors introductory biology course. They came from throughout the United States, particularly from Minnesota. Participation in the survey was voluntary, anonymous, and had no impact upon student grades. The questions in the survey asked: "if your high school biology course included creationism, how was it presented? If your high school biology course included creationism, which, if any, creation stories were included? What is evolution? What is creationism?"

The findings for this study showed that 27% of students surveyed identified that a form of creationism was taught in their public high school biology class and 80% of those teachers only presented the Biblical story of creationism. Generally speaking, Christian Mythology is taught in these classes and other religions ignored or presented only rarely. Most of the students who were taught creationism identified that it was taught as a scientific alternative (54%) to evolution and not as a philosophical or religious idea.

The strengths in this study include the number of participants and diversity of the group surveyed. A large weakness in this study is the lack of statistical analysis and validity of the instrumentation. Other weaknesses include the maturation, history, selection, and mortality involved in the process. Due to the fact that this study did not include a random sample of a larger population, it may not be generalized.

Like Moore (2007 & 2008), Chuang (2003) wanted to determine what Utah educators taught about evolution but he also wanted to see if any demographic, educational, or religious factors effected those decisions.

Chuang (2003) performed a correlational survey based quantitative study that examined the attitudes and strategies of biology professors in Utah on the teaching of evolution. The 78 professors in this study represent eight universities throughout the state of Utah, were chosen at random and the survey was anonymous.

Each participant received a survey in the mail at his or her office address with a return self-addressed stamped envelope.

Chuang (2003) compared the views of professors between universities by using the Kruskal-Wallis H test and discovered a significant difference in educators' ratings of the importance of teaching evolution between universities ($p = 0.01$). One university in particular rated the importance of evolution much lower than any other university and also rated their students' understanding of evolution also very low. Teaching experience did not significantly affect the ratings of the importance of understanding evolution in the biology field ($p = 0.13$). Participant responses were also analyzed based on basis of whether or not their university required an evolution course for all majors in their program. Those without this requirement ranked the importance of evolution in biology fields significantly lower than those who had this requirement ($p = 0.002$) along with student understanding of evolution ($p = 0.0003$). Educators at universities where evolution is not a requirement were less likely to state that it should be a requirement than those whose programs require an evolution course ($p = 0.02$). Finally, educators who did not find evolution very important to the biology field were more likely to report that students frequently challenged them than those who find evolution important ($p = 0.03$). In analyzing the statements of how professors handle student conflict and questioning about the validity of evolution, most educators explained the nature of science to students or explained that religion and science are distinct from one another.

The correlational data presented in this study is very clear. The strengths are seen in the random selection, anonymity of the survey, and extensive statistical analysis performed to find correlational factors about the teaching of

evolution. The researchers presented enough information to reproduce the study. Due to the fact that this study did not include a random sample of a larger population, it may not be generalized.

Moore (2007 & 2008) and Chuang (2003) all addressed what science educators currently teach about evolution and how much they teach about creationism. Both studies showed that although creationism was not considered science, it received teaching time in several public science classrooms and teachers who did not see the importance of evolution to science were less likely to teach it and had more reports of student beliefs conflicting with the teaching of evolution. The following studies address teaching strategies that could improve student understanding of biological evolution.

Practices for Better Understanding

Verhey (2005) performed a quantitative research study in order to see if using students' prior knowledge about creationism and evolution and emphasizing the nature of science in an introductory biology course effects students' understanding of evolution. The data for the study came from four sections of an introductory biology course for majors at Central Washington University. Verhey found it important to examine the effects of learning through engaging students in concepts at the level of their initial understanding to see if students are more likely to come to accept the new information with less conflict with what they already know or believe.

The research population included 103 students enrolled in an eleven-week, fall quarter biology 110 course, an introduction biology course for majors at

Central Washington University. The course was broken down into four separate sections taught by three different instructors. To randomize which students attended which sections, the university's registrar randomly assigned students to the four sections. Each section contained approximately 25 students and contained similar demographics in terms of gender, amount of college experience, and similar grade point average (GPA).

Two of the sections, A and B were taught by the same instructor using the same syllabi and approach and are treated as replicas. Sections C and D were taught by different instructors using the same syllabi and are also treated as replicas. The time allotted for the course for each section remained the same and all sections covered similar textbook material related to evolution. Sections A and B used supplemental reading about Intelligent Design (ID) along with a rebuttal against ID and were discussed in seminar each week and had access to the website for the Discovery Institute, the leading promoter of ID, from their class webpage for their specific class sections. Sections A and B also covered the Nature of Science and discussed the uncertainty in science. Students also discussed and practiced writing using scientific and nonscientific explanations. Finally, sections A and B were encouraged to look at other beliefs about the origins of life besides evolution. At the end of the course all students were given the opportunity to complete a brief anonymous and voluntary survey about their attitudes towards creationism and evolution. The survey was administered as after the class ended through fear that the survey as a pre-test would influence student attitudes during the course.

Verhey (2005) collected surveys from 66 of the 103 students in Biology 110. In the survey students were offered six descriptions of attitudes toward creationism and evolution and were asked which attitude they identified before taking the course and which attitude they identified with after taking the course. Students were also surveyed about their prior learning on creationism and evolution. The six attitudes included Christian literalist, young-Earth creationists, progressive creationist/intelligent design, theistic evolutionist, non-theistic evolutionist, and atheistic evolutionist; each attitude was also captioned with a brief description. An analysis of variance (ANOVA) was used to test for significance in prior learning and changes in creation-evolution attitudes between the four sections. When the ANOVA test showed a significant difference between the sections ($p < 0.05$) they were further analyzed by using the chi-square analysis.

Through the analysis of the data from all four sections, Verhey (2005) discovered that at least some students in all four sections reported having changed their views about creationism and evolution. Sections A and B had a 61% change toward a more scientific attitude as compared to 21% in sections C and D and ANOVA testing showed a significant difference between the four groups ($p = 0.028$) and further chi-square analysis indicated the differences between sections A-B and C-D were significant ($p < 0.01$). These finding promote the use of a curriculum involving students' prior knowledge to increase attitudes about evolutionary beliefs.

Strength of the study (2005) was using two separate copies of the study with two experimental and two control groups along with the use of statistical analysis to show the variation between each section and the experimental and control. The researcher controlled for randomness as much as possible in this study through random assignment of students and control for similar demographics in each section. The researcher showed a fair representation of how the attitudes of the students changed.

A weakness of the study was the localization to one college and small number of students participating. Since the survey was anonymous, voluntary, and at the end of the course, it may have been difficult for students to recall their beliefs before the course and may have been tempted to give false answers. Due to the fact that this study did not include a random sample of a larger population, it may not be generalized.

The study of Verhey (2005) shared common features with the study of Alles (2001) as they both studied the effects of evolutionary academic achievement when using a biology curriculum that focused on the nature of science. While Verhey (2005) used the nature of science in a unit about evolution, Alles (2001) used the nature of science and evolution as a framework for teaching an entire biology course.

Alles (2001) performed a qualitative case study to identify the positive teaching effects upon evolutionary understanding of a college, non-majors, introductory biology course using the nature of science and evolution as the major framework for teaching biology. The study was performed on ~700

students at Western Washington University and based on recommendations made for the structure of teaching biology from a booklet released by the National Academy of Sciences in 1998 titled *Teaching about Evolution and the Nature of Science*.

The students involved in is study included 696 students in a biology 101 course at Western Washington University taught by the same instructor over seven different times using the same methods and syllabi. The demographics of the students were not given and a survey of their beliefs about evolution was also not given.

The course taught by Alles used the 1998 National Academy of Sciences booklet *Teaching about Evolution and the Nature of Science* as the framework for teaching his introductory biology course. The course did not follow a traditional teaching of biology as outlined by a typical text book but followed a modified structure divided into four parts: the nature of science, the conceptual framework of biology, the integration of biological knowledge, and biology and society. Each course consisted of ten weeks and 28 lectures. The items in the course followed a chronological order for the purpose of building knowledge and using previous knowledge as the course progressed. The course contained four short essay quizzes and a short response midterm and final to test for understanding, retention, and synthesis of the course material. The course was graded by the professor and also anonymously evaluated on a Likert scale by students for overall likability and intellectual challenge.

The findings for the study showed that students consistently rated the course an average of 3.85 (n = 696) on a Likert scale of one to five with three meaning good and four meaning very good, for the overall likability of the course and rated it an average of 4.0 for the overall intellectual challenge presented. The overall class average (n = 696) has been 79% with 93% of students passing the course. Written evaluations by students were also taken into consideration based upon how students reacted to the structure of the course and if they felt challenged. Alles (2001) concluded that there is a natural sequence for teaching the topics of biology and through observing those rules, students will have less conflict with the nature of science because they understand it from the very beginning and can build off of evolution which incorporates the origins of life, in a chronological order to create an ordered level of understanding instead of piecing knowledge together with less organization.

Although this study provided an outlined structure of the course along with credible reasons, the lack of input from the students creates weak validity since the researcher used a structure that he saw fit and based his conclusions on the ratings of the course and student success in the class. The author did not outline the testing methods and offered little information on the regression and mortality of the study.

Alles (2001) and Verhey (2005) used a curriculum involving the nature of science and discovered that teaching students about the nature of science allowed students to better understand the evidence supporting evolution and how scientists test theories such as evolution. Jensen and Finley (1996) used a

method of teaching evolution by creating a natural timeline of evolutionary events and using student paired investigation to promote the understanding of Darwinian evolution.

Jensen and Finley (1996) performed a quantitative research study on university general biology students to see if incorporating a historically rich curriculum and paired problem solving instruction in a unit about evolution, would promote students' understanding of Darwinian evolution more than an evolution unit using traditional course content in a lecture instruction format.

The subjects for this study attended the University of Minnesota and were enrolled in one of four sections of a general biology course for students who were unprepared to enter a regular biology class. The students came from a variety of ethnic and socioeconomic backgrounds and had diverse demographics. To participate in the study students were required to attend all six class sessions about evolution and complete the pre and post-evolution concept test. Section one contained 22 subjects who were taught using lecture instruction and traditional content, section two contained 20 subjects who were taught using lecture instruction and a historically rich content, section three contained 30 subjects who were taught using the paired problem solving instruction with traditional content, and section four contained 32 subjects who were taught using paired problem solving with historically rich content.

Jensen and Finely (1996) hypothesized that students with historically rich content materials and paired problem solving instruction would perform better than those with lecture and traditional teaching styles. Two professors each

taught two of the four sections studied, one professor taught the lecture instruction sections and the other taught the paired problem solving sections; both collaborated with creating a syllabus and outline of the traditional content along with the historically rich content and each completed the same material each day. They devoted six lecture days to evolution out of the 40 lectures for the course. They administered a pre-test at the very beginning of the course, five weeks before the unit on evolution and a post-test two weeks after the unit about evolution. The assessment included 17 questions that included five types of questions: Likert scale, multiple choice, justification, explanation, and definitions. The analysis did not include the information from the Likert scale or multiple-choice questions. Two evolutionary biologists examined the assessment for validity purposes. They analyzed the pre and posttest by placing students' responses into Darwinian categories or alternative evolutionary categories. The researchers used a computer program to randomize the pre and posttests for evaluation performed by evolutionary biologists and then linked together for analysis. The researchers expected an increase in Darwinian categories while they expected alternative categories to decrease in comparison to the pre test. To compare the four class sections the researchers performed a Kruskal-Wallis one-way analysis of variance and Mann-Whitney U test.

Overall findings showed that changes from pre test to post test were significant for the total Darwin change score and for the total alternative conception score. The section that received the traditional curriculum using traditional instruction received the worst mean rank total Darwin change score.

The section that used the historically rich content and paired problem-solving instruction received the best mean rank total Darwin change score. Students who studied a historically rich curriculum reduced their use of alternative conceptions more than the students who studied the traditional curriculum ($p = 0.005$) and students who used paired problem solving instruction reduced their use of alternative conceptions more than students who received lecture instruction ($p = 0.03$). The general trend showed that students' knowledge of Darwinian evolution increased significantly for each combination of the two instructional strategies. Students' overall use of alternative conceptions decreased for both types of curriculum and instruction and increased use of Darwinian explanations for both types of curriculum but increased significantly more with use of paired problem solving instruction and historically rich content.

The validity of the instrumentation used in this study was prepared and reviewed by many biology experts and used in other studies. The use of statistical analysis to showed significant differences in the control group to the test groups. The history, selection, and testing methods were all accounted for in this study.

In the same way Verhey (2005) used students' prior knowledge to teach evolution, Matthews (2001) used creation stories that students might be more familiar with for comparison and testing for the theory of evolution. Both researchers took into account what students would know coming into the classroom and started teaching from the knowledge level of the students.

Matthews (2001) performed a quantitative study which analyzed students' scientific attitudes toward evolution before and after instruction about evolution involving non-scientific creation stories, in order to identify whether this altered evolution course affects students understanding of scientific views about evolution more than a traditional evolution curriculum. The survey sought to determine if students gained a greater scientific understanding about evolutionary concepts after the course containing creation stories. In order to analyze gain in scientific understanding, the researchers used a 15-item questionnaire on 34 students enrolled in a General Biology course at a junior college in upstate New York.

The data collected for the Matthews (2001) study included 15 questions assessing the students' belief in creation, evolution, or related beliefs. The General Biology course at a Junior College in upstate New York was split into two sections both of mixed-majors with 78% of the total as non-majors with both sections taught by the same instructor utilizing the same teaching methods altered to include creation stories during the four week evolution unit in contrast to the traditional evolution unit not containing creation stories.

Matthews (2001) hypothesized that students would have an increased scientific understanding of evolutionary concepts after learning about evolution through the reading of and comparison of creation stories along with discussion of the validity of evolution. The course contained reading and discussion of Genesis 1:1-30; Genesis 2:1-24, a Bering Strait Eskimo Creation Myth, a Hopi creation myth, *The Sixth* Extinction, and *The Beak of the Finch.* Students

watched videos and read about scientific beliefs leading up to evolution and created a timeline about evolution and several creation stories to show overlapping information and identify the evidence that supports evolutionary theory from what they have read and studied. All 37 students entering the class were given an optional 15 item anonymous questionnaire used to identify students' ideas about the origins of life before instruction in the four-week evolution unit. The 15 items on the questionnaire were statements about evolution or creation in which the students were asked to identify whether they strongly disagree, disagree, unsure, agree, or strongly agree with. In order to identify the students' ideas about the origins of life after the four-week unit about evolution, the same optional 15 item anonymous questionnaire was given at the end of the evolution unit. A the end of the general biology course the same optional 15 item anonymous questionnaire was given for a final time to test the effectiveness of the rest of the course on the evolutionary concepts. 34 of the 37 students completed the pre-test, post-test, and post-post-test.

Matthews (2001) collected and analyzed the data by using a Likert scale with 1 = strongly disagree, 2 = disagree, 3 = unsure, 4 = agree, and 5 = strongly agree, where lower total values of all items on the questionnaire represented a more scientific view while higher values represented a more nonscientific view. The data collected for each student was analyzed using analysis of variance (ANOVA) to check for significant differences between students' prior beliefs and knowledge to beliefs and knowledge after the evolution unit and course.

The findings for Matthews' (2001) study showed that there was no significant difference in the surveys for gender ($p > 0.05$) but discovered a significant difference in the scores of the survey from the beginning of the course to the end of the unit and the end of the course ($p < 0.05$) showing that students responded more scientifically at the end of the unit and course than they did at the beginning. Matthews concluded that students have previous knowledge about origins of life on Earth and through providing evidence, discussion, and comparisons about various creation stories to evolution, students can have a cognitive shift from more nonscientific beliefs to more scientific beliefs about origins of life.

This study is a questionnaire survey that showed the change in thinking for students in a particular course containing creation stories to compare to evolution along with the evidence to support. It contained evidence that supported using these strategies to teach evolution to gain greater student acceptance and understanding of scientific beliefs surrounding evolutionary concepts.

This survey contained a large weakness in that this study did not have a control group for students who might have taken the same class using traditional curriculum standards for the teaching of evolution. It is therefore difficult to answer the question of whether a course involving creation stories creates better understanding of evolutionary concepts than a course using a traditional approach toward the teaching of evolution. The transferability of this study could also be in question because of the localization of the study and low number of

participants. The background of the students besides gender was not analyzed and individual change between the pre-test and post-test was not taken into consideration. This study offered little information on the history, maturation, testing, and instrumentation involved in the process.

The studies of Matthews (2001) and Jensen and Finley (1996) were of particular interest because it tested the effects of using specific teaching strategies for cognitive change. Strategies that involved logical order, emphasized the nature of science, and gave a wide variety of examples showed a more positive cognitive change toward the understanding of evolutionary theory. The following study by Sandoval and Morrison (2002) examined the effects of using inquiry investigation to build understanding of the nature of science.

Sandoval and Morrison (2002) conducted a quantitative research study to test the effects of high school biology students' engagement in inquiry investigation about natural selection on their understanding and beliefs about scientific investigation specifically the relation of theory to experimentation. They performed a pre and post interview of eight high school biology students before and after a unit about natural selection and evolution that included two inquiry investigations where students performed complete scientific experiments using computer simulations to test their own hypotheses.

The researchers selected subjects in this study from four high school biology classes in a major Midwestern city taught by two experienced teachers using a four-week inquiry unit on evolution that included two complete scientific

investigations. The researchers selected eighty-seven ninth grade students in biology classes at the same high school, 44 males and 43 females, and eight students conducted a pre-interview and a post-interview about the nature of science. Students volunteered to participate in the study.

The researchers performed the pre-interview just a few days before the start of the four-week evolution unit and included 16 questions from a Nature of Science interview used in previous studies about student understanding of the nature of science. Researchers asked the students 16 questions and additional questions only to clarify answers. During the last two days of the evolution unit researchers asked the exact same questions in the post-interview and reminded students not to remember their answers from the previous interview. Researchers used the Nature of Science interview because it focused on relationships between theories and experimentation to identify understandings about how those two items relate to each other in scientific terms.

The four-week evolution unit consisted of a week devoted to a lecture about Darwin's theory of evolution and several labs where students measured individual variations of attributes within a population and graphed them in ways that would be useful in identifying trends and patterns for use in further investigations. In the second week, students worked on their first inquiry problem of testing the environmental factors on survival of Galapagos finches with different physical attributes. This was followed by three periods of labs about human evolution. In the third week, students worked on the second inquiry problem of how *M. tuberculosis* bacterial can develop resistance to antibiotics.

The last three periods of the unit the students were engaged in discussion activities to relate their inquiries to the broader theory of natural selection. Students in groups of three to four created their own hypothesis, reasoning, testing instrumentation, graphing, and evidence to support or refute their own hypothesis. Each group received peer feedback from other groups about their investigation and were allowed time to make changes or investigate other possibilities. Students were required to have evidence that supported their final conclusions.

Sandoval and Morrison (2003) hypothesized that because students created their own ideas and generated their own data about what is happening in their inquiry investigation, this would change students' ideas about the relationships between theories and experimentation in formal science. They analyzed the findings by categorizing responses into themes and then into levels of one through three from a basic to more detailed epistemological understanding of the theme. The results showed no statistical difference in overall beliefs about the nature of science from the pre-interview and post-interview when using paired sample t-tests. Most students were at a level two understanding of most of the themes measured in the study which represents that they understand the purpose of science but do not understand the tentative nature of ideas and theories as being broader sorts of ideas than hypotheses. Also, students' epistemological levels of responses were not consistent over the interview as would have been expected with a certain level of understanding. This showed that students do not have a stable, coherent, epistemological framework for

understanding the nature of science. When explaining how scientific investigations work, students did not explain how scientists answer questions correctly showing that they did not see their own inquiry investigations within the evolution unit as “real science.” Students were also unable to correctly articulate the relationships between theory and experimentation and described experiments as a way to “prove” things rather than evidence to support a hypothesis and commonly expressed that when a hypothesis is proven wrong they believe the scientist has not made any forward progress.

This study showed that mere inquiry investigation is not enough to allow students to correctly correlate understanding of theory and experimentation. Sandoval and Morrison (2003) suggested that explaining the epistemological value behind scientific inquiry and deemphasizing creating a “right” answer to investigations may allow students to examine the value of scientific research better than asking them to use their current knowledge to create an understanding.

The strengths in this study were in the selection, testing, mortality, and instrumentation. The students selected for the interviews represented a spectrum of capabilities in each classroom and the instrumentation used has a repeated reliability and validity as shown in previous studies about the nature of science. Although the study showed no correlation between the inquiry unit upon student understanding of scientific theory and experimentation, statistical analysis was used to check for reliability. The researchers took considerable efforts to create a valid analysis through using a double-blind approach to

categorizing students' responses and the involvement of a third party in the analysis. A weakness in this study is the low number of subjects used for this study.

Robbins and Roy (2007) conducted another study using inquiry-based learning by performing a quantitative writing survey on 141 students from a non-majors biology course at Xavier University in Cincinnati, Ohio to identify and correct student preconceptions about evolution through an inquiry-based and critical approach to evolution. They encouraged inquiry-based learning because of its grounding in fundamental logic and exploration of evidence that may or may not align with the facts of evolution and it allowed students to criticize and reject information as it fits the nature of the facts.

Robbins and Roy (2007) conducted their study on 141 students in a non-majors biology lab where no prerequisites were required for admittance into the course and it is not a prerequisite for any other course. Most of the students had not taken any other college science course and the average cumulate grade point average for students entering the class was 2.3 with a standard deviation of 0.8. During the fourteen-week lessons with lab, the class met for one 110-minute class per week. The first weeks of the course were not devoted to evolution but included group work, trust related exercises, and labs unrelated to evolution.

For the study, the week before the unit on evolution the instructor administered an unannounced pre-quiz to be 5% of their final grade but all sincere responses would receive full credit. The instructor asked students to write for ten minutes on an open ended prompt: "Explain the theory of evolution;

do you believe it; why or why not?" (Robbins, J. & Roy, P., 2007, p. 462). During the four week unit on evolution students received a lecture on drug resistance in bacteria, participated in an exercise involving fossils from different time periods and in different rock strata, took a trip to the zoo to identify homologous, analogous, and vestigial structures, used open ended worksheets to identify examples of adaptation and endangered species, and finally a computer simulation to show the connections between genes, alleles, and proteins and compare DNA sequences of common organisms. Following each activity, students had open-ended discussions about their findings and questions in peer groups. On the last day of the evolution unit 62 students were given a written post-assessment asking them to "Explain the theory of evolution; do you believe it; why or why not;" in which only the first part of the question was graded and credit was given for the second part of students responded sincerely. The same question was given on the final to test for validity and retention of the material. Scores for the pre-assessment and post-assessment were compared for changes over the unit on evolution.

The findings for Robbins and Roy's (2007) study showed that through inquiry-based instruction about evolution, students entered the unit on evolution with 59% accepting evolution as the explanation for the state of organisms on the Earth and 92% accepting evolution after the unit was over. Finally 92% of students gave correct answers to the definition of evolution along with evidence that supports evolutionary theory, a 33% increase from the beginning of the unit.

Strength of this study comes from the participation of all students in the course so the knowledge and beliefs of all students are accounted for.

A weakness of the study is the significance of the pre and post-assessments to the students' grades. Although the researchers explained that they were not graded for content but through sincere responses, some students may be swayed to answer what they think their professors want to hear since their names will be attached to their responses. Another weakness is the lack of statistical analysis between the pre and post-test creating the assumption that an increase in percentage shows that the inquiry based learning stemming from students' preconceptions about the evolutionary theory is the main source of knowledge for the students. This study does not control for the history, testing, and instrumentation in this process.

Robbins and Roy (2007) and Sandoval and Morrison (2002) used inquiry-based teaching methods to allow students to investigate concepts and create their own information. Khourey-Bowers (2006) understood that controversy had the ability to arise when teaching evolution so he performed a study to test a peaceful dialogue discussing evolution and the evidence supporting evolution.

Khourey-Bowers (2006) conducted a qualitative case study implementing a structured academic controversy (SAC) to show how to maintain a peaceful and constructivist approach while teaching about evolutionary theory. Since evolution can cause classroom conflict, use of SAC is meant to "create a positive learning experience by removing the negative connotations of teaching a controversial topic" (p. 44).

The subjects for this study Khourey-Bowers (2006) included 11 undergraduate middle childhood pre-service science teachers in a senior-level science methods course. A schedule for the Structured Academic Controversy (SAC) was handed to students before the study. It was conducted over a single three-hour class period. After the instructor divided the students into two or three person cooperative groups, they were assigned readings from Barbour (2000) and instruction about the SAC and expectations for individuals and group rolls. Each group read a specific topic such as evolution, origin of life, quantum physics, and genetics and presented to the class. Students were expected to prepare the presentation to explain the historical and current scientific knowledge about their topic and discuss the interactions between science and religion. The expectations included that each group had to present more than one stance on a concept and had to understand multiple perspectives. Through the presentation, students were to discuss, "refute different positions, reverse perspectives and create a synthesis that all group members could agree to" (Khourey-Bowers, 2006, p. 45).

During the implementation of the SAC students questioned each other about the content knowledge for each topic and "were respectful of each other's work and opinions" (Khourey-Bowers, 2006, p. 45). All students worked to explain their positions and backed their discussion with knowledge from various perspectives. When creating a shared consensus, each shared personal opinions along with the content knowledge to support their ideas. Some students visibly changed their personal views but were also able to explain the reasoning

for changing their own views and how they worked through their own conflict. A brief survey was given after the SAC which showed that it promoted "consensus building among students, enhanced students' propensity for including evolution into their future classrooms, avoided confrontation, and emphasized currently accepted scientific thinking" (Khourey-Bowers, 2006, p. 46). All students reported feeling comfortable exploring evolution using a SAC and understand the complexities of the issues surrounding evolution. In using a SAC format, personal beliefs are not compromised but it also allows for student advancement in scientific knowledge and understanding.

A weakness of this study (2006) is found within the explanations of student interactions. It is difficult to tell what types of interactions are occurring between the students and how well it would carry over to a high school setting where students have even less prior knowledge about evolution and hold on to more nonscientific beliefs than pre-service teachers who have taken higher-level science courses.

Strength of the study is seen in the predictability of the outcome and congruency with other studies. The Structured Academic Controversy is used in other studies that create controversy in much the same way that evolution does and the outcome allows for a more comfortable setting with clear goals and shared perspectives.

Bischoff and Anderson (2001) performed another important study mapping how students' knowledge frameworks are constructed in an ecology course.

They observed the changes in students' ability to link previous knowledge to new acquired knowledge over a course of time.

Bischoff and Anderson (2001) performed a quantitative research study to identify how knowledge frameworks and patterns of explaining information develop among high school students over a course of ecology instruction. The study asked three questions: 1) what changes in knowledge organization occur? 2) What higher order cognitive operations are used during recall of information? 3) What relationships between information exist? The researchers performed the study through an interview process on high school biology students before, during, and after a four-week unit about ecology. Previous studies have shown that students build upon knowledge they already have and it becomes important to look at how students are linking new knowledge with their prior knowledge and if they are eliminating misconceptions in their thinking and at what cognitive levels students are able to discuss the material they are learning. This helps to identify the level at which students understand the material presented.

The subjects of this study included thirteen high school biology ninth and tenth graders selected randomly from a pool of 30 students receiving a C+ or better who were about start a four-week course about ecology. The researchers interviewed the students four times over the course of the ecology unit, once before, during week two, week three, and at the very end of week four. Researchers interviewed each student individually and it was voluntary with no impact on grades and consisted of the interviewer displaying a simple version of an aquatic food chain connected by various lines and the interviewer asked the

students to identify the main things about the display, to identify anything else, and any other information from observations.

The researchers transcribed student interviews and a third party put their ideas and linkages of knowledge into a flow chart. The flow chart represented the students' links between knowledge and idea in much the same way as a mind map might but without descriptions of the linkages in between the concepts. Along with creating the flow map, students' responses were also categorized into four forms of declarative knowledge for higher-level cognitive thinking. The flow charts and response categories were analyzed for number of linear linkages and number of recurrent linkages and number of uses of higher-level cognitive thinking.

Finding for this study showed that students' flow charts showed increasingly larger linear linkages up until week four where students created a very large number of recurring linkages. The recurring linkages show that students were connecting pieces of knowledge together to create a more substantial cognitive picture of ecology. Students began to use higher cognitive level examples and explanations starting in week three and four in categories from statements starting out as direct observations to statements conveying knowledge of comprehensive concepts. The complexity of the maps represents how students are thinking about the new knowledge and expressing higher order cognitive abilities around that knowledge.

The strengths in this study are the use of a complex but reliable testing instrumentation to observe student cognitive development about ecology. The

selection of the subjects and testing allows for the researchers to identify where the knowledge forms and if it happening for all students and not just for some.

A weakness in this study is the small number of subjects used in this study and the limitation of just one class to study. Other weaknesses include lack of information about the history, maturation regression, and mortality involved in the process.

Marbach-Ad (2001) performed a similar study to Bischoff and Anderson (2001) where they conducted a quantitative research study to learn about students' understanding of relationships between genetic concepts through administration of a questionnaire, and interview, and concept mapping of 9th graders, 12th graders, college pre-service teachers, and university pre-service teachers. High school science teachers typically regard genetics as difficult to teach and learn so they usually do not include it in their curriculum but several studies show that students who understand genetic concepts are more able to discuss ethical discussions around evolutionary and genetic concepts.

The researchers selected subjects from four different populations to compare the level of knowledge and difficulty students face at different educational levels. The first group consisted of 164 ninth graders who all completed a questionnaire and twenty students who completed an interview and prepared a concept map. Subjects completed the questionnaire, interviews, and concept maps following a twenty-hour unit on genetics. The second group consisted of 100 12th graders who completed the questionnaire and 21 and also completed an interview and prepared a concept map. The questionnaire,

interviews, and concept map followed three months of genetics instruction about the macro level of genetics as well as the processes and concepts at a cellular and molecular level. The third group consisted of fourteen college students who completed the questionnaire and 15 who prepared a concept map in their third and final year of teachers' training to become middle school biology teachers. The fourth and final group consisted of twelve university students who completed the questionnaire and ten who completed a concept map and already earned a university degree in biology.

This study used three different measurements to examine students' understanding of genetic concepts. The written open-ended questionnaire had two types of questions, the first was about single concepts and the second was about the relationships between concepts. The open-ended responses allowed for students' responses to be categorized by the students' spontaneous conceptions in genetics. The interviews consisted of the same questions as in the questionnaire but asked students to explain their answers aloud to control for difference in written explanation versus verbal explanation. The last measurement used a concept mapping exercise where subjects were asked to connect concepts by drawing lines between them and to explain the connections they made. The concept mapping technique was described by a previous study also asking subjects to create concept maps for visual understanding of student thoughts.

Findings for this study showed that answers to questions about single concepts fell into two types of categories: functional explanations describing the

transfer of information between generations and gene expression within a generation or structural explanations describing chemical composition. Most students in ninth and twelfth grade described DNA using a functional explanation as a flow of information between generations and referred to the connection between DNA and traits rather than DNA and proteins. When asked to describe a gene, most ninth graders, twelfth graders, and pre-service teachers referred to the flow of information within a generation but a hierarchy of explanations increased with the experience of the subjects. The most common answer from all subjects to the question 'what is a chromosome?' was 'a segment of DNA' and most subjects did not answer the question at all. When the Marbach-Ad (2001) analyzed the questions forming relationships between concepts he found most answers fell into four categories: coding relationships, direct causal relationships, composition relationships, or identity relationships. Ninth graders did not consistently use coding relationships in their answers. Many twelfth graders gave correct and consistent explanations using coding relationships but the explanations were very general. At the college and university level many students correctly and consistently use the coding relationship in their answers and contained detailed explanations. A few ninth and twelfth graders used direct causal relationships in some explanations but their answers were typically incomplete. Most college and university students did not use direct causal relationships in their explanations. Some ninth and twelfth graders incorrectly used composition relationships in making connections between genetic structures and students at the college and university level did not make

compositional relationships. Misconceptions about identity relationships were common among ninth graders showing an inability to differentiate between certain structures. Students at the college and university level did not use identity relationships in their explanations. The analysis of the concept maps showed that ninth and twelfth grade students typically connect each concept with only one connection each where college and university students had more connections explained correctly.

This study clearly showed the compartmentalization of genetic concepts that students created along with several misconceptions specifically around the relationships of genes and traits. As students gain more experience about genetics it shows that they can create a broader picture of how concepts are linked together as shown in the concept maps by younger students compared to college and university students. Although twelfth graders studied more in depth genetics concepts, it was clear that connections were not happening between the information they learned in their classical genetics course in ninth grade as they are not likely to make correct or in depth connections to various genetic concepts.

This study uses a moderate number of subjects, valid and reliable instrumentation, and statistical analysis to find relationships among genetic concepts displaying the connections that students have difficulty. However, this study does not explain the demographics of the students within the study or the history, maturation, selection, or mortality involved in the process.

Finally, Stern (2004) performed a study around teaching practices for better understanding of evolution and sought to identify if high school biology textbooks adequately evaluate student understanding of the evolutionary concept of biology.

Stern (2004) conducted a qualitative research investigation to identify how high school biology textbooks monitor the learning of the evolutionary concept natural selection and to see if any of them illustrate characteristics of a good assessment by examining nine commonly used high school biology books. This study originated from previous studies that have shown natural selection to be an extremely difficult concept to understand even for students who have had considerable exposure and instruction on natural selection.

The nine high school biology textbooks used in this investigation were selected based upon their common use in various high schools or because they were newly developed. The books were all intended for an introductory high school biology course. The assessment of the textbooks focused upon the information about natural selection and any assessment within the book about natural selection and its concepts. The criterion for evaluation of the assessments included: if they aligned with the goals or matched the content, if it tested for understanding not just rote memorization of the material, and if it helped to inform future instruction. An overall evaluation of the assessment strategies in the book for teacher assistance was based on: if it was a routine strategy, if it assists in interpreting students responses and if specific instructions were given to make instructional decisions based upon the assessment. The

evaluations of the three criteria were scored on a Likert scale of one to five with one meaning poor and five meaning excellent.

The findings of the evaluation showed that most textbooks do not adequately assess students on their understanding of the key ideas chosen for this study with the exception of two of the books that received an evaluation of three (satisfactory) and two (fair) on criterion one aligning assessment to goals and criterion two testing for understanding. The other seven books received ratings of one (poor) for criterions one and two. All textbooks received ratings of one for criterion three using assessment to inform instruction. The assessments included within all nine textbooks are not adequate for a meaningful evaluation of students on key concepts about natural selection and evolution. The questions evaluated are not sufficient or frequent enough to monitor students' progress nor do they guide teachers in how to interpret students' responses or modify instruction.

Strength in this study is the selection of the textbooks for evaluation based upon their frequency of use and textbooks that are new to the market. However, this study does not use a large number of textbooks in the evaluation and does not make specific statements outlining an ideal example of a criterion. This study does not take into account the history, instrumentation, or mortality involved in the process.

Verhey (2005), Alles (2001), Jensen and Finley (1996), Matthews (2001), Sandoval and Morrison (2002), Robbins and Roy (2007), and Khourey-Bowers (2006) conducted research based on teaching methods that could influence

student understanding of evolution and biology and Jensen and Finley (1996) discovered that a curriculum with historical evolutionary background along with paired problem solving teaching methods allowed for an increased understanding of evolutionary theory. Bischoff and Anderson (2001), Marbach-Ad (2001), and Stern (2004) identified areas of weakness in some current teaching practices and how they affect student achievement. All of these studies show that using certain techniques such as inquiry learning and questioning and investigative techniques help students to better understand evolutionary concepts without the conflict of personal beliefs about the origins of life.

The next section will review studies that identify science teachers' beliefs that affect their teaching of evolution.

Teachers' Beliefs

This section reviews research that examined influencing factors of teachers' propensities to teach evolution and other theories about the origin of life.

Rutledge and Warden (2000) performed a quantitative supplied-response survey study to identify high school biology teachers' acceptance and understanding of biological evolutionary theory and understanding of the nature of science and their relationships. The participants in the study included 552 Indiana public high school biology teachers who completed an anonymous and confidential 68-item supplied-response questionnaire asking questions about their acceptance of evolution, their understanding of evolution, and their understanding of the nature of science.

The subjects for this study included all 1,039 public high school biology teachers in the state of Indiana. The researchers sent post cards announcing the study to all teachers' schools, briefly explaining the study and the importance of their participation. They mailed the questionnaire four days later to the same addresses as the post cards and included a cover letter explaining the study and assured the participants that participation in the study was confidential, anonymous, and voluntary, along with a self-addressed stamped envelope to return the completed questionnaire. Rutledge and Warden (2002) received 552 completed questionnaires for a response rate of 53%.

The researchers divided the questionnaire into three sub-categories used to identify the teachers' acceptance of biological evolutionary theory, understanding of biology theory, and understanding of the nature of science. The first category identifying the teachers' acceptance of evolution contained twenty items about the concepts and validity of evolution and scored using a Likert scale of one to five with one meaning least acceptance and five meaning the greatest acceptance. The scoring range for this category was from 20-100 with a score of twenty representing a very low or no acceptance of evolutionary theory and a score of 100 representing a very high or complete acceptance of evolutionary theory. To check for teacher understanding of evolutionary theory a 21-item multiple choice scale taken from a previous study done by Johnson in 1985 was used with a cumulative score of 21 representing a very high level of evolutionary understanding. Finally to test for teacher understanding of the nature of science the researchers administered another seventeen-item scale

borrowed from the Johnson 1985 study with scoring done on a Likert scale. A score of five on each item represented the most correct response with a cumulative score of 85 representing a high level of understanding of the nature of science and a score of seventeen representing a very low level of understanding. To test for validity of these sub-scales, the researchers selected a jury consisting of evolutionary biologists, science educators, and a philosopher of science to analyze the questionnaire. Reliability for these scales were found by gathering measures of internal consistency with reliability coefficients of 0.84 for the teacher acceptance of evolution, 0.78 for the teacher understanding of evolution, and 0.94 for the teacher understanding of the nature of science.

Generally speaking, the subjects had a moderate level of acceptance of evolution, understanding of evolution, and understanding of the nature of science. Analysis showed that the average acceptance of evolution was on a score of 20-100 was 77.59 (SD = 19.83) with the least acceptance in the testability of evolution and the evolution of man. The most accepted concept of biological evolution was the overall acceptance by the scientific community. Examination of the level of understanding of evolutionary biology showed an average score of 14.89 (SD = 4.05) out of 21. The most difficult concepts were the ideas of environmental change, genetic variability in the process of natural selection, the date of the first life on earth, and radiometric dating. The most understood concepts were the characteristics of the first land animals, the mechanisms of genetic variability, and genetic mutations. Analysis of the understanding of the nature of science displayed an average score of 59.49

(SD = 12.46) on a scale of 17-85 with the most difficulty in understanding the goals and scope of science, the tentative nature of scientific knowledge, indirect observation and scientific methodology. The greatest understanding of the nature of science was the repetition of experimentation, scientific inquiry, and independence of science from religion. To test for statistical relationships between the three categories Rutledge and Warden (2000) performed a Pearson-product-moment correlation and discovered that acceptance of evolutionary theory was positively related to the understanding of evolutionary theory ($r = 0.71$) and the acceptance of evolutionary theory was also positively related to the understanding of the nature of science ($r = 0.76$). These findings demonstrate that teachers who have a greater understanding of biological evolutionary theory and the nature of science have a greater overall acceptance of evolutionary theory.

The correlational data present in this study is very clear. The researcher presented information about the instruments in such a way to support their validity and managed to accumulate a research population of medium size. Like many of the previous studies, Rutledge and Warden (2000) developed this work as a one shot case study, which unfortunately contained a large degree of invalidity in the design and leaves the conclusions weak. Rutledge and Warden described the research population but provided no information about history or maturation with regard to this population.

Rutledge and Mitchell (2002) performed another study to identify biology teachers' knowledge structures and conceptions about evolution.

Rutledge and Mitchell (2002) developed a quantitative survey to explore the knowledge structures and conceptions about evolution held by teachers with varying levels of acceptance of biological evolutionary theory. Rutledge and Mitchell described that previous studies have show that knowledge structures and conceptions in students typically reflect that of the teachers. By learning about teachers' knowledge structure, one can gain an understanding of a student's knowledge structure. This study was performed in two parts, a six-item survey completed by 552 teachers and a concept mapping activity completed by 235 of the 552 teachers. The survey questions asked about the teacher's academic background and teaching of evolution and the concept mapping activity developed by Novak (1984) was used to see the relationships teachers have among evolutionary concepts.

The subjects for this study consisted of Indiana public high school biology teachers. A supplied response survey, instructions, and concept mapping activity were sent to 989 teachers at the school where they taught, and 552 teachers returned the completed survey items and 235 also completed the concept mapping activity. The concept mapping activity asked teachers to generate concepts connected by lines along with indicate how they thought the concepts related. Some concept maps supplied the subjects with the concepts and asked them to link them together and explain their reasoning, but to avoided influence by the researchers, the subjects generated their own concepts varying the size and complexity of the maps received. The responses to the survey were recorded and concept maps evaluated for trends and categorized by non-

acceptance of evolution, undecided, and acceptance of evolution based upon their survey response to “do you accept evolutionary theory to be a scientifically valid explanation of the state of living organisms in the present and past?” (Rutledge, M. & Mitchell, M., 2002, p. 23). Comparison of concept maps between groups provided a way to determine differences in knowledge structures for teachers who accept or do not accept evolution as a means for explaining the state of living organisms.

The responses to the survey described the teachers’ academic background, teaching of evolution, and their personal acceptance of evolution. A chi-squared analysis showed no significant association between numbers of hours devoted to evolution, acceptance of evolutionary theory, completion of a course in evolution, and a completion of a course in the nature of science. The survey revealed that 43% of teachers described their teaching of evolution as “Avoidance” or “Briefly mentioned” and showed an association between teacher acceptance of evolution and the amount of time devoted to the teaching of evolution with an increased time devoted to the topic with teacher acceptance of evolution ($p < 0.001$). The concepts maps divided into groups of acceptance of evolution 59%, undecided 19%, and non-acceptance of evolution 14%, showed that the trends for teachers with a non-acceptance of evolution contained the smallest average number of concepts and relationships, typically believed that evolution is supported by little evidence, contained religious concepts, and had little to no detail about the mechanisms of evolution. The undecided group created more detailed concept maps in comparison to the non-acceptance group,

tended to include scientific concepts as well as religious theories, and commonly used “natural selection” and “speciation” to explain the mechanisms of evolution. The acceptance group created the most elaborate concept maps typically devoid of religious concepts and explained the mechanisms of evolution with more detail and lines of support than the other groups.

Although the state of Indiana’s science educational standards state that evolution is a major unifying theme in science, many teachers in Indiana do not believe or follow the state standards and allow their personal beliefs and conceptions to hinder the information that their students receive in the classroom. Teachers who lack an understanding of evolutionary theory may not be capable of making informed decisions about teaching evolution to their students.

The strengths of this study are in its numbers of teachers and in allowing subjects to create their own concept maps for the least amount of influence by the researchers. The use of a concept map allows for the researchers to identify trends without biased input into the creation of the individual maps.

A weakness in the study is in how the maps are evaluated and lack of statistical analysis. Part of Rutledge and Mitchell’s (2002) study was to identify how teachers’ knowledge structure effects a student’s knowledge structure specifically about evolution, this study does not show how teacher’s structure knowledge in their classroom and does not imply that the same results would occur for the students. This study offered limited explanation about history, maturation, and mortality of the process.

Along side the two previous studies which identified how biology teachers viewed and understood the theory of evolution, Weld and McNew (1999) performed a study to specifically identify factors that affect whether or not a biology teacher will emphasize evolution in their classroom.

Weld and McNew (1999) conducted a quantitative study to examine the factors that shape teachers' inclinations to emphasize evolution in their classroom since all teachers do not teach evolution to the same extent. The researchers based their study on an anonymous survey administered to secondary life science teachers from all parts of Oklahoma. A total of 224 or 26.7% of all secondary life science teachers in the state of Oklahoma completed the survey.

The researchers selected the subjects for this study randomly from the state records of secondary life science teachers in the state of Oklahoma. A questionnaire, letter explaining the research and a stamped return envelope was sent to 462 of the 840 secondary life science teachers in the state of Oklahoma. From the 462 teachers in which the questionnaire was sent, 224 replied with completed questionnaires. The questionnaire contained many features including asking teachers to list their demographics such as years of experience, gender, school size, college of preparation, academic degrees, and professional association memberships. The largest part of the questionnaire consisted of questions and statements measuring the teachers' emphasis on evolution in their courses by using phrases taken from the National Science Teachers Association position statement along with some phrases from other statewide studies.

Through the compilation of all the data the researchers used two-tailed t-tests to test for significant differences between the sub-populations and observed the overall trends for teachers who emphasize or deemphasize evolution in their classroom.

Findings demonstrated that there no difference in the emphasis placed on evolution by male or female teachers, new teachers versus veterans, rural versus urban and suburban teachers, or those with a bachelor's degree versus those with a master's degree. However, teachers who belonged to a professional science association were more likely to agree that evolution is a unifying theme in biology ($p = 0.002$) as compared to teachers who reported no professional science association memberships were more likely to emphasize creationism in their instruction ($p = 0.002$) and agree that there is much scientific evidence for creationism ($p = 0.043$). Finally, the researchers discovered a positive correlation between teachers' level of training in the nature of science and the perception that biology requires discussion and laboratory experiences on evolution and that evolution is a unifying theme in biology ($p < 0.05$). The overall factors observed by the researcher in teachers' philosophies toward emphasizing evolution in their own science classrooms was the teachers' coursework and study of the nature of science, membership in a professional science teacher organization, and use of state standards in guiding their teaching practice.

Strength of this study was the overall statistical analysis of the various trends in what causes teachers to emphasize or deemphasize evolution in their own classrooms. With the large number of subjects studied, the researchers can

predict with reasonable assurance that teachers who fit the above profile are more likely to correctly represent and devote time to evolution in their classrooms.

A weakness of this study was the many factors that the researchers used to create correlations with the emphasis of evolution in the classroom and the small number of subjects they used for a correlation. The study was localized to the state of Oklahoma where the data may not be representative of all states.

Ghaith and Yaghi (1997) performed another study about identifying factors that encourage or discourage teachers from implementing specific teaching practices in science. They conducted a quantitative survey study to identify the factors, specifically experience, teacher efficacy, perceived congruence, cost, importance and difficulty of implementation that influence teachers' attitudes toward the implementation of innovative or recommended practices on 25 teachers following a four day staff development workshop on cooperative learning.

The subjects in this study consisted of 25 teachers attending a four-day in-service staff development program at the American University of Beirut, Lebanon. The teachers consisted of 16 middle school teachers and 9 high school teachers, 20 female and five male with a combined average experience of 6.36 years with a range of 21 years (SD = 5.45). The four-day workshop consisted of training in a cooperative learning method called Student Teams Achievement Divisions (STAD). Each of the four days had two two-hour workshops and all teachers successfully developed and demonstrated lesson

plans based on STAD and using their own curriculum and context and received feedback from their colleagues and the workshop instructor.

The survey which was given at the end of the four-day workshop contained demographic questions such as educational attainment, teaching experience, gender, school at which they teach, and grade they teach. To measure the teachers' sense of efficacy a 16-item self-report instrument was borrowed from previous studies about teacher efficacy where subjects used a six point Likert scale agree/disagree to respond to nine statements which measure personal teaching efficacy and seven statements which measure general teaching efficacy. To understand teachers' attitudes toward the implementation of the new cooperative learning method the researchers borrowed another survey from previous studies about implementation of instructional innovation where subjects used a five point Likert scale to rate four statements about the congruence, cost, difficulty, and importance of using the new cooperative learning method.

To analyze the data Ghaith and Yaghi (1997) used product-moment correlation coefficients for all variables to identify the relationships among the determinants of teachers' attitude toward implementation of STAD. They used a series of t-tests to determine if teachers' attitudes differed by experience, personal teaching efficacy, and general teaching efficacy. The researchers placed the categories into low and high categories based upon the median scores.

Findings for this study show that teachers' experience negatively correlated with their general teaching efficacy ($r = -0.50$) and their ratings of the importance of implementing the new cooperative learning strategy ($r = -0.57$). Experience was positively correlated with the difficulty rating of implementing the new teaching strategy ($r = 0.43$). Teachers who had positive sense of personal teaching efficacy had a correlation with their ratings of the new cooperative learning strategy as congruent with their practices ($r = 0.62$), less difficult to implement ($r = -0.39$), and important to use in their classroom ($r = 0.55$). Finally the teachers' sense of the difficulty of implementing STAD negatively correlated to the importance of using this method ($r = -0.40$) and was positively correlated to the perceived cost of implementing this method ($r = 0.52$). In testing teacher experience against the perceived congruency, cost, difficulty and importance of using STAD, the researchers found that less experienced teachers perceived it as more congruent with their current practices, less difficult to implement, and more important to implement than the more experienced teachers expressed ($p < 0.05$). Teachers with a higher efficacy saw STAD as more congruent with their current practices and found it more important to implement than lower efficacious teachers ($p < 0.05$).

This study clearly shows a correlation between a teacher's experience and efficacy in their willingness to implement instructional innovation specifically the Student Teams Achievement Divisions (STAD). It showed that teachers with less experience and higher efficacy perceived STAD as less difficult to implement, and important for their teaching than more experienced teachers.

The researchers gathered a fairly small number of subjects selected from a limited setting based around one specific learning experience. They showed strong statistical analysis and used instruments from valid studies however the study failed to mention the history, mortality, and maturation involved in the process.

Meadows, Doster, and Jackson (2002) performed another study involving teachers' beliefs and the teaching of evolution. They conducted a qualitative research study to see if teachers who's religious or philosophical viewpoints conflict with biological evolution, can resolve these issues. This study consisted of 17 participants who had identified themselves as Christian fundamentalists who were involved in science education.

The research participants were self-proclaimed conservative Christians diverse in age, gender, and professional status and included two university professors of science, a professor and two graduate students in science education, four high school biology teachers, and eight prospective middle or secondary-level science teachers. The 17 subjects consisted of eleven females and six males; all were white and natives of the southeastern United States.

The study consisted of fairly informal exploratory conversations with each of the participants in a naturalistic, emergent style without a formal protocol except for three broad questions: what do you believe about evolution, or the history of the Earth and of life? How are your beliefs about evolution related to your religious beliefs? Given your career interest in science, do you feel a conflict between your professional and personal beliefs and values; and, if so, how do

you resolve that conflict? The researchers transcribed and reviewed each interview to reveal themes in the participants' comments.

The findings of the study showed that all of the participants' comments fell into one of four categories of approaches to dealing with the conflict between their beliefs about religion and evolution. The first category showed that some participants separated their religious beliefs and evolutionary beliefs by compartmentalizing each and not having an awareness of the conflict between the two. Participants in this study did not see the conflict because they had not thought about it or tried to relate their personal life with their professional life. The resolution of the conflict was farthest from happening with participants in this category. Subjects in the second category were aware of the conflict between their religious beliefs and evolution but avoided it by compartmentalizing the two and treated them as unrelated concepts even though they explained similar outcomes. Educators who fell into this category may have been ignoring the inherent connection and conflict between the two topics that occurs natural in students' minds. The third category was educators who were disturbed by the conflict between their religion and evolution. Participants in this category were not sure what to believe but struggled between their faith and scientific evidence. The fourth and final category contained subjects who have managed the conflict by constructing mental models that incorporated elements of both evolution and biblical understanding of creationism into their personal beliefs. Some of these models included only believing in some parts of evolutionary theory and others incorporated and molded biblical creationism into evolution without such a direct

literal interpretation of the book of Genesis. The overall message is that dealing with the evolution and religion conflict is a very personal experience and one prescribed treatment may not work for all. Through examination of all four categories, literal interpretation of creationism and evolution do not overlap but they can parallel as one comes to reconciliation as described by category four. The subjects who fall into category one and two distance the two parts of their lives as to avoid the conflict completely while category three is unwilling to alter their religious beliefs or separate them entirely in order to even consider evolution without emotional stress and conflict. Managing conflict appears to be the most effective strategy because it allows educators to comfortably engage in learning about evolution while maintaining their religious beliefs without feeling compromised.

The strengths of this study are seen in the analysis of the interviews about religious and evolution conflict and selection of the subjects for diversity in demographics. Weaknesses in this study are evident in the instrumentation of the interview because it was formatted as a very subjective interview and the required questions may not have been asked in the same setting or style for each interviewee. Other weaknesses include lack of description in the history, maturation, testing, regression, and mortality involved in the process.

Meadows, Doster, and Jackson (2000) identified that some teachers cannot resolve the conflict between their religious belief and the theory of evolution. Trani (2004) conducted a study to see if there is a correlation between

teachers who reject evolution because of their religious values and their understanding of the nature of science and biological evolution.

Trani (2004) conducted a quantitative research study to determine if there are significant correlations between teachers who reject evolution on religious grounds and those teachers' understanding of the nature of science and theory of evolution and if teachers who have a strong understanding of evolution and the nature of science still accept evolution despite their religious beliefs.

The subjects in this study were high school biology teachers from various locations in Oregon. The researcher selected teachers for the study based upon the size of their school as categorized by the Oregon State Athletic Association who categorized schools into four categories based upon their size. Seventy-nine schools participated in the study but Trani (2004) used only 20 for analysis of the research questions to equally represent the four school size categories. Trani contacted each school principle and science department head asking for participation in the study along with instructions relating to the study. All schools agreed to participate in the study. Each school received a letter with a self addressed stamped return envelope and three identical, 90 item, color coded surveys one to be completed by the most experienced biology teacher in the department, the least experienced biology teacher in the department, and a teacher that represents the average experience of all biology teachers in the department. Smaller schools received a number of surveys appropriate for their situation.

The survey consisted of 90 items created from a compilation of survey questions from other studies asking similar questions. The first three parts of the survey assessed the teachers' acceptance of evolution, understanding of evolution, and understanding of the nature of science. The fourth section asked questions to quantify teachers' religious convictions. The fifth section contained questions to identify the teachers' presentation of evolution in their classroom. The final question asked an open-ended question to determine the teachers' religious affiliations. The survey questions were presented using a five-point Likert scale with the exception of section one using multiple-choice questions to assess the Teachers' understanding of evolutionary theory.

Findings of this study showed that Oregon biology teachers have a high level of acceptance of evolutionary theory with the average score of 85.9 with a range of 20-100. Oregon biology teachers also have a high level of understanding of the theory of evolution with an average score of 17.51 on a range of 0-21. Oregon biology teachers have a moderate to high level of understanding of the nature of science with an average score of 66.08 and a range of 17-85. Finally, Oregon biology teachers have average religious convictions as they could be described as neither religiously dogmatic nor dogmatically atheistic with an average score of 45.01 with a range of 15-75. In the presentation of the theory of evolution most teachers teach it as a major roll in biology with the average score of 15.83 in a range of 4-20. Correlations were observed between teacher acceptance of evolution and religious convictions in a negative correlation of $r = -0.80$, teachers' presentation of evolution and their

acceptance of evolution with a correlation of r = 0.72, teachers' presentation of evolution and their understanding of evolution and the nature of science with correlations of r = 0.50 and r = 0.59 respectively, and finally teachers' presentation of evolution and their religious convictions with a correlation of r = -0.65. In answer to the question of whether teachers who have strong religious convictions understand can understand evolution and the nature of science, this study indicates that teachers who have strong religious convictions can still understand evolution and the nature of science and it does not prevent them from presenting evolution in their classroom. However, one can see the negative correlation between religious conviction and the understanding of evolution and the nature of science in many cases.

The strengths of this study are seen in the selection of participants for equal representation of schools and teachers with various levels of experience. The instrumentation used in this study has been used for previous studies with a high reliability and validity.

Since this study was an empirical survey, weaknesses in this study include the history, maturation, and regression involved in the process. A main weakness of this survey was the limitation of the analysis based on primarily Christian religious convictions that may have affected some of the data since that was the main religion taken into consideration for the survey. It may also be difficult to generalize outside of the region of study.

Nehm and Schonfeld (2007) followed Trani's (2004) study to see if increasing a teacher's knowledge about the nature of science and evolution increases their propensity toward teaching evolution.

Nehm and Schonfeld (2007) conducted a quantitative research study to see if a teacher's increase in knowledge about evolution and the nature of science increases their preference for teaching evolution and preference that students believe in or accept biological evolution. This study was performed on in-service biology teachers taking a graduate biology course focusing on evolution for a state teaching certification.

The research subjects consisted of 44 students at New York City College in a fourteen-week graduate biology course. All participants were currently teaching high school biology or had taught for at least a year, had a mean teaching average of 1.6 years, a mean age of 27.4 years, and contained students from a range of ethnic and racial backgrounds.

The researchers asked the students in the course to voluntarily participate in a confidential pre- and post-course questionnaire containing several questions regarding their demographics, teaching goals, religiousness, and what they want their students to know about evolution along with an essay question that would identify what they know about evolution and the nature of science. All of the questions except for the essay question were based on a Likert scale. The researchers administered a pre-course questionnaire on the first day of class and administered the post-course questionnaire on the last day of class. The course professor used the knowledge gained from the pre-course questionnaire to

decide what and how to teach based upon the prior knowledge of the students. For reliability of the instruments, the researchers tested the questions by comparing the Likert questions to the essay to see if students maintained consistency. In examining the data, they used eleven variables to determine teacher knowledge of evolution, nature of science, how they plan to teach about evolution in their class, and what they want their students to believe about the diversity of life.

Findings for this study showed that the number of misconceptions significantly decreased from the pre- to post-course questionnaire ($p < 0.001$). Pre and post-course comparisons showed statistically significant increases in knowledge of evolution ($p < 0.001$) and in the nature of science ($p < 0.001$), however there was no significant change in preferences for whether evolution or creationism should be taught in their classroom ($p = 0.25$). There was also no significant change in teachers' preferences in what they want students to believe about the diversity of life ($p = 0.62$). Overall, teachers showed an increase in knowledge about evolution and the nature of science but that did not affect their preference for teaching evolution in their classroom or what they want their students to believe about the diversity of life.

Although this was an empirical survey meant to identify a correlation between knowledge of evolution and increased propensity to teach evolution, the statistical data provided evidence that evolutionary knowledge does not change teachers' views about teaching evolution in their own classroom. The

instrumentation was tested for reliability through comparison of two types of questioning.

A weakness in the study is found in the low number of participants in the study and limited selection from one location. The history and mortality involved in the process was not explained.

Rutledge and Warden (2000), Rutledge and Mitchell (2002), Weld and McNew (1999), Ghaith and Yaghi (1997), Meadows, Doster, and Jackson (2000), Trani (2004), and Nehm and Schonfeld (2007) all performed studies surrounding biology teachers' personal beliefs and views and how it could affect their teaching of evolution. Many of the studies showed that teachers who have strong Christian religious values were less likely to teach, support, or understand evolutionary theory. Rutledge and Warden (2000) identified that many teachers have creationist beliefs and Weld and McNew (1999) observed that teachers who had creationist beliefs were less likely to teach evolution or understand it.

The next section of this chapter reviews research about the effects students' and teachers' personal views of the evolution-creation controversy and student prior knowledge on the understanding and teaching of evolution.

Prior Knowledge

This section reviews research that examined teacher and student prior knowledge of evolution and the origin of life and how it affects the teaching and learning about biological evolution.

Dagher and BouJaoude (1996) performed a quantitative research survey to identify how biology students at an American university in Beirut, Lebanon

accommodate their religious beliefs with the theory of biological evolution and which arguments they justify their position with, in order to discuss the implications to curriculum and instructional practices. In the United State conservative Christian groups typically have conflict with the biological theory of evolution but other religious groups such as Muslim and some Catholic groups also have conflict.

The subjects of this study consisted of 62 undergraduate biology majors in a required weekly senior seminar course at a private American university in Beirut, Lebanon. Not all students in the senior seminar had taken a course about evolution. The average age of the students was 20 and they represented seven major religious sects of Christianity and Islam. A confidential non-graded questionnaire was administered to students during the first two weeks of the seminar and included questions about the students' demographics along with identification of their personal religion and sect and included three essay questions to allow the researchers to identify and categorize the religious conflicts they have with evolution and how they manage those conflicts. The three questions were: 1) List the major principles of the theory of evolution. Use examples to clarify your answer. 2) Do you believe that theory of evolution presents a conflict between science and religion? Explain in detail. 3) Does the theory of evolution clash with your own beliefs about the physical and biological world? Discuss in detail. After the results of the questionnaire were categorized 15 students were selected from their questionnaire responses to participate in a more detailed interview to clarify and elaborate their answers. The 15 students

were selected based on the interest of including students with diverse religious backgrounds and whose views had personal perceptions of conflict.

The results of the study showed that students answered the first essay question with any one or a combination of 27 principles of evolution. The most commonly mentioned principle of evolution was natural section and survival of the fittest. While some of the identified principles represented commonly held misconceptions such as man evolving directly from ape or the end product of evolution is perfections, other principles displayed a selective interpretation such as all organisms evolving from lower organisms except for man. The researchers categorized personal positions toward evolution into four categories: acceptance of evolutionary ideas using arguments from an evolution or reconciliation perspective, no acceptance of evolutionary ideas presenting arguments from a religion or antievolution perspective, a reinterpretation of evolutionary theory presenting arguments from a compromise perspective, and a neutral perspective reflecting either a non-committed or confused view of evolutionary theory acceptance. A greater number of students with Christian beliefs accepted evolutionary ideas at 82% of all Christians in the study compared to only 35% of all Muslims. Forty seven percent of Muslims were against evolution while no Christians were completely against evolution and compromised and neutral beliefs were similar in both Christian and Muslim groups. Students also held various objections to evolutionary theory that were classified as conceptual difficulties, alternative interpretations, nature of science, and nature of religion. Many students that refuted evolutionary theory stated they

could not believe in it because it has not been proved 100% or discounted it because it is a theory and not a law. Some students interviewed had very good conceptual understandings about evolution but did not accept the theory. Other interviewed students reported their professors explained evolution in a very neutral matter without trying to convince them to believe in the theory and they learned it because it was required of them and did not incorporate biological evolution into their own beliefs. Students maintain prior religious beliefs that conflict with evolutionary theory without reconciliation because of their distorted understanding of the nature of science and the way that professors present evolution in a neutral way so students to do not have to confront their religious conflicts.

Strength in this study is the selection of students from a wide variety of demographics. By comparing two different religious groups, one can see how they are similar and different in light of a conflict that has historically only been associated with one of the groups. The two groups hold similar beliefs and maintain prior knowledge as has been seen in many previous studies about religious and evolutionary conflict.

A weakness in the study is the lack of statistical analysis and empirical nature of the survey. The study ignores the validity and reliability of the instrumentation, maturation, and regression involved in the process.

An important study linking students' beliefs about evolution and achievement was performed by McKeachie, Lin, and Strayer (2002) who conducted a quantitative study to test students' beliefs about evolution and how

they affect their performance and motivation in biology and how a biology course affects student beliefs about evolution. This study specifically assessed the changes in beliefs from the beginning of a biology class to the end of the class and the overall achievement of students who believed more in creationism versus evolution.

This study was based on a survey of a pre-test and a post-test on 28 students enrolled in an intro biology course at a Midwest community college. Sixty students in the same intro biology course completed the pre-test with 28 students completing both the pre-test and post-test, 19 students dropped the class before the end of the quarter and 13 students did not complete the post-test.

McKeachie, Lin, and Strayer (2002) conducted their study using a four item questionnaire where students rated their own beliefs using statements that best fit their views, students also completed the Motivated Strategies for Learning Questionnaire (MSLQ) to assess students' motivation and learning strategies. The MSLQ uses a seven-point scale with one meaning "not at all true of me" and seven meaning "very true of me." The MLSQ was used to compare the motivation and learning strategies of students who have different beliefs about evolution.

The findings of the study (2002) revealed that the changes in beliefs after the class in the post-test tended to lean more toward belief in evolution. In correlation with the students that dropped the courses, those who did not believe in evolution as shown in the pre-test were more likely to drop the course than

those who leaned more toward believing in evolution. In the post-test, students who believed in evolution tended to have a higher final grade than those who did not believe in evolution. The Motivation and Learning Strategies Questionnaire revealed that students' who's beliefs were challenged, began the course with a lower level of interest, had higher anxiety, and lower intrinsic motivation than students who showed their beliefs were not challenged. Through the comparisons of the four-question survey and the MLSQ clearly showed student motivation dropping when personal beliefs were be challenged.

McKeachie, Lin, and Strayer (2002) identified a correlation in students who believed in evolution with higher grades and motivation for learning with use of a renowned survey for testing student motivation and learning strategies. However, there are several weaknesses that hinder the validity of this study.

Two major weaknesses of this study include the small size of the participants and lack of statistical analysis of the data collected. With the number of students that dropped the class, any number of reasons besides their disbelief in evolution could have caused them to leave the class on their own accord. The survey size was limited to the number of students in one class and without documentation of what and how it was taught. Through the lack of statistical analysis one can see the correlation discussed but the root and extent to which the correlation exists is not explored to a level to deem them highly significant. This study gave little or no information about the history, maturation, testing, instrumentation, and regression involved in the process.

McKeachie, Lin, and Strayer (2002) concluded that student motivation and achievement could be affected by their beliefs about whether or not their religious views accept evolution as the origin of life. Blackwell, Powell, and Dukes (2003) also studied how student acceptance of evolution can affect student achievement in learning about evolution.

Blackwell, Powell, and Dukes (2003) conducted a quantitative survey on 125 undergraduate students at the University of Alabama to answer the question of how student acceptance of evolution affects their understanding of evolution. The reason for this study comes from previous studies that showed high school teachers imparting their own view of evolution upon students rather than objectively teaching evolution to students using knowledge they may already have. In effect, college professors are passing down their knowledge and acceptance or non-acceptance to students who will be the future teachers of high school students. This study shows how students are able to link facts and concepts they are already very familiar with to the concepts of biology even without complete acceptance of the biological theory of evolution.

The subjects in this study consisted of 74 students in a freshman seminar class and 51 students in a general biology class at the University of Alabama. The general biology class contained fewer freshmen than the freshman seminar. The students were given an anonymous and voluntary multiple-choice questionnaire divided into four parts. The first part contained questions regarding dog breeds and common behaviors followed by definitions of evolutionary terms, the second section asked students to label each previous dog-related question

with the evolutionary term defined previously, and finally the last set of questions asked about the students' acceptance of evolution and its application to everyday life.

The findings for both classes were similar and showed an average understanding of the principles of evolution based on using the knowledge about dog breeds and behavior and linking them to evolutionary terms and definitions even though the student may not have completely accepted evolution based on the last set of questions in the survey. As expected by the researchers, evolutionary concepts can be understood when linked to prior knowledge and understanding does not have to be linked to acceptance. Most students in the study had openness to the theory of evolution but questioned some of the mechanisms and relevance to their own lives.

This study used two separate groups to check for reliability and a used a moderate number of participants but did not explore the causes or results behind understanding the relationships behind the dog questions and the evolutionary definitions. This descriptive study also lacked an explanation of the demographics of the participants and use of statistical analysis and offered little information on the testing processes, instrumentation, selection, or mortality involved in the process.

A survey to compare high school biology and college biology students' views about the evolution-creation controversy was performed by Moore, Froehle, Kiernan, and Greenwald (2006) who administered a survey to Minnesota high school and university students to determine how high school

students understand and view the evolution-creation controversy, compare the views of university students to high school students, and determine if Minnesota high school biology teachers emphasize evolution in their classrooms as mandated by the state's educational standards. The subjects consisted of 111 public high school students currently taking a biology class, 135 private parochial high school students currently taking a biology class, and 889 students from the Twin Cities campus of the University of Minnesota attending an introductory biology course.

The high school students receiving the survey were chosen based upon their attendance at the schools chosen for the study and enrolled in a biology class at, Central High a public school in St. Paul, Minnesota or Cretin-Derham Hall a private school associated with the Catholic Church in St. Paul, Minnesota. University students chosen for the study attended the Twin Cities campus of the University of Minnesota and were enrolled in an introductory biology course. The survey received approvals from all schools participating and permission forms were sent to parents of high school students describing the study and providing permission for their student to participate in the study. Students whose native language was not English received permission letters and surveys in their native language. The survey was anonymous, voluntary, and had no impact upon students' grades.

Researchers administered the survey to students on the first day of class to check for students' prior knowledge about evolution and to avoid the possibility of students trying to answer questions in a predictable manner. The surveys for

the high school students consisted of 19 items to determine the students' prior declarative knowledge about evolution, the teaching of evolution, and the evolution-creationism controversy in the classroom and asked students to rate statements on a Likert scale with 1 = strongly disagree and 5 = strongly agree. The survey administered to the university students contained the same 19 items from the high school survey and an additional five items about the teaching of evolution in their own high school biology class using the same Likert scale in the high school survey.

The researchers compared the answers of the public high school, private high school, and university students using the Likert scale and percentages of students for each category and observed for trends. The findings showed that the public and private high school students in the survey had similar views about evolution and creationism along with having similar misconceptions surrounding the mechanisms of evolution such as most students believed that the theory of evolution is full of conflicts and contradictions, that there are many good scientific theories to explain the origins of life, and that a scientific theory is a hunch or an educated guess. The findings also displayed that university students shared similar views and understandings of evolution that as that of high school students. Both groups had misunderstandings about evolution such as that there are many good scientific theories to explain the origins of life and about the nature of science. The similarities between the two groups showed that high school biology courses have had little to no effect upon students' understanding of evolutionary theories and prior beliefs. The results from the survey of

university students asking to describe their evolution education in high school displayed that only 38% of students claimed that their high school biology class emphasized evolution and 20% emphasized creationism, showing results similar to other studies. These results show that although the state of Minnesota has had state educational standards that emphasize the teaching of evolution as a central theme in biology, the state standards did not affect whether or not teachers taught evolution in their classroom to the extent that the standards warrant.

Although this study gathered a moderate number of subjects the lack of statistical analysis creates a weakness in the study. The selection of the subjects was limited to one school for each category and the demographics were not described. This study answered the questions of students' views and understanding of evolution and whether state standards matter to the teaching of evolution but his descriptive study offered little information on the instrumentation, selection, or mortality involved in the process.

To link together how students view the evolution-creation controversy and how it affects student understanding of biological evolution, Sinclair and Pendarvis (1998) conducted a quantitative survey of 218 students at Southeastern Louisiana University enrolled in an introductory college zoology course to see which topics behind evolutionary theory give students the most distress. Through assessing student understanding of various evolutionary topics before and after a unit in evolution the researchers could identify topics that students understood the least even after instruction on those topics.

The 218 subjects of the study were enrolled in an introductory zoology course. The survey was administered at the beginning of the semester and after a focused study of evolution that took place during the third month of the semester. It contained twelve multiple-choice items and four open ended narrative response questions.

During the focused study on evolution, all students received similar instruction as all instructors followed the same content outline and used the same laboratory investigations which included the history of evolutionary thought, basic premises of Darwin's theories, and mechanisms of natural selection, speciation, and evolutionary trends. Sinclair and Pendarvis (1998) analyzed the multiple choice data using descriptive statistics to test for significant differences between the pre and post-test and the narrative response questions were summarized to identify commonly occurring and noteworthy comments.

The findings for this study showed that students did not understand the basic concepts of biological evolution even after a unit in evolution. Only 18.0% of students correctly identified how species change over time on the pre-test and a small increase of students to 28.1% correctly answered this question on the post-test. Even after instruction, most students hold on to misconceptions about evolution and only 33.9% of students on the post-test as compared to 21.2% on the pre-test correctly identified Darwin's explanation of "survival of the fittest." Before and after the unit on evolution 25% of students believed that none of the arguments presented by biologists about biological evolution were weak. One of the multiples choice questions asked if their religious beliefs were in conflict with

the theory of evolution and 45.6% on the pre-test answered yes and 29.6% on the post-test showing a slight change in students' understanding about their religious beliefs and evolutionary theory.

The findings for this study do not show an increased overall student understanding that might be expected from unit about evolution. Students hold on to many misconceptions that may hinder learning unless otherwise addressed with palpable evidence to support reasoning. Sinclair and Pendarvis (1998) offer suggestions to increase student understanding such as addressing students' beliefs, address misconceptions, and teach through inquiry investigation. Strength in the study is the anonymity of the survey but a major question about the study comes from the lack of detail of how the lessons about evolution were taught. It is difficult to discern why correct scores on the post-test did not increase very much and without explanation of the teaching and learning process it is difficult to use this as a reliable study. The study omitted pertinent information such as the demographics of the students in the study, the questions on the survey, method of administering the survey, methods of teaching, and statistical analysis used to analyze the data.

The previous five studies provided insight into how and why students' prior knowledge and beliefs can affect their understanding of evolutionary biology. Moore, Froehle, Kiernan, and Greenwald (2006) and Dagher and BouJaoude (1996) described the feelings and thoughts of students who do not accept evolution because of their religious beliefs and how they interpret the educational evolution-creation controversy. McKeachie, Lin, and Strayer (2002) and

Blackwell, Powell, and Dukes (2003) provided specific evidence showing how acceptance of evolutionary theory affects complete understanding for academic purposes.

The next section of this chapter reviews research that examines other external stimuli that affects the teaching and learning of evolution in public high school.

Other Factors

This section reviews research that examined influencing factors for the teaching of evolution from other stimuli besides teachers' personal beliefs. The other stimuli include state science standards, laws surrounding the teaching of evolution and creationism, professional development, and stress.

Bandoli (2008) performed a quantitative survey to determine the extent at which state standards determine how teachers cover evolution in their high school biology classes. This study was performed by comparing two state educational standards, Ohio who has been rated by a previous study as having evolution state standards as useless or nonexistent to Indiana who has been rated as having excellent evolution state standards. Students at state universities in Indiana and Ohio were surveyed to identify how their high school biology teachers taught evolution.

The subjects of this study consisted of 268 students from four Indiana state universities and 285 students from four Ohio state universities. Researchers selected the students based upon their registration for an introductory biology class at their university, the fact that they were no more than

a year graduated from high school, and that they reported having only taken one biology class in high school. The demographics of the students were similar for each research population in each state with a similar number of students majoring in biology, a science major, and majoring in something other than science.

The survey was anonymous and voluntary and contained eight questions which consisted of where the students attended high school, the demographics of the school, the amount of time their biology teacher spent on evolution and cell structure, the average age of their biology teachers, what explanations for the diversity of life were taught, how the student thinks the scientific community regards evolutionary theory, and the student's personal preference for an explanation of the diversity of life. The results for the questionnaire were tallied by state and then compared by using two-sample chi square tests in which the degrees of freedom equal the number of categories.

Results of the Bandoli (2008) study showed that despite having different state standards for the teaching of evolution, the average time high school biology teachers spent teaching evolution was not significantly different between the two states. The amount of time spent covering cell structure and function in both states was significantly more than the time teachers took to cover evolution but was not significantly different between the states. The age of the teacher also did not have an effect upon the amount of time they took to teach evolution between the two states. However, students who reported that their teachers emphasized evolution in their class rather than creationism were more likely to

accept evolutionary theory as the explanation for the diversity of life. Overall, the results of this study suggest that the coverage of evolution in public high schools in Indiana and Ohio is not influenced by state standards.

This study contains two strengths, the number of participants in the study and the selection criteria. Also the statistical analysis involved in comparing the outcomes of the two states proved to show no correlation between the state standards and the amount of time devoted to evolution. The validity of the instrumentation was described and used by other studies to identify what teachers teach about evolution.

A weakness in this study is the reliability of the students to remember exactly how their teacher taught their biology class without influence from other sources and biases.

Bandouli (2008) studied the state standards of only Ohio. The next study by Moore and Kraemer (2005) compared two states with two different science-teaching standards to see if there was a correlation between better state standards around the teaching of evolution and actual classroom practice in teaching evolution.

Moore and Kraemer (2005) conducted a quantitative study to see if strict state education standards for the teaching of evolution and rejection for the teaching of creationism actually matters in the actions of high school science teachers. This study was conducted in the state of Minnesota where the state education standards for the teaching of evolution incorporates the National Science Education Standards which includes the teaching of evolutionary topics

such as common descent, similarities among organisms, biodiversity, heredity, biological evolution, and natural selection and clearly rejects the teaching of creationism/intelligent design due to the fact that it is not science.

Researchers administered the survey in 1994 and 2003. They selected the 203 subjects for the study in 1994 randomly from a list of public school biology teachers provided by the Minnesota Department of Education. They included a stamped, self-addressed envelope with each survey. They had an anonymous return rate of 45% (91 of 203). The researchers selected the subjects for the 2003 study randomly from Minnesota public high school biology teachers that attended the National Science Association Convention in Minneapolis, Minnesota in 2003 and the Tenth Annual Biology-Life Science Teachers Conference in St. Paul, Minnesota in 2003. A total of 107 of the 132 teachers completed the anonymous survey.

To examine the results from the surveys, Moore and Kraemer (2005) displayed the percentages of respondents to each of the 27 questions separately for the two years of the survey. Since the two surveys were separated by eight years and there was “much evolution-related activity in the state” (Moore & Kraemer, p. 460) such as the adoption of educational standards that emphasized the teaching of evolution, a revision of the state science educational standards that caused a public discussion about the teaching of evolution, and finally a publicized lawsuit by a biology teacher demanding that he has the right to create his own curriculum including creationism, allowed the researchers to hypothesize

that there could be a significant shift toward the teaching and support of evolutionary theory in Minnesota's biology teachers.

The results of the study showed that many of the teachers' responses to the survey in 1994 to 2002 had not significantly changed. Compared to the 1994 survey, the number of teachers who included evolution in their classroom increased from 69% to 88% in 2002 along with the percentage of teachers who devote at least six hours of evolution instruction increased from 43% to 57%. The percentage of teachers who felt pressured to teach evolution increased from 5% to 17% however, the percentage of teachers who reported pressure to avoid evolution increased from 19% to 48% and the percentage of teachers who teach creationism increased from 16% to 20% despite the fact the Minnesota Educational Standards now include a strong rejection to the teaching of creationism in the science classroom. The study was not performed to find correlations between demographic variables with the teaching of evolution or creationism.

This study showed that there was an increased pressure on biology teachers to devote teaching time to nonscientific beliefs such as creationism. Even through the years and increased educational standards outlining what students should be taught about evolution, there were significant increases in time devoted to creationism even though teachers realized that evolution is a widely accepted scientific view that the state deemed valuable for students to understand.

Strength of this study is the number of teachers they used in their study and the time in between the study to check for changes in views and practices. The researchers were also able to compare the demographics of teachers from both studies to see if they were similar or different.

The point of the study was to see what changes occurred over the course of time to teaching practices when the state teaching standards for biology changed to include more evolutionary concepts. A major weakness in the design of the study was the way in which they collected data in the two different years of study. In changing their methods for collecting data, the study groups may have been more biased toward the teaching of evolution since they were voluntary attending professional conferences that endorse the teaching of evolution. The study offered limited information about testing, instrumentation, and regression of the process.

The following study focused on the legal issues surrounding the teaching of evolution. Moore (2004) explored how well public high school biology teachers understand the legal issues surrounding the teaching of evolution and how it affects their teaching of evolution and creationism in the classroom. Moore administered a survey to 103 public high school biology teachers in the state of Minnesota where subjects would answer yes or no questions based on laws and rights about the teaching of evolution and creationism, in order to identify which legal issues teachers do and do not understand.

The subjects of the study were selected from Minnesota public high school biology teachers that attended the National Science Teachers Association

meeting in Minneapolis, Minnesota in and the Biology and Life-Science Teachers Conference in St. Paul, Minnesota in 2003. Subjects were selected at random and were anonymous. The 20 item survey consisted of questions about the laws and rights on the teaching of evolution and creationism that were based on a previous study discussing the most common questions about legal issues surrounding the teaching of evolution in public schools. If the subject did not know the answer to a question they were instructed to leave it blank. The researcher collected 103 surveys from public high school biology teachers in the state of Minnesota. At least 91% of subjects answered each question on the survey.

From analysis of the answers to the survey, Moore (2003) found that most teachers had a moderate understanding of the legal issues surrounding the teaching of evolution and creationism. More than 75% of teachers understood that they are not required to give equal time to creationism if they teach evolution, they do not have modify the teaching of evolution because it may offend some students' religious views, the government can use tax money to promote the teaching of evolution but not promote creationism, the First Amendment does not entitle a teacher to teach creationism, and a school can force a teacher to teach evolution and not teach creationism. These results suggest that most teachers understand how to resist the pressures to teach creationism on a legal basis. Still there is concern because this research indicates that a large number of teachers believe they may give equal time to creationism if they teach evolution, they may teach the alleged "evidence against

evolution," they believe they can be required to read aloud a statement that their teaching of evolution is not meant to turn students away from accepting creationism, they do not know that the courts have evaluated the scientific and educational value of creation science, they believe that it a crime to teach evolution in some parts of the United States, and they do not have an understanding of the history of the evolution education in the United States. Many teachers are misinformed about the legal issues associated with the teaching of evolution which may have a direct impact upon valuable science education.

Moore's (2003) research clearly shows trends in teacher understanding of laws surrounding the teaching of evolution but lacks statistical analysis and creates a comparison with other studies that have shown similar results. The research population is of a medium size but a weakness may be in the selection of the subjects. Moore explained that he selected the place to collect subjects because of the low response from previous mail-in studies performed about evolution related topics but this selected population of teachers may not be representative of the rest of the teachers in the state who may not attend conferences or belong to professional science organizations. Although Moore makes assumptions about the correlation of understanding these laws and the teaching of evolution, this study does not answer this question as stated in the purpose of this survey.

Moore (2004) discovered that many teachers understand some laws surrounding the teaching of evolution and creationism in public schools but some

are very unclear about what school administrators cannot force a teacher do around teaching evolution. The next study by Supovitz and Turner (2000) studied professional development and if it increased a teacher's propensity toward teaching evolution and science using innovative methods.

Supovitz and Turner (2000) performed a quantitative survey to answer the following questions: Does high quality professional development relate to inquiry-oriented teaching practices and what number of hours are associated with higher inquiry practices used; does a teacher's background, school demographics, and environmental characteristics support or hinder inquiry-based teaching? This research followed questions about the effectiveness of in-service teacher training on the implementation of various innovative teaching practices presented in workshops and professional development training. This study focused on the implementation of inquiry-based practices in science classrooms that have been proven to work specifically well with the learning of science concepts and evolution more specifically. The surveys in this study were from a wide range of teachers from various schools around the United States who participated in specific extended professional development workshops from the National Science Foundation's (NSF) Teacher Enhancement program called the Local Systemic Change (LSC) initiative.

The subjects in this study consisted of 3464 science teachers and 666 principals from 24 localities and 787 schools across the United States in diverse school populations. The teachers in this study ranged from K-8 science teachers. Each survey was weighted correctly for the number of teachers and

principals surveyed in the different localities. Before attending the extended professional development program by the NSF, the teachers surveyed had various degrees of participation in professional development; some had 120+ hours while others had none.

The professional development series focused on implementing inquiry-based learning in the science classroom and had six basic principles in the implementation of the workshop: it must immerse participants in inquiry, questioning, and experimentation, it must be intensive and sustained, it must engage teachers in concrete teaching tasks and be based upon teachers' experiences with students, it must focus on subject-matter knowledge and deepen teachers' content skills, it must be grounded in a common set of professional development standards and show teachers how to connect their work to specific standards for student performance, and strategies must be connected to other aspects of school change. This highly intensive series consisted of 160 hours of workshop time over the course of three to five years, some participants in the survey had no workshop experience and some completed all 160 hours. After the workshops a survey was required and completed by each teacher participant and principal as part of the evaluation for the LSC initiative. The teachers' survey contained questions about their attitudes, beliefs, and teaching practices on a five-point frequency scale (from never to almost daily) along with demographic information. The principals received surveys asking about their support for the new teaching innovation as well as the demographic data for their school and community. The

instrumentation for the surveys was analyzed for reliability and each analysis has a reliability factor. Each variable had a reliability scale of > 0.80 found by using Cronbach's internal consistency measure coefficient alpha. To analyze the relationship between professional development and the indicators of inquiry-based teaching practices and investigative classroom culture, they used a series of hierarchal linear models.

The results of the study showed that increasing amounts of professional development time was statistically associated with greater teacher use of inquiry-based teaching practices and higher levels of investigative classroom culture. Only after 80+ hours of professional development did teachers report using inquiry-based teaching practices significantly more than the average teacher at a standard deviation of 0.2 more. The study also showed that minority teachers who represented 23% of the sample, demonstrated significantly more use of inquiry-based classroom practices and investigative classroom culture than their White counterparts. Teaching experience was associated negatively with investigative classroom culture. The greatest influence on teaching practices and investigative classroom culture was the teachers' content preparation and attitudes toward reform. Finally, teachers with a greater sympathetic attitude toward reform used inquiry-based practices significantly more frequently and had a more investigative classroom culture than more skeptical teachers ($p < 0.001$). Other school factors that played roles in the teachers' use of inquiry-based practices and investigative classroom cultures included the supportiveness of the school's principal, available resources, and time for planning. The largest

influence on teacher implementation of inquiry-based learning was the level of school poverty. In schools with higher levels of poverty, teachers were less likely to have an investigative classroom culture and use inquiry-based learning despite the hours of professional development.

This study indicates that although history has shown that professional development does not correlate with innovative teaching practices, using specified practices and extended practice in professional development series can increase teacher use of innovative practices. Other research has show that inquiry-based learning is key for understanding evolutionary theory and Suppovitz and Turner (2000) used inquiry as an innovative teaching technique in professional development. Supovitz and Turner selected subjects from a variety of demographics and clearly explained their selection and reliability and validity of their analysis backed by statistical data. Due to the wide range of participants and extensive number, this study has a higher mortality and transferability. A weakness of the study lies in the self-reported empirical nature of the survey and regression of the information.

A final study about other factors influencing the teaching of evolution in public schools was performed by Griffith and Brem (2004) who conducted a qualitative research study on 15 high school biology teachers to identify stressors surrounding the teaching of evolution as well as cognitive behavior processes that teachers develop to deal with those stressors. The study was voluntary, with participants from six schools in Phoenix, Arizona and consisted of six focus groups, a one-to-one interview, and a questionnaire.

The subjects in this study participated voluntarily and received letters about the focus groups for stress surrounding the teaching of evolution and a letter about the study on stress. Fifteen secondary high school biology teachers participated in the study and all were currently teaching a biology course or had taught at least one biology course that year.

The study consisted of six focus group meetings and teachers from the same schools were asked to attend different group meetings to allow each participant to speak freely about their experiences and feelings without fear of their responses getting back to other teachers or administrators in their school. In the videotaped focus group the teachers were asked to talk about their experiences with teaching evolution and could turn off the video tape if they felt necessary but only one group asked to turn off the tape for ten minutes to keep names off the record. After the focus group, the teachers completed a questionnaire that consisted of thirteen items about their demographics, 29 items about possible stressors surrounding the teaching of evolution, and asked them to complete a visualization activity in which they wrote down a brief curriculum surrounding a unit about evolution and also described their class during this unit. Directly following the visualization, the researchers administered a State-Trait Anxiety Inventory (STAI) to each teacher that lasted about 45 minutes. The STAI is a widely used clinical inventory to test how and where stress is coming from and has a reliability measure of 0.94. When teachers were done with the questionnaire, visualization, and STAI they had a 15 to 30 minute one-on-one interview with the researchers that focused on the school environment, perceived

impact of evolutionary theory on students, feelings experienced when writing the evolution lessons, and exploration of what elements of teaching evolution make them uncomfortable. At the end of the sessions, the teachers were encouraged to talk about their experience for another 30 minutes and discuss supports they believe would help them feel more comfortable teaching evolution.

Griffith and Brem (2004) examined the interview and discussion data by identifying all themes in each individual's dialogue and then placed them into three major categories: scientist teacher, selective teacher, and conflicted teacher. Through each category stressors and coping strategies were identified and then analyzed quantitatively through the questionnaire and State-Trait Anxiety Inventory by using a chi-square to compare the three groups. To check for reliability, other researchers and science educators reviewed their results.

The results showed that all studied teachers fell into one of three major categories, the scientist teachers, selective teacher, and conflicted teacher, based upon their dialogue, how they teach evolution, their identified sources of stress, and their coping strategies. The scientist teachers did not identify any internal stress, but expressed some situational and external stressors. Their coping strategies had to do with the fact that these teachers were not at all conflicted with their understanding and belief in teaching evolution but understood some of the problems with teaching evolution coming from outside sources and student conflict. This group of teachers had the greatest comfort teaching in teaching evolution, did not see as many possible negative consequences with teaching evolution ($p < 0.05$) and had the least anxiety

($p < 0.05$). The selective teachers used a lot of coping mechanisms to deal with a variety of stressors. It was too difficult to point out patterns of stress because it varied for these teachers and they coped with their stress by selectively choosing what to teach regarding content. The conflicted teachers had many stressors that usually came from internal pressures of how the teaching of evolution would be perceived. They also had difficult coping strategies that did not always work. These teachers had the least comfort in teaching evolution ($p < 0.05$) and had the greatest anxiety ($p < 0.05$). The overall result shows that teachers do not all have the same stressors surrounding the topic of teaching evolution and different coping strategies are used by different people.

The strengths in this study are in the reliability of the instrumentation, review of their analysis, and testing process to check for validity and reliability. Two weaknesses include the selection of the teachers for the study because it was limited to a small area and a small population of teachers and the nature of the empirical study simply identifying areas of stress and coping strategies.

The last five reviews of research articles all addressed other factors besides teaching practices and teachers' personal beliefs that affect the whether or not evolution is taught in their classroom. Bandouli (2008) and Moore and Kraemer (2005) looked at the effect of state standards upon whether or not public biology teachers teach evolution to the level specified. Bandouli discovered that state standards did not have an affect upon what teachers taught and Moore and Kraemer furthered this study by showing that two states with differing standards about teaching of evolution, does not have any effect upon

how teachers teach evolution. Moore (2004) discovered that teachers are not very aware of the legal issues surrounding the teaching of evolution and that many teachers are unaware that their teaching of creationism is unlawful. Teachers' personal beliefs interfere with the curriculum they are supposed to teach as described by the state curriculum standards. There are not any standards that allow or encourage teachers to teach creationism and there are not any laws that will not allow teachers to teach evolution in their classroom because it is such a large part of science and biology.

Supovitz and Turner (2000) discovered that teachers who attend lengthened, in depth professional development sessions over a longer course of time will be more likely to implement instructional innovation in their classroom which could help to alleviate the stress that teachers have about teaching evolution as seen in the study performed by Griffith and Brem (2004). Not all teachers are afflicted with the same type of stress and internal stress can be harder to cope with than external stress. Teachers, who believed they had a better understanding of the evolution-creation controversy and understood evolution and the nature of science, were more likely to teach evolution without worry of how students will react to a scientific theory that they may not believe due to their personal religious beliefs.

Summary

The analytical review of current teaching practices of biological evolution indicates that most biology teachers may cover evolution in their classroom although over a very brief amount of time, but many teachers may not cover

evolution at all, or instead teach creationism or both evolution and creationism. Studies about how to implement instructional strategies to deal with the controversial nature and difficult content around evolution suggest that courses that involve student prior knowledge, inquiry-based instruction, investigation, the nature of science, and structured discussion methods create better understanding in students and helps students to understand how the scientific community came to the acceptance of evolution. Research about biology teachers' beliefs about evolution imply that many teachers do not teach evolution because they themselves do not believe in it because of their religious values. Teachers who held misconceptions and had little knowledge about evolution were less likely to teach it. Students' prior beliefs also played a role in the difficulty in teaching evolution. Students who did not accept evolution because of their religious beliefs were less motivated to learn and learned facts rather than trying to understand. Other factors that affect the teaching of evolution in public school are state science standards that either do or do not emphasize the teaching of evolution, laws, professional development, and teacher stress.

In Chapter Four, the focus of this paper will be restated, findings summarized, classroom implications suggested and ideas for further research outlined.

Chapter Four: Conclusion

Introduction

This paper addressed the question, “What are the factors that affect how students understand the theory of biological evolution?” Chapters One and Two discussed societal, cultural, and educational issues that have historically influenced student acceptance and understanding of biological evolution. Chapter One concluded that the science has encountered many disagreements with several religions and science education has battled with the religious controversy surrounding the teaching of evolution since Charles Darwin published his book *On the Origin of Species* in 1859. Chapter Two outlined how the evolution controversy has played out in American schools and why it continues today.

Chapter Three reviewed the research that examined factors affecting and influencing student understanding and acceptance of the theory of biological evolution. The studies were organized into five major sections. Section one discussed the current evolution teaching practices of biology teachers. Section two reviewed innovative teaching practices toward the teaching evolution and its effects on student understanding of evolution. Section three outlined teachers’ personal beliefs and how they affect their teaching practices around evolution. Section four took into account students’ prior knowledge about evolution and the origins of life and how it affects their learning, understanding, and acceptance of evolutionary biology. Section five discusses other factors that influence how evolution is taught in public high school biology classes including state

standards, laws, professional development, and stress. In general, all the studies found evidence that personal beliefs played a major roll in attitudes about the teaching of evolution.

Summary of Findings

This first section of Chapter Three summarizes the finding of the reviewed literature. The literature search resulted in three research articles that identified the current evolution teaching practices, ten articles testing several methods of teaching evolutionary concepts for better understanding, seven articles identifying teachers' personal beliefs and the effects on teaching evolution, five articles about students' prior knowledge about evolution and the origins of life, and five articles identifying other factors that influence the teaching of evolution.

In the first section, which investigated the current teaching practices around evolution, all three articles were quantitative research studies and measured data through surveys. Moore (2007, 2008) used the three surveys identified to learn about what high school biology teachers taught about evolution and creationism in their classroom. Moore discovered that most teachers teach evolution in their classroom but for a short amount of time and some even teach creationism as a scientific alternative to evolution. Chuang (2008) surveyed biology professors at universities in Utah and discovered that some of them do not promote evolution or believe that evolution is central to biological concepts. All three of these studies show that some educators at high school and higher education are conflicted in their beliefs about biological evolution.

In the first section, the general weaknesses of the quantitative surveys chosen for this review were as follows. First, two of the studies had limited statistical analysis of their data and used percentages to compare correlations. Second, not all of the studies used a random population and limited where the study was performed. Moore (2007, 2008) used a single university in Minnesota to gather data possibly limiting the mortality of the study and also used data from students who were asked to remember back to their high school biology class and what their teacher taught about evolution. This data may not be very reliable because their memory might not be accurate.

In the first section, some strength in the studies were that Moore (2007, 2008) used a very large population to survey which contained a very diverse group of students from various ethnic and racial backgrounds. Chuang (2008) chose students in a random sample in the state of Utah and used samples from several universities and also used lots of statistical analysis for correlation between professors' demographics, their propensity to teach evolution, and their personal beliefs about evolution.

The second section examined new teaching practices and their effect upon students' understanding of biological evolution and related concepts; seven of the ten articles were quantitative and three were qualitative. In summary of the findings Verhey (2005) and Alles (2001) both studied the effects of using the nature of science to teach evolution and found that by using the nature of science and students' prior knowledge to structure a unit about evolution, students may understand evolutionary concepts better. Jensen and Finley (1996) and

Matthews (2001) used pedagogical strategies involving students' prior knowledge and evidence leading to evolution to teach students about evolutionary theory and discovered a positive gain in understanding of biological evolution. Sandoval and Morrison (2002) and Robbins and Roy (2007) used inquiry-based learning methods to teach students about evolution and found that students had a decrease in misconceptions and higher cognitive thinking about evolution. Khourey-Bowers (2006) discovered that using a Structured Academic Controversy could help students to peacefully discuss the controversial issues behind evolution and understand how scientists can accept evolution as the origin of life. Bischoff and Anderson (2001) and Marbach-Ad (2001) examined how students' cognitive frameworks form around science concepts and at what level of understanding students are able to use higher cognitive functions. They discovered that higher cognitive functions did not increase until students had lots of exposure and hands-on experience manipulating models. Finally, Stern (2004) evaluated biology textbooks and what levels of questioning they use in their tests and quizzes about evolution and discovered that most textbooks do not use appropriate questioning for allowing students to use higher-level thinking and evaluate what students really do or do not know.

In the second section of research reviewed, there were sampling weaknesses in several of the studies. Sandoval and Morrison (2003), Matthews (2001), Bischoff and Anderson (2001), and Stern (2004) all used a low number of subjects and did not use a very random sampling of students. Although Verhey (2005) used a larger number of subjects, the subjects studied were localized to

one school and class making the transferability difficult. Several studies did not account for the reliability of their instrumentation, Matthews (2001), Khourey-Bowers (2006), and Robbins and Roy (2007) did not explain how they arrived to the questionnaires or surveys used in their studies.

Strengths in the researchers' methods include the reliability in the instrumentation by Bischoff and Anderson (2001), Jensen and Finley (1996), and Sandoval and Morrison (2003) who used several experts to analyze their study, prototyped their questionnaires, and performed a reliable analysis with third parties. Sandoval and Morrison (2003) and Stern (2004) used a random selection of subjects in their study allowing for greater validity and transfer of results to other populations.

The third section of Chapter Three, which identified teachers' beliefs and how it affects their teaching of evolution, six of the seven articles reviewed were quantitative research studies. One was qualitative. Out of the six quantitative studies in this section, three measured data through surveys, and three used questionnaires. The qualitative study in this section combined questionnaires and interviews in its analysis.

The seven research articles reviewed what teachers personally believe about the origins of life and how it affects the teaching of biological evolution in their classroom. Rutledge and Warden (2000), Rutledge and Mitchell (2002), Trani (2004), and Nehm and Schonfeld (2007) researched if greater knowledge about evolution and the nature of science increased the likelihood that a teacher would teach evolution. Rutledge and Warden (2000), Rutledge and Mitchell

(2002), and Trani (2004) discovered a connection between teachers' knowledge about evolution and the nature of science and teaching evolution in their classroom. Nehm and Schonfeld (2007) found that increased teacher knowledge about evolution and the nature of science but did not see an increase in teachers who would teach more about evolution. Weld and McNew (1999) studied the relationship between teacher demographics and whether or not they teach evolution and discovered that teachers who belonged to a professional science education association and who had a good understanding of the nature of science were more likely to teach evolution and support the teaching of evolution. Meadows, Doster, and Jackson (2000) discovered that teachers who's religious beliefs conflicted with evolution had a very difficult time reconciling those differences enough to teach a fair representation of evolution in their classroom. However, their research indicated that some teachers are able to have religious values and still believe in evolution showing that there can be reconciliation. Ghaith and Yaghi (1997) used new teaching practices to see if teachers would feel comfortable using these new practices to not interfere with their personal faith and discovered that those teachers did not want to implement the new teaching practices.

In the third section, the general weaknesses of the quantitative studies chosen for this review were as follows: First, three of the studies had a low number of subjects and were localized to a small area. Ghaith and Yaghi (1997) selected a few teachers from one school to identify if teachers are willing to implement new teaching methods about evolution in their class and discovered

that many were not willing to change their current teaching practices. Second, not all of the studies used reliable instrumentation of statistical analysis of their data. Rutledge and Mitchell (2002) also did not answer the question they originally asked. Their study wanted to determine if teachers' knowledge structures were passed down to students and they discovered that there were correlations between more complex knowledge structure and more exposure to knowledge but the teachers were never analyzed to compare to students' knowledge structure.

In the third section, some of the strengths of the survey and questionnaire studies were that Trani (2004) and Nehm and Schonfeld (2007) used a very reliable and valid instrumentation method that has been used in several studies and had a reliability correlation of more than 0.84. Ghaith and Yaghi (1997) and Weld and McNew (1999) used extensive statistical analysis to see if their data correlated between various factors.

In the fourth section, which investigated the effects of students' prior knowledge on the learning of biological evolution, all five articles reviewed were quantitative studies. Four of the five articles measured data through surveys and one used a questionnaire.

The five research articles reviewed students' prior knowledge about biological evolution and the origins of life before entering a biology course and how it affects their understanding and learning about evolution. McKeachie, Lin, and Strayer (2002) and Blackwell, Powell, and Dukes (2003) studied topics about student achievement in evolution based upon religious beliefs. Blackwell,

Powell, and Dukes discovered that students who accept evolution have a better understanding of evolution than students who do not accept it. McKeachie, Lin, and Strayer (2002) found that students who perceived their religious beliefs to conflict with biological evolution had a lower motivation for learning about evolution that in turn affected achievement. Sinclair and Pendarvis (1998) studied evolutionary concepts that students have the most difficulty with and discovered that students have a lot of misconceptions about evolution that are not resolved in biology classes.

In the fourth section, a weakness was the poor sampling of some of the studies due to localization of the subjects to a single class or school. McKeachie, Lin, and Strayer (2002) and Moore, Froehle, Kiernan, and Greenwald (2006) studied a single class in one school that limits the transferability of the study and the number of subjects in the study. McKeachie, Lin, and Strayer (2002), Moore, Froehle, Kiernan, and Greenwald (2006), and Dagher and BouJaoude (1996) lacked statistical analysis of their data. All three studies relied upon percentages to make correlations. Sinclair and Pendarvis (1998) and Blackwell, Powell, and Dukes (2003) the demographics of the subjects in the study were omitted.

In the fourth section, some strength of the studies was that McKeachie, Lin, and Strayer (2002) used a well-known instrument that has been tested repeatedly for reliability in measuring student motivation for learning. Blackwell, Powell, and Dukes (2003) used a moderate number of subjects in their study in identifying how student acceptance of evolution affects their understanding.

The final section examined other factors that can affect student learning about evolution in a high school biology class. Four of the five articles were quantitative studies that used surveys to gather data for analysis and one article was a qualitative study that used a questionnaire and one-to-one interviews for data. In summary of the findings, Moore (2004) surveyed teachers to see if they understood the laws surrounding the teaching of evolution. The study showed that many teachers did not understand that they could not teach creationism in their classroom and even taught creationism along side evolution. Moore and Kraemer (2005) performed a study to see if state standards mattered when teaching evolution and discovered that two states with different science standards did not affect what teachers taught. Bandoli (2008) also studied state standards and teachers' propensity to teach evolution and found the standards did not matter. Supovitz and Turner (2000) studied professional development methods to see if focused sessions about innovative teaching methods would cause teachers to teach using those methods and discovered that newer teachers were more likely to use the teaching method and the more focused professional development hours teachers had, the more likely they were to use the new method. Finally, Grffith and Brem (2004) studied the stress that teachers get from teaching evolution and how teachers cope with those stressors. They found that not all teachers experience the same stressors and many cope with them in a variety of ways.

In the fifth and final section of research reviewed, there were sampling weaknesses. Griffith and Brem (2004), Moore and Kraemer (2005), and Moore

(2004) had localized samples that were not random. Moore and Kraemer (2005) and Moore (2004) used subjects that attended a science teacher conference and may have had biased views toward the teaching of evolution.

The strengths of the researchers' methods were how Moore (2004) and Moore and Kraemer (2005) were able to gather such a large sample size for their study. Supovitz and Turner (2000), Bandoli (2008), and Griffith and Brem (2004) used very reliable instruments in their studies that had been tested by third parties and in other studies for validity.

The research reviewed provided a good beginning for understanding some of the factors that influence achievement in evolutionary concepts while revealing the difficulties/limitations for conducting scientific research that succeeds in objectivity with transferable results.

Classroom Implications

What does the reviewed literature suggest for improvement in the teaching of evolution for better academic achievement and understanding of biological evolution? The information suggested from these articles presents many interesting possibilities.

The research of Moore (2007, 2008) suggests that teachers devote more time to evolution in their classroom and less time to creationism. Meanwhile, Chuang's (2003) study suggests that teachers need to place more importance around evolution as a major concept of biology and science and pass that importance off to their students. In addition, Chuang reported that professors from different universities held different beliefs that may be linked to school and

departmental values rather than their own personal beliefs. Matthews (2001) suggests that adding creation stories into the curriculum for students to examine along side evolution could help students to understand why creation stories exist and help to show how the nature of science provides evidence for biological evolution even though direct observation of some evidence is very difficult. Verhey's (2005) research indicates that using students' prior knowledge and understanding the level at which students are at in the nature of science and evolutionary theory can help improve overall achievement and motivation. Sandoval and Morrison (2002), Jensen and Finley (1996), and Robbins and Roy (2007) suggest that inquiry-based methods and problem solving can improve learning and helps students with hands on methods. By using inquiry methods students are able to see how evidence is produced and where it fits into scientists' understanding. Lengthened exposure and study of evolutionary concepts can help understanding as suggested by Bischoff and Anderson (2001) and Marbach-Ad (2001) who observed an increase in student understanding and higher level thinking in students exposed to evolutionary concepts after at least three weeks. According to other studies identifying what teachers teach about evolution, many teachers devote less than four class periods to evolution giving little time for students to think critically and understand the concepts put before them. Stern's research (2004) suggests that textbooks include better assessment of student understanding of evolutionary concepts so teachers can follow them and use them as guides of how to teach further lessons and where students are currently at in their understanding.

Ghaith and Yaghi (1997) and Weld and McNew (1999) showed that there is a significant correlation between teacher understanding and acceptance of evolution and the nature of science and whether or not a teacher teaches evolution in their classroom. This would suggest that teachers who understand and have better training in evolution and the nature of science will teach evolution in their classroom. These studies are supported by Rutledge and Warden (2000) and Rutledge and Mitchell (2002) who identified biology teachers' acceptance of evolution and misconceptions teachers had about evolution. Teachers who had many misconceptions about evolutionary theory were less likely to teach evolution such as belief that there is not much evidence supporting it. Trani (2004) and Nehm and Schonfeld (2007) tested to see if increasing a teachers' knowledge about evolution and the nature of science would increase their propensity to teach evolution. Their findings imply that some teachers are willing to teach evolution better than they had before because of the increased knowledge.

McKeachie, Lin, and Strayer (2002) and Blackwell, Powel, and Dukes (2003) found that students who did not accept evolution had a more difficult time understanding and had a lower motivation. Their research suggests that teachers take into account students' prior knowledge and teach about the nature of science and evidence that supports the scientific theory. That it is not a teachers' job to turn students away from their faith but to show them the evidence that supports the reasons the science community believes that evolution theory of the origin of life.

Bandoli (2008) and Moore and Kraemer (2005) discovered that state science standards did not affect how and what teachers taught students about evolution. This research suggests that better informing teachers about these standards and their importance may increase teacher awareness of why evolution should be taught to students. Moore (2004) examined the extent to which teachers understand the laws surrounding the teaching of evolution and discovered many misconceptions. Moore's study indicates that pre-service science teachers should have courses that explain their roles in teaching evolution and how legal issues fit into those roles. Supovitz and Turner (2000) saw some increase in teachers using innovative teaching methods after attending focused professional development sessions. Professional development sessions that focus on specific topics and strategies and extend over the course of more than one session may help to increase how and what teachers teach students about biological evolution. Griffith and Brem (2004) categorized the stress that teachers feel about teaching evolution and suggested that teachers learn to cope with stressors in a way that does not affect their teaching of evolution. They also found that teachers who had a broad understanding of evolution and the controversy had less internal stress and devoted more time to evolution in their classroom.

Though the studies indicate many implications for the classroom, it is important to examine the context and demographics of students in the education system and remember that science class is not a place for proselytizing or a place for changing students' religious views. With the inherent flaws in the public

school system, it is important not to loose sight of the laws that govern what can be taught in a public school. As a teacher, each period and classroom contains students with a wide variety of beliefs and conceptions about the world. It is the profession of the teacher to teach skills for students to use in the larger world.

Suggestions for Further Research

In the future, there could be more good long-term studies with more attention to student prior knowledge and overall achievement. Larger samples and larger demographics of subjects would be useful in further research. Studies that focused more upon high school students and changing classroom practices of evolution would be extremely useful in identifying what could be done for students in higher education.

Moore and Kraemer (2005), and Moore (2003, 2007) used data from college students who were asked to recall what their biology teachers taught about evolution. Those studies suggest that it would be very helpful if high school students could report what they were taught in biology for more accurate portrayals of what is taught in biology classrooms across the United States.

Few studies used a true experimental design with control groups. Using control groups to test innovative techniques toward teaching evolution would be very helpful to identify what improves student achievement.

It would also be useful to understand knowledge formation of students with prior knowledge about evolution or the origins of life a suggested by Blackwell, Powell, and Dukes (2003).

Summary

The major purpose of this study was to determine the factors that affect student achievement in biological evolution. The conclusions drawn indicate that teachers are faced with many conflicts in the teaching of evolution because of their personal religious beliefs, their students' religious beliefs, the communities' religious beliefs, and the difficult nature of evolution and the nature of science. Teacher need to have a strong understanding of evolution, the nature of science, and the controversy surrounding the teaching of evolution in public schools. These goals can be achieved if teachers are made aware of state science standards, laws surrounding the teaching of evolution, innovative teaching methods for better understanding, and how to gain information about evolution.

The evolution-creation controversy can be traced back to when Darwin wrote *On the Origin of Species* and it conflicted with previous held beliefs about how life was created. It is difficult for many people to reconcile their religious beliefs with the theory of evolution but many science educators and scientists have done just so. The amount of people believing in creationism is not shrinking and the controversy exits with the teaching of evolution. Students can understand evolution if teachers are aware of what they already know and they themselves understand as much as they can about evolution and the nature of science.

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