Understanding and acceptance of biological evolution and the nature of science: Studies on university faculty

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CHAPTER 1: INTRODUCTION

There are serious problems with biological evolution education. Since the time of Darwin resistance has existed to the idea that biological evolution via natural selection occurs. America has seen more than its fair share of opposition, particularly in recent history. From Scopes to Dover the teaching of biological evolution has been under attack. Most recently foes of biological evolution have argued that intelligent design (ID) is a valid scientific alternative. Those that suggest this hold fundamentally incorrect concepts of the nature of science (NOS), which has been shown to be a factor related to knowledge and acceptance of biological evolution.

But is biological evolution even worth fighting over? Isn't it "just a theory?" Isn't all science unproven? These are questions that members of the American public are struggling with and science educators need to help them address. Misconceptions about biological evolution specifically and science in general are pervasive in American society and culture. Some think biological evolution explains life's origins. Others think that hypotheses become theories, which then become laws. These misconceptions are reinforced in the media, in people's personal lives, and in some unfortunate cases in the science classroom.

Previous work has looked at several factors that are related to a person's knowledge of biological evolution, their acceptance of biological evolution, and their understanding of the NOS. Yet no one has examined the three variables together and how they relate to each other as a whole. It has not been determined which factors are the most pervasive influencers of a person's knowledge of biological evolution, their acceptance of biological evolution, and their understanding of the NOS. These are gaps in our knowledge that must be filled if we want to address the myriad issues surrounding BEE.

I was interested in investigating these variables in a highly educated population: university faculty. These are people who are not only involved in instruction, but are also active researchers. I suggest that by learning what faculty members understand about the NOS, their knowledge of biological evolution, their acceptance of biological evolution, what misconceptions they have, how those are related to their personal views as well as other factors we will gain an understanding of what we can do to make improvements that lead to a better education for students.

The primary questions of interest are:

1. What knowledge of biological evolution do faculty have?
2. How, if at all, does faculty knowledge of biological evolution differ among disciplines?
3. How, if at all, does faculty knowledge of biological evolution differ between theistic views?
4. What level of acceptance of biological evolution do faculty have?
5. How, if at all, does faculty acceptance of biological evolution differ among disciplines?
6. How, if at all, does faculty acceptance of biological evolution differ between theistic views?
7. What understanding of the Nature of Science (NOS) do faculty have?
8. How, if at all, does faculty understanding of the NOS differ among disciplines?
9. How, if at all, does faculty understanding of the NOS differ between theistic views?
10. How, if at all, do knowledge of biological evolution, acceptance of biological evolution, and understanding of the nature of science relate to each other?

There are also secondary questions of interest:

11. What is the relationship, if any, of these variables to the amount of science education received?
12. What is the opinion held by faculty across science disciplines of science teaching policies?

In order to effectively cover these questions, the content has been broken up into several chapters. Chapter 2 details much of the relevant background needed to understand the degree and scope of the BEE problem. It covers the recent history, including the political and the legal aspects, of the teaching of biological evolution. Additionally, current research on the effective methods of teaching evolution, the relationship between the Nature of Science and evolution, and those groups that have already been studied are discussed.

Chapter 3 presents data and analysis collected from faculty members at a large, Midwestern, public university regarding their knowledge and acceptance of biological evolution. Chapter 4 presents data collected from the same population, but focuses on their understanding of the NOS, as well as the relationship between evolutionary knowledge, NOS knowledge, and acceptance of evolution.

Chapter 5 discusses the importance of the results of this research, as well as the some of the participant responses to questions that were not discussed in Chapters 3 and 4, and concludes with some recommendations for further research.

CHAPTER 2: Literature Review

What is Biological Evolution?

In order to understand some of the complexities of the resistance to biological evolution education, it is necessary to first understand something about biological evolution. At the most basic level, biological evolution is a type of change over time. But that is far too simple a description. As time passes, many things change. In biological evolution change over time is better called "descent with modification". Basically, biological evolution proposes that all life on Earth shares a common ancestry, and that traits we see in populations of organisms can be inherited by future generations. It is this common ancestry, with the possibility that heritable traits can be modified that has led to the enormous diversity of life on Earth.

Biologists commonly represent the relationships between organisms in a phylogeny or "family tree". These phylogenetic trees branch and split to represent how closely related types (or species) of organisms are to each other. In Figure 1 for example, the phylogenetic tree shows species 1 and species 2 are more closely related to each other than either is to species 3. Additionally, species 1 and 2 share a common ancestor at split a, and all three species share a common ancestor at split b. These splits are speciation events resulting in two distinct species where before there was only one. Point c represents the original ancestor species of the entire lineage. Evolutionary biologists use many different kinds of information to form phylogenetic trees, including DNA sequence comparisons, physical characteristics, and observed behaviors.

One kind of information used to generate a phylogenetic tree is the presence or absence of homologous structures. A homologous structure is one that is derived from the same structure in an ancestor species. It is present in different organisms and is similar across those organisms. The forelimbs of vertebrates are one commonly cited example of a homology, because the bone structure and placement in the forelimbs of a human, cat, whale, and bat underlie the same basic pattern and position of anatomical structure (which is also apparent in their ancestor species). Granted, specific bones have undergone changes, (some becoming elongated, some thickened, etc.), but the similarity is there.

Another important piece of the BEE puzzle is deep time. The phrase deep time represents the billions of years that the Earth has existed, and thus the billions of years that life has had to evolve. Since the average human life span is not yet a hundred years, let alone thousands of years, it can be very difficult for us to comprehend just how much time we are talking about. Various analogies have been used, including comparing 4.54 billion years (the current best estimate of the age of the Earth) to the twenty-four hours of a day, the sixty seconds on a watch face, or the length of a football field. For example, the current estimate for the age of the earth is 4.54 billion years. If we imagine the Earth is a football player running from one goal line to the other (100 yards away), and as time passes he moves farther down field, we can place key events in earth's history on the field to help conceptualize how long 4.54 billion years is. The first evidence of land plants would be when the player makes it 90 yards downfield just a hair under the 10 yard line. Recorded human history (about 5000 years) would be when the player is one tenth of a millimeter (0.004 inches) from the goal line. Understanding deep time helps scientists explain how seemingly large changes can occur gradually through natural selection. Scientists use several tools to help them figure out approximately when certain evolutionary events occurred, including radiometric dating, stratigraphy, and molecular clocks.

There are several important property of organisms that results in biological evolution, but heritability is arguably the best to start with. When biologists talk about heritability, what they mean is that traits in one generation can be passed to future generations. When the frequencies of heritable traits change over time across generations, biological evolution is said to have occurred. For example, let's say you observe a population of birds that are 50% blue and 50% red. After 10 generations you observe the population again and find that it is now 80% blue and 20% red. Since the frequency of the traits has changed over time we would conclude that biological evolution has occurred in this population.

What can cause such a drastic change in a population? One possible explanation used by evolutionary biologists would be migration. In this case, the change in the frequency of the traits can be explained by either the arrival of blue birds into the population, the departure of red birds from the population, or a mix of both.

Genetic drift is a second possible explanation for the observed changes. Perhaps a tornado came through the habitat and, by chance, only hit trees containing red bird nests. This chance elimination of individuals that express one trait but not the other could also account for the change in the frequency of the red and blue traits observed in the population.

The cause of biological evolution that is most discussed by evolutionary biologists, and was the seminal idea of Charles Darwin and Alfred Russell Wallace, is natural selection. There are four postulates that result in evolution by natural selection. 1: there is variation in traits in populations of organisms; 2: this variation is tied to fitness; 3: at least some variation is heritable; and 4: more individuals are produced than can survive and reproduce in the next generation. In the example above, there is some variation in the trait of coloration (red and blue), coloration is heritable, the environment that these birds inhabit cannot support an infinite amount of individuals (no habitat can), and not every bird will be able to maximize their reproductive output. It could be that as the habitat gets crowded the blue birds are more difficult prey for a predator species, leading to more red birds being eaten and thus removed from the population prior to reproduction (thus lowering the fitness associated with being a red bird). Blue birds would be more likely to survive and reproduce leading to the observed shift in the frequency of the coloration traits.

State of Biological Evolution Education Research

History of issues with Biological Evolution Education (BEE)

That some segments of humanity have rejected biological evolution (the production of biological diversity by evolutionary processes such as natural selection) as the explanation for the diversity of life on Earth is not surprising to most people. What they may not be aware of, however, is how long resistance to biological evolution has existed. Prior to the publication of Darwin's *On the Origin of Species* in 1859, the concept of divine (or godly) design in nature was largely assumed by the scientific community, as well as the population of the European/Western world as a whole (Paley, 1794). Their thinking was largely informed by Aristotle, and his philosophy of the 'perfect kind' from which we have the 'type' specimen and imperfections around the archetypical design. The scientific philosophy of Aristotelian Essentialism prevailed from the Renaissance through the late 17th century. Species were believed to be immutable, perfect, and eternal. Thus, everything that is has always been, and nothing ever changes. It was during the 17th and 18th centuries that data began to get in the way. Fossils of currently extinct species (e.g. dinosaurs) were found more and more frequently. Voyages around the world were eliminating the possibility of refuges. Additionally, animal breeders had already shown that they could change the traits of organisms across generations, so they clearly were not immutable. These events and data, coupled with the release of Darwin's concept of biological evolution via natural selection forced a debate among philosophers and scientists. Some seriously doubted whether design was truly represented in nature, while others strove to reinforce and defend its presence.

Among the most well known of these defenders was the Archdeacon William Paley. His argument of design in nature was that: "as the telescope has a telescope maker, so likewise the eye has an eye maker . . ." (Paley, 1802). This was a very powerful analogy in the minds of the learned elite of the1800's. So convincing is this argument, that even two hundred years later it has adherents. Paley was not the only voice for design during this period. Other arguments developed around the proto-evolutionary concepts that came about in the late 18th and early 19th centuries. Both Jean Lamarck and Erasmus Darwin (grandfather of Charles) argued for the inclusion of the Christian god in evolutionary thinking (Darwin, 1794; Lamarck, 1809).

Resistance to a theory of biological evolution that did not require a designer was not limited to the British Isles. The scholars of mainland Europe had access to similar data, but were coming up with their own explanations for what they saw. One such scholar was Georges Cuvier, who cited the lack of intermediate forms in the fossil record as evidence against the possibility of gradual biological evolution. His theory of Catastrophism suggested that the fossils seen in the geological record were a result of major destructive events, such as worldwide floods, which would lead to drastic changes in organisms. According to Cuvier, these events wiped out the majority of life in a particular area each time, and migration from other unaffected areas filled in all the newly empty spaces (Cuvier, 1827; Ruse, 2005). While Cuvier himself was not a proponent of design, he was aware that his theories aligned with events described in Christian mythos. Even today his papers are cited by creationists as supporting evidence that their own ideas about several concepts, including the biblical flood, are accurate (Gillispie, 1996).

It was in this context that Charles Darwin returned after his five-year voyage on the HMS Beagle. After arriving home in 1836, he spent over two decades compiling his thoughts, fully aware of how divisive his concept of biological evolution would be to the scientific community. At several points during this twenty-year period, Darwin tested the waters of the scientific community to see how they would react to his ideas of biological evolution by natural selection. Each time he felt that they were not yet ready to objectively judge his work (Ruse, 2005). Eventually another biologist who

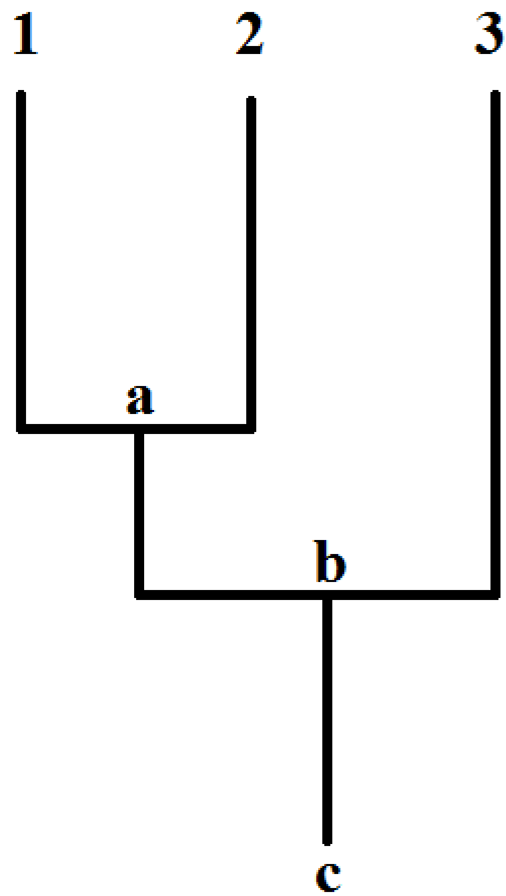

Figure 1: A basic phylogenetic tree of three species

had traveled the world, Alfred Russell Wallace, would also realize the power of biological evolution by natural selection as a scientific explanation for the diversity of life on Earth (Wallace, 1870). Wallace contacted Darwin for comments on his idea of natural selection, and Darwin realized that he was about to be scooped on his life's work. Fortunately for Darwin, he had friends who were able to setup a joint reading of both of their works in front of the academic community (Darwin and Wallace, 1858; Ruse, 2005). This was the encouragement that Darwin needed to publish his work separately as a book, and describe his evidence for how species arose. Once *The Origin of Species* was published, Darwin encountered the public reaction that he expected, one that was both intensely positive and intensely negative. Religious scholars, scientists, and even members of the general public contested the validity of his theory of biological evolution by natural selection, while others vigorously defended it and his overwhelming evidence for evolution (Browne, 1995; Browne, 2002; Ruse, 2005). Darwin soon found himself maligned in the public press, both in text and in caricature.

While the initial reaction to Darwin's concept of biological evolution via natural selection was mixed, by 1865 it had become required reading as part of a degree in the sciences at both Oxford and Cambridge (Hull, 1973; Ruse, 2005). The acceptance of biological evolution in the scientific communities of Europe would not, however, initially translate to the United States of America.

In the U.S., as in Europe, Darwin's theory received a mixed reception. One advocate for biological evolution via natural selection was Asa Gray, the noted Harvard botanist. While Gray was an ardent supporter of Darwin's theory, he remained a theistic evolutionist (i.e., someone who accepts that evolution occurs, but insists that god must have played some role) throughout his life. His interpretation of natural selection was that it was actually directed process, and that director must be the Christian god.

Geologist/paleontologist Louis Agassiz, also of Harvard, did not find Darwin's work convincing. On multiple occasions in the 1860's Agassiz and Gray debated the topic of biological evolution in public forums with neither being convinced of the other's viewpoint. Agassiz continued to resist biological evolution for the rest of his life, stating that Catastrophism theory based on ice-age events was a more reasonable explanation for the fossil record (Agassiz, 1885).

The debate between Agassiz and Gray was a well-publicized example of the larger debate occurring in American society. Eventually biological evolution became widely accepted in academic circles, but amongst the general public it was largely ignored or forgotten. From the average person's perspective, knowledge of biological evolution had little impact on their daily life. Public schools across the U.S. were largely free to teach biological evolution, creationism, or a mix of both in any way that they wished. The academic debate on the validity biological evolution was over, but the debate of whether to teach it in public schools was yet to come.

Biological Evolution and America

The discussion of the relative merits of creationism and evolution was relatively quiet for several decades, until just after World War I. It was the trial of teacher John T. Scopes that would ignite the fire of the educational debate of whether to teach biological evolution in public schools. By the time of the Scopes trial in 1925, there was little discussion of the scientific validity of biological evolution in the scientific community. What had been festering for the last few decades in school systems across the U.S. was a resistance to students being instructed in biological evolution via the governmentally funded public education system. Many parents were not comfortable or happy with their children being taught science that contradicted their theological beliefs. While this "discomfort" was widely publicized in the southern states, there were also instances of dissent in the more industrial north such as in Delaware and Minnesota (Scott, 2005). Many state legislatures began explicitly banning the teaching of evolution or other non-Christian based explanations for biological diversity in their K-12 public school systems. One such ban, The Butler Act, was a law in Tennessee that prohibited all public school teachers from denying the Christian biblical account of man's origin, as well as making illegal the teaching of the biological evolution of man from "lower orders of animals" in place of the biblical account. The American Civil Liberties Union decided to test the legality of this state law and actively sought a Tennessee biology teacher who would intentionally violate the law so that a test case could be brought to trial. They found their volunteer in John T. Scopes. Scopes went about incriminating himself (by teaching biological evolution), and just two months after the Butler Act had been signed into law, he was indicted by a grand jury (Larson, 1997).

The trial quickly became national news, billed in the Baltimore Sun as the "monkey trial" and was the first criminal trial to be broadcast over the radio in the U.S. (Clark, 2000). The trial was full of exciting debate and theatrics, but ended with Scopes being found guilty and required to pay a fine of $100 (around $1,250 in 2010 dollars). Following the conclusion of the trial an appeal was filed, which resulted in the Butler Act being declared constitutional by the Tennessee Supreme Court. The court set aside Scopes 'conviction however, due to a legal technicality. According to the state constitution the jury should have decided the fine, rather than the judge. Soon after the trial was over, state legislatures across the U.S. tried to pass similar anti-evolution laws. By 1927 thirteen other states had considered some form of anti-evolution law, with such laws being fully adopted in Mississippi and Arkansas (Curtis, 1986; Halliburton, 1964).

For 30years after the Scopes trial, discussion of the teaching of biological evolution was again quiet in public arena (Moran, 2004). States were again left to enact whatever anti-evolution law they saw fit. It was not until the launch of the Soviet Union (U.S.S.R.) satellite Sputnik-1 in 1957 that America began to doubt its scientific dominance. With the Russian satellite beeping overhead, terrified Americans began demanding improved science education. Biological evolution education (BEE) received significant attention as a by-product of the larger discussion on improving science education. In response to the public's fear that America was lagging behind the U.S.S.R in science, the federal government began a textbook development program with the explicit goal of bringing science education in the K-12 system up-to-date in all fifty states. The content and organization of these new textbooks reflected the way science was being taught at the university level, rather than as it had been previously taught at the K-12 level. The result was detailed inclusion of current biological evolution content in textbooks distributed throughout the U.S. Biological evolution also featured prominently in National Science Foundation (formed in 1950) supported biology curriculum projects of the 1960s. These events quickly drew the attention of fundamentalist Christians in America, who were not pleased to see their religious beliefs once again contradicted by scientific teachings in the schools (Scott and Branch, 2006).

The reaction of the fundamentalist Christian community to biological evolution being introduced in every public school system in the U.S. was to produce their own "scientific" data that they claimed contradicted biological evolution. The shift away from pursuing purely legislative measures was largely due to the lack of progress they had found outside of Mississippi, Arkansas, and Tennessee. One book fundamentalist Christians pushed to have included in schools was *The Genesis Flood* (1961) by John C. Whitcomb and Henry Morris. Morris and Whitcomb claimed to have scientific evidence that the flood described in the Bible actually occurred. They also stated that their evidence supported a 10,000-year-old (or younger) Earth, which would contradict not only biological evolution, but most of the geological sciences. Henry Morris would end up becoming a major figure in the fight against the teaching of biological evolution. He was the founder of both the Creation Research Society (CRS) in 1963 and the Institute for Creation Research (ICR) in 1972. Both of these institutions became significant players in the debate over BEE (Scott and Branch, 2006).

As groups like the CRS and the ICR began to push for laws either allowing their creation science in public schools or banning biological evolution from the classroom; proponents of good science education fought back. One specific legal fight culminated at the U.S. Supreme Court. In their ruling on Epperson v. Arkansas in 1968, the Supreme Court found that the Arkansas statute banning the teaching of biological evolution in public schools violated the Establishment clause of the First Amendment of the U.S. Constitution. They argued that such a ban was tantamount to the state tailoring teaching and learning to the principles, or prohibitions, of a specific religious sect or dogma (in this case, a Christian-based one) (Larson, 2003).

With banning the teaching of evolution completely off the table, the push to develop and implement "creation science" quickly led to other legal challenges. Soon laws were being submitted in state legislatures calling for equal time for both biological evolution and creation science. Equal time laws required that biological evolution and creation science be given the same amount of instructional time in public schools. Laws of this type succeeded in several states including Arkansas (McLean v. Arkansas, 1982), and national attention was brought to the issue again in 1987. That was the year the U.S. Supreme Court in Edwards v. Aguillard struck down a Louisiana statute called the Balanced Treatment Act. The Balanced Treatment Act required the Louisiana public schools to teach creation science if they taught evolution, and to teach evolution if they taught creation science. In their brief, the Supreme Court held that the statute violated the Establishment Clause of the First Amendment by implying a governmental endorsement of a specific religious belief system (again, a Christian-based one) (Beckwith, 2003). The court's majority opinion in that case and similar later cases was focused on the need/desire to keep state and federal agencies out of religious matters. Initially the court's opinions were based on their interpretation of the First Amendment of the U.S. constitution and used both the Lemon test and later the endorsement test (Edwards v. Aguillard, 1987).

The Lemon test is made up of three prongs, which are considered to be separate, yet complementary. The three prongs of the Lemon test are: 1) The government's action must have a legitimate secular purpose; 2) The government's action must not have the primary effect of either advancing or inhibiting religion; and 3) The government's action must not result in an "excessive entanglement" with religion. If any of these prongs are violated then the law or policy being examined is considered to be unconstitutional (Lemon v. Kurtzman, 1971).

The endorsement test, originally proposed by Justice Sandra Day O'Connor, states the following: "The Establishment Clause prohibits government from making adherence to a religion relevant in any way to a person's standing in the political community. Government can run afoul of that prohibition . . . [by] endorsement or disapproval of religion. Endorsement sends a message to non-adherents that they are outsiders, not full members of the political community, and an accompanying message to adherents that they are insiders, favored members of the political community" (Lynch v. Donnelly, 1984).

These two tests, as well as other legal rulings over the next decade forced the creation science movement to change their tactics. The idea of equal time for creation science was eventually discarded, and a new focus on what they called "intelligent design" was put forth. Intelligent Design "Theory" (ID) is the idea that "certain features of the universe and of living things are best explained by an intelligent cause, not an undirected process such as natural selection" (IDEAC, 2004). It should be considered a form of creationism as it attempts to adapt the traditional teleological argument for the existence of a deity into "an evidence-based scientific theory about life's origins" rather than "a religious-based idea". While the connection between creationism and ID is well established, most proponents of ID specifically avoid the suggestion that the intelligent designer is a deity (god) (Kitzmiller v. Dover Area School District, 2005).

ID was first popularized by the conservative Christian non-profit organization: The Foundation for Thought and Ethics (FTE). The FTE, along with the ICR, the Discovery Institute, and other groups, have been responsible for several books, lectures, and films on the topic of creationism and intelligent design. Perhaps the most well known of these products are the book *Of Pandas and People: The Central Question of Biological Origins* (also called *The Design of Life: Discovering Signs of Intelligence in Biological Systems*) and the movie *Expelled: No Intelligence Allowed* (Scott and Branch, 2006; Shermer, 2008). The most damning evidence that ID is based on creationist thinking rather than sound science was the "Pandas" book. During a recent major legal case investigators found that everywhere that an earlier edition of the book used the term “God”, the current edition used the term “intelligent designer”, in a literal word-for-word replacement (Matzke, 2006).

One of the current major modern players acting in the debate on BEE on the side of intelligent design is the previously mentioned Discovery Institute. This group considers itself to be an ID think tank and currently serves as the primary base for publications and media related to the ID movement. The Discovery Institute claims to fund research in ID, produces publications on ID (including multiple online podcasts and related material), and encourages legal action promoting ID in public and private school systems. The legal actions supported by the Discovery Institute typically take the form of bills put forth before state legislatures calling for schools to “teach the controversy” or to teach “all the science” on the topic of biological diversity (implying that ID is science) (Scott and Branch, 2006). The goal of these actions is to force instructors to teach the false controversy that they claim exists in the scientific community’s understanding of the theory of biological evolution. This can take various forms, including pressuring teachers to have their students “critically analyze” biological evolution and to teach that biological evolution is “just a theory” (using the lay definition of theory) rather than being based on massive amounts of evidence.

The most recent major legal event of note was in 2005. A lawsuit between the Dover Area School District and parents from Dover, Pennsylvania was brought before the United States federal district court. The Dover case is an example of fundamentalist Christians attempting to directly influence local school board policy, rather than pass a law at the state level. In Dover, the school board enacted policies that explicitly endorsed intelligent design as an alternative to evolution. The case received national publicity in both print and television media, and suddenly the debate about BEE was at the forefront of the public’s mind. Former President George W. Bush (in office at the time) was asked about the issue of teaching intelligent design alongside biological evolution during a press conference, responding: “I felt like both sides ought to be properly taught” (Baker and Slevin, 2005). U.S. District Court Judge John E. Jones III presided over the six-week trial, during which a large amount of evidence and testimony from scientists, intelligent design proponents, school board members, and parents was presented. The primary issue at hand was a resolution that had been passed by the Dover Area School Board. It stated: “Students will be made aware of gaps or problems in Darwin’s theory and of other theories of evolution, including, but not limited to, intelligent design. Note: Origins of Life is not taught” (Kitzmiller v. Dover Area School District, 2005).

In the end, Judge Jones applied the same tests that had been used regarding creation science: the endorsement test and the Lemon test (Kitzmiller v. Dover Area School District, 2005). In his ~125 page decision, he found that intelligent design was not science, rather it was creationism given a new label. In his brief, he describes how the policy set by the Dover Area School Board amounted to an endorsement of religion, and the clear purpose of the policy was to advance/promote a specific religion (in this case, Christianity). Most legal scholars agree with the ruling that the school board’s policy was clearly a violation of the First Amendment (Irons, 2007).

While many of those who support ID and creation science would have the public believe otherwise, it is critically important to keep in mind that this issue of teaching evolution, creationism, and intelligent design in public schools is a science education controversy, rather than a controversy within the scientific community (Hildebrand et al., 2008). Scientists across the globe have long agreed that biological evolution is a proper field of research and an integral part of an effective education in the biological sciences. It is only in the sphere of public education that any noteworthy disagreement occurs.

All of the arguments put forth by creationists, ID proponents, and fundamentalists have failed when put under the legal microscope, though not for lack of trying. While it has been several years since the last major legal battle, it is reasonable to predict that legal challenges will continue in the future. In the last two years alone state legislatures and school boards in thirteen states have attempted to pass laws or policies that are anti-evolution in some way (NSCE, 2012).

Importance of Biological Evolution Education

An underlying assumption running through this work is that having an understanding of biological evolution is important, and thus effective education in biological evolution is also important. But is this case? What is gained by someone who understands biological evolution?

The often quoted Theodosius Dobzhansky said “Nothing in biology makes sense except in the light of evolution.” One of the most impressive aspects of biological evolution is how it ties the field of biology together. It is a unifying concept that informs every aspect of biological knowledge, from genetics to ecology, from medicine to molecular biology. Our understanding of the consequences of biological evolution allow us to make improvements at both the societal and personal level.

Some philosophers would agree that an understanding of human nature begins with an understanding biology in the sense that one can now (with our current understanding of biological evolution) possibly grasp what a human being really is. We also can understand the limitations and characteristics of human beings that come from our own evolutionary history.

In addition, an understanding of biological evolution provides a useful context from which to consider the natural world. While some worry that biological evolution removes humanity from the “special” or “favored” status described in some religious texts, in fact many find that an understanding of biological evolution reinforces our unique position in the tree of life. Given the amount of time and the likelihood of various events occurring, humanity can be considered a unique and interesting product of the natural world.

The field of medicine is a good example of an area where an understanding of biological evolution is resulting in significant improvements in human welfare. The premise behind evolutionary medicine is that since human beings are animals we are subject to the same sort of natural phenomena, including natural selection and other evolutionary mechanisms. In this context, evolutionary medicine attempts to understand the origin of disease, why we have certain kinds of disease, and how we can fight them using evolutionary principles (e.g. our co-evolution with various pathogens). One prominent example is that of bacteria and antibiotics. For decades we have not been using antibiotics intelligently. We should use multiple antibiotics in a careful regimen. If we use single antibiotics and we don't use them carefully enough (ensure an effectively 100% kill rate), what we end up doing is selecting for antibiotic resistance in the pathogen. The origin of resistance to antibiotics is an eminently evolutionary mechanism, and if we understand how biological evolution works, then we can more effectively deal with current and future bacterial pathogens.

Biological evolution is important for conservation because conservation biology, dealing with how species expand or contract in the environments they occupy, is an evolutionary problem. Some species are very successful and they occupy many different environments. They spread very rapidly, and in some cases invasively. Other species are dwindling down to extinction. Their environments are changing too rapidly for them to adapt. These are evolutionary and ecological processes. Changes in populations, demographics, and genetics over time are all factors relevant to biological evolution. Thus biological evolution is relevant to conservation because conservation biology essentially represents the same sort of basic questions and problems that evolutionary biologists deal with. With a better understanding of biological evolution, those responsible for conservation policy should be able to make more informed decisions regarding the welfare of a species or habitat.

Agriculture as it is today is essentially applied biological evolution. Farmers (and agricultural corporations) use evolutionary processes to improve their crops and their animals. This form of selection (artificial selection) was noted by Darwin and has been known (if not wholly understood) by humanity since before recorded history (~5000 years). Humanity is also actively changing the environment via agricultural and other processes, creating new challenges to the species that surround and exist in them. When we plant a particular crop in a particular area, for example, all of a sudden that environment has changed, from an ecological perspective, and all the animals and plants that live in that area are now faced with a new environment. A new environment poses an evolutionary challenge. There will be natural selection on the insect population to take advantage of the new plants in this new environment. In a sense agriculture is both an example of how human beings can use biological evolution to their advantage, but also how people change their environment and cause new natural evolution as a response to the changes.

Modern forensics is another example of the usefulness of biological evolution. The way that investigators interpret and analyze DNA evidence in forensic cases depends on the principles of biological evolution. To be able to say that a DNA match for a suspect is significant to a case, investigators have to know something about the distribution of that particular kind of DNA in a human population and the frequencies of DNA involved in that population. Knowledge of how human populations evolve is required to make meaningful comparisons between the suspect data being considered.

Misconceptions regarding BEE

One the major hurdles to overcome in BEE is the prevalence of misconceptions about biological evolution. Some misconceptions are more commonly encountered than others, and some are more relevant to the groups examined in the following pages.

A commonly encountered misconception about biological evolution is that it explains the origin of life (Paz-y-Mino and Espinoza, 2009; Rice et al., 2010). While the theory requires the origin of life by some mechanism as a starting point, this is not the central focus of biological evolution. Biological evolution deals with how life diversified *after* its origin. Precisely how life started is largely irrelevant to biological evolution, as it simply explains the process by which life diversified from that starting point to the current biological diversity we see on earth today.

Some people take exception to the presence of any randomness in biological evolution. While stochasticity (randomness) is a prominent element of mutation, the other important mechanisms of biological evolution are non-random and result in the overall process being very non-random. For example, consider the process of natural selection, which can result in adaptations to an environment, e.g., the ability of bats to echolocate. Such an amazing adaptation clearly did not come about "by chance." It evolved via a *combination* of random and non-random processes. Certainly the process of mutation, which generates genetic variation, is random, but natural selection is not. Natural selection favors variants that are better able to survive and reproduce, e.g., navigate in the dark. Over many generations of random mutation and non-random natural selection, complex adaptations evolve. To say that evolution happens "by chance" is to ignore much of the evolutionary picture.

Another common misconception about biological evolution is that understanding it will lead to a person becoming an atheist. Depending on where you live and work in the U.S. it may or may not be socially acceptable to be openly atheistic. Many people in the U.S. still associate atheism with an inherent lack of morals and even explicit evil. Some fear that if a person understands biological evolution they will automatically disregard their previous belief systems and replace them with one based on biological evolution.

Biological evolution does not make ethical statements about good and evil. Some misinterpret the fact that it has shaped animal behavior (including human behavior) as supporting the idea that behaviors that are "natural" are therefore the good or "right" ones. This is not necessarily the case. It is up to society and individuals to decide what constitutes ethical and moral behavior. It is important to understand that while biological evolution does inform us regarding what traits and behaviors are evolutionarily preferred (e.g. result in increased fitness), this does not translate to a ethical or moral judgment. Organisms that exhibit behavior X might produce more offspring than organisms that exhibit behavior Y, but that does not make behavior X ethically or morally correct. Biological evolution helps us understand how life has changed and continues to change over time, but it does not tell us whether these processes or the results of them are "right" or "wrong". This misconception has led to some of the worst misuses of scientific knowledge in history, such as forced sterilization and genocide.

It has been suggested that since biological evolution includes the idea that all organisms on Earth are related, and thus that humans are animals, humanity should to behave as animals do. While we do share anatomical, biochemical, and behavioral traits with other animals it does not logically follow that a person, upon learning that they are related to all other animals, will start to behave like a tree sloth or any other animal. Neither is this supported by evidence. We do not see preeminent evolutionary biologists building nests of twigs in their homes or flinging feces when they are upset. Of course, there is no evidence for the reverse viewpoint, that humanity is “special”. The evidence shows that we are one twig on a large branching tree of life on earth, not the lone organism sitting atop the ladder of life.

Contrary to the beliefs of some members of the public, the theory of biological evolution is not in crisis. Scientists accept biological evolution as the best explanation for life's diversity because of the multiple lines of evidence supporting it, its broad power to explain biological phenomena, and its ability to make accurate predictions in a wide variety of situations. Scientists do not debate whether evolution took place, but rather continue to refine the many details of how evolution occurred, and continues to occur, in different circumstances. It is these debates over the details of biological evolution that some in the public hear about and misinterpret as debates about whether evolution occurs. Evolution is sound science and is treated accordingly by scientists and scholars worldwide.

Some people get the impression (thanks in no small part to the national media) that science (which includes biological evolution) and religion are at war, and that one has to choose between them. This is not necessarily correct. People of many different faiths and levels of scientific expertise see no contradiction between science and religion. For many of these people, science and religion simply deal with different realms. Science deals with natural causes for natural phenomena, while religion deals with beliefs that are (for the most part) based on ideas beyond the natural world (i.e. the supernatural). Furthermore, the idea that people cannot understand and accept biological evolution and still hold onto their personal religious faith is not supported by the available data. Many scientists and religious scholars accept the validity of biological evolution, and yet continue to practice (or fervently believe) their personal religious faith (Miller, 1999).

Of course, some religious beliefs do explicitly contradict scientific conclusions. For example, a literal interpretation of story of the creation of the earth in six days (as found in the Bible, the Torah, and the Quran) does conflict with currently accepted data (e.g. the fossil record) in biological evolution (as well as geology and cosmology). Many religious groups, however, have no conflict with biological evolution or other areas of science. In fact, many religious people, including theologians, feel that a deeper understanding of nature enriches their faith.

When science and religion are presented as opposing sides, instead of pushing for the elimination of the science content, people argue that both should be discussed equally. Specifically, in this case they want both biological evolution and creationism taught in science classes as viable explanations for the diversity of life on earth. Pushing for equal time for two “sides” does not make sense when the two "sides" are not actually equal. A significant amount of data from multiple lines of investigation exists that supports biological evolution. No such scientific evidence exists supporting any other explanation (religious or otherwise) for the diversity of life on earth.

Religion and science are very different endeavors. Religious views do not belong in a science classroom. A debate that pits a scientific concept against a religious belief has no place in a science class and misleadingly suggests that a "choice" between the two must be made. The "fairness/equal time" argument used by groups attempting to insert their religious beliefs into science curricula creates this forced choice. It is perfectly reasonable to teach alternative supernatural explanations for the diversity of life in a religious setting, but not in a science classroom. Science deals only with the natural world. To suggest that a particular religious concept must be taught in a science class (or as science) is no more logical than if we were to force science content to be taught in churches. Even if it were appropriate, by definition the “equal time” argument means that all alternative supernatural explanations for the diversity of life on earth must be discussed. At last count humans have thought up over eighty seven distinct supernatural explanations for the existence (and by extension the diversity of life). A science class forced to cover all of these explanations would not have time to cover any actual science!

The misconception that biological evolution is not observable and/or testable encompasses two incorrect ideas: 1) that all science depends on controlled laboratory experiments, and 2) that evolution cannot be studied with such experiments. First, many scientific investigations do not involve controlled experiments or direct observation with the naked eye. Astronomers cannot hold stars in their hands and geologists cannot go back in time, but both can learn a great deal about the universe through observation and comparison. Detectives need not be present during the commission of a crime to be able to deduce who stole what from where. In the same way, evolutionary biologists can test their hypotheses about the history of life on Earth by making observations in the real world. Second, while scientists can't run a direct experiment that will tell us how the mammalian lineage diversified, many aspects of biological evolution can be examined with controlled experiments in a laboratory setting. Organisms with short generation times (e.g., bacteria or fruit flies) can be used to actually observe biological evolutionary processes in action over the course of an experiment. There even are some cases where biologists have observed biological evolution occurring in the wild (Grant and Grant, 2002). Humans are often the cause of major changes in the environment, and thus are frequently the instigators of biological evolution in other organisms. Scientists have observed insects like bedbugs and crop pests evolving resistance to our pesticides. Bacteria and viruses have evolved resistance to our drugs. These are just a few of the examples of observable biological evolution.

In addition, science can make predictions and hypothesize about phenomena that cannot be tested with current methods. An excellent example of this is the work of Albert Einstein. Parts of his theory of general relativity were not testable given the methodology available at that time (1915), but are now being tested (such as the existence of gravitational waves). Others such as the Einstein-Rosen Bridge (commonly known as a wormhole) have been shown to be theoretical possible, but have not been observed and are thought to be not yet testable given current technology and methods.

In an evolutionary sense, the word “fitness” has a very different meaning than the way we might use it in every day discourse. An organism's evolutionary fitness does not indicate anything about its health, but rather its ability to pass its genes to the next generation. The more offspring an organism leaves in the next generation, the fitter it is. This does not necessarily mean the offspring are the strongest, fastest, or largest. For example, a physically weak male bird with bright tail feathers might leave behind more offspring than a stronger, dull-colored male. Evolution is not ‘survival of the fittest’ but rather ‘survival of the good-enough’.

Though "survival of the fittest" is the catchphrase of natural selection, "reproduction of the fit enough" is more accurate. In most populations, organisms with many different genetic variations survive, reproduce, and leave offspring carrying their genes in the next generation. It is not simply the one or two "best" individuals in the population that pass their genes on to the next generation. This is apparent in the populations around us. For example, a plant may not have the traits (genes) to flourish in a drought, or a predator may not be quite fast enough to catch her prey every time she is hungry. These individuals may not be the "fittest" in the population, but they may be "fit enough" to reproduce and pass their genes on to the next generation.

Biological evolution is based on changes in the genetic makeup of populations over time. Populations, not individual organisms, evolve. Changes in an individual over the course of its lifetime may be developmental (e.g., a white tailed deer growing antlers) or caused by environmental factors (e.g., a snowshoe hare’s fur becoming white as winter approaches); but these changes are not caused by alterations to their underlying DNA sequence that could be passed on to their progeny.

One important mechanism of biological evolution, natural selection, does result in the evolution of improved abilities to survive and reproduce under particular environmental conditions. This does not mean (as some believe) that biological evolution is progressive. First, natural selection does not produce organisms that are perfectly suited to their environments. It allows the survival of individuals with a range of traits, individuals that are "good enough" to survive. Many groups of organisms (e.g. mosses, fungi, sharks, opossums, and crayfish) have members that show little physical change over significant periods of geological time.

Second, there are other mechanisms of evolution that don't necessarily result in adaptations. Mutation, migration, and genetic drift may cause populations to evolve in ways that are actually harmful overall or make them less suitable for their environments. Additionally, if we consider a single environment and habitat, how do we to measure "progress"? From the perspective of a plant species, the best measure of progress might be photosynthetic ability under low light conditions. For a snake species it might be the efficiency of a venom delivery system. From an evolutionary perspective, what matters is that they survived and can reproduce in the next generation. If the natural selection pressure remains the same (though it often does not), those individuals better adapted for a particular task will have a higher chance of survival and may better pass on their genes for that trait to the next generation. Each species in each environment has its own measure of progress, and what is adaptive for one species is not necessarily adaptive for another. It is tempting to view biological evolution as a grand progressive ladder with humanity at the top, with each adaptation pushing life farther up the rungs. The more accurate representation however, is that of a great many-branched tree. Humanity is just one of many twigs on one of many branches on this enormous tree of all life on earth.

Another misconception is that since there are areas of biological evolution that are not yet fully understood by science, it is not correct. This stems from a misunderstanding of the nature of science and scientific theories. All of science (physics, chemistry, etc) and scientific theories (evolutionary theory, atomic theory, etc.) are works in progress. As new evidence is discovered and new ideas are developed, our understanding of how the world works changes. This is a fundamental element of how science works.

While scientists don't know everything about biological evolution, we do know a great deal. The theory of biological evolutionary, as with all scientific theories, does not explain everything we observe in the natural world. Yet it does help us understand a wide range of observations, it does make accurate predictions, and it has proven itself time and again in thousands of experiments and observational studies. To date, evolution is the only well-supported explanation for the enormity of the biological diversity on Earth.

Some opponents of biological evolution try to put their god in places where our current understanding of biological evolution is incomplete. One such example in the "god of the gaps" argument is that the lack of transitional fossils means that god caused those transitions to occur. While it's true that there are gaps in the fossil record, this does not automatically constitute evidence against biological evolution. Paleontologists have found many fossils with transitional features, and new fossils are discovered all the time. However, scientists do not expect all transitional forms to be preserved in the fossil record. Many organisms don't have body parts that fossilize well, and the environmental conditions for forming good fossils are rare. Additionally, only a small percentage of the fossils that might be preserved somewhere on Earth have been discovered. It is actually expected that for many evolutionary transitions, there will be gaps in the fossil record. Even so, scientists continue to fill in the gaps with new archeological finds such as Tiktaalik, a recently discovered fossil example of the transition from lobe-finned fish to tetrapods (Daeschler et al., 2006).

Reasons for Resistance to BEE

Acceptance of one or more misconceptions about biological evolution can play a role in an individual's resistance to evolution, but there are other underlying factors influencing their viewpoint.

A major factor is personal religious beliefs/theistic view. Significant previous work has been done examining the percent of various groups that hold specific theistic views related to biological evolution. While there is little consistency in the methodology of these studies, most used questions designed to place their participants into one of the major categories of creationism. These categories include: Young Earth Creationism, Gap Creationism, Day-Age Creationism, Progressive Creationism, Evolutionary Creationism, Intelligent Design Creationism, and Theistic Evolutionism (Scott, 2005). Researchers in both science education and BEE have examined diverse groups with respect to their religious beliefs, such as clergy (Colburn and Henriques, 2006), college students not majoring in the life sciences (Bishop and Anderson, 1990), college freshman and sophomores (Sinatra et al, 2003), private Christian university students (Ladine, 2009), Christian and Muslim college students in Lebanon (Dagher and BouJaoude, 1997), freshman biology majors in the United States (Verhey, 2005), biology majors in Scotland (Downie and Barron, 2000), freshman and senior biology and genetics majors (Rice et al., 2011), biology textbooks (Aleixandre, 1994), high school student teachers (Zuzovsky, 1994), and high school biology teachers (Moore and Kraemer, 2005; Osif, 1997; Tatina, 1989; Van Koevering and Stiehl, 1989).

Ingram and Nelson collected data from college students enrolled in an upper level biology course in Evolution at a major public University. Thirty percent of the students from three sequential semesters strongly agreed with the statement: “A supreme being (e.g. God) created humans pretty much in their present form; humans did not evolve from other forms of life (e.g. fish and/or reptiles)” (Ingram and Nelson, 2006). Similarly, Moore and Kramer collected data from high school biology teachers in Minnesota during the 2003 school year, and found that the proportion of teachers who reflected creationist views was 30%. These questions and statements included: “Which statement best represents your understanding of evolution?”, “Creationism should be taught in public schools.”, and “Do you think that creationism has a valid scientific foundation?” (Moore and Kramer, 2005).

Verhey's 2005 study examined college students enrolled in an introductory biology course for biology majors at a midsized public University in the northwest United States in 2003. Approximately 50% of the students held attitudes that would be considered creationist (Verhey, 2005).

In 2003 Brem presented data from college students attending a large, public university in the Western United States in 1999. The subjects were taken from the general student population and were pursuing a wide range of majors, including life science majors. Fifty nine percent of the students surveyed held views between Theistic Evolutionist and Young Earth Creationist. An additional 15% provided inconsistent or neutral responses (Brem et al., 2003).

A national survey (Miller et al., 2006) of the opinion of evolution of 1484 U.S. adults was performed in 2005. This survey was widely publicized on television and in the national press. The question most attended to was that of "general" acceptance or rejection of evolution. That question led to the conclusion that only 39% of the U.S. public holds creationist positions. However, an examination of certain specific statements that were asked on the survey revealed a more detailed view of the nation's opinion. The first statement was: "Over periods of millions of years, some species of plants and animals adjust and survive while other species die and become extinct." Seventy eight percent of U.S. adults surveyed stated that was true. The second statement was: "Human beings were created by God as whole persons and did not evolve from earlier forms of life". Sixty two percent of U.S. adults surveyed stated that was true. These data lead to the conclusion that at least 62% of the nation holds viewpoints between Theistic Evolutionist and Young Earth Creationist, with respect to the origin of humans (Miller et al., 2006).

Colburn and Henriques did a study in 2006 in which they collected data from clergy including Catholics, Lutherans, Methodists, as well as other Christian denominations. Seventy-four percent of the clergy surveyed agreed with the concept that God must play a role in the creation of life and the evolution of life. An inspection of the other relevant data in the paper reveals that the clergy held notably variable viewpoints along the creationist-evolutionist continuum (Colburn and Henriques, 2006). A common assumption is that Christian religious beliefs and a disbelief in evolutionary theory are correlated. In every direct and indirect measure of this correlation it has been shown that it is indeed the case, Christian religiosity is correlated with a disbelief of evolution (Mazur, 2004; Rice et al., 2011; Sinclair and Pendarvis, 1998).

Students' own beliefs and dispositions can influence their understanding and acceptance of evolution, particularly when students' initial understanding about biological evolution is poor (Sinatra, et al., 2003). Many students who outright reject evolution appear to do so because they hold onto various cognitive rationales supporting their rejection. In addition, there are data that suggest it is a combination of religious and nonreligious rationales that are impacting their decision to reject evolution (Alters, 2005).

It appears clear that a person's personal theistic view is related to their understanding of and opinion of biological evolution. While this is a major factor to consider when attempting to improve BEE, it is not the only potential factor to consider. Since science is constantly changing as we learn more about the natural world around us, it is common to encounter people who fear or distrust some particular change in their previous "relationship" with the changing aspect of science or technology. This "denialism" takes many forms, such as holocaust deniers or moon landing deniers, but in recent times denialism has been largely an anti-science endeavor (Specter, 2009). In the U.S. there has been a recent push back against the use of vaccines, the validity of climate change, and of course biological evolution. Many Americans prefer the advice of celebrities and radio hosts to that of scientists, particularly when the scientists are saying things that they either disagree with or want to be false. This anti-intellectual arc in society has the potential to be quite dangerous. The recent push back against the vaccination of children because of unsubstantiated fears that the vaccine caused autism is an excellent example. The number of reported pertussis cases in the U.S. jumped from 1,000 in 1976 to 26,000 in 2004. About 2% of California's kindergartners are currently unvaccinated (approximately 10,000 kids). One in four Americans believes vaccines can poison kids, according to a 2008 survey. Proponents of the anti-vaccine movement include US senator John Kerry of Massachusetts, former senator Chris Dodd of Connecticut, Robert F. Kennedy Jr., and actress Jenny McCarthy. An unvaccinated population creates a serious risk of an outbreak, and with an outbreak the opportunity is presented for the virus to evolve to a point where the vaccine is not longer effective (Offit, 2010).

It has also been shown that there is a correlation between the amount of education a person has received and their acceptance of human evolution. In a 2004 survey fifty-five percent of respondents with some college education believed that humans evolved from other species, while only thirty-nine percent of respondents with a high school education or less believed this (Mazur 2004). This suggests that additional college-level instruction may influence a person's view of biological evolution. We should also consider the link between scientific literacy and acceptance of evolution. According to recent estimates, only 17% of the adult population in the U.S. is considered scientifically literate (Gross, 2006). Coupled with the religious influences on the U.S. political system we are facing a serious basic science education problem. Many states (including Texas, Oklahoma, Iowa, Kansas, Missouri, and Oregon) have official Republican platforms that include pushing for the teaching of creationism in the public schools. In many states acceptance or rejection of evolution is a political litmus test for candidates. At a press conference in early 2011, popular Republican New Jersey Governor Chris Christie was asked whether he believes in evolution. He quickly responded "That's none of your business" (Fox News, 2011). One week prior to that statement he was quoted as saying local school districts should be free to choose whether to teach creationism (Opposing Views, 2011). Given his answer to the question of his beliefs, many political pundits think he does accept evolution. Governor Christie may very well accept evolution as fact. So why would he avoid answering such a straight-forward question? One likely explanation for his evasion is the potential that he may wish to run for President, or some other political office, sometime in the future. Those who follow Republican politics have come to the conclusion that candidates for major office (and minor office in many places) only have a chance to be elected if they avoid or reject the topic of evolution (Salon, 2011). The problem has extended into the federal agencies that politicians influence. In 2006 the Social Sciences and Humanities Research Council (SSHRC) rejected a research proposal from a well-known evolution education researcher Brian Alters. In the rejection letter sent by the SSHRC, it stated that they felt there was insufficient "justification for the assumption in the proposal that the theory of evolution, and not intelligent-design theory was correct." Given that the SSHRC is the major funding source for social science research in Canada, this rejection is of serious concern (Hoag, 2006).

Education Policy, Practice, and BEE

While we have little data available regarding the opinion of university level instructors on the teaching of biological evolution, a fair amount exists for K-12 instructors. Twelve percent of biology teachers surveyed in Oklahoma favored omitting evolution from their biology classes and replacing it with a form of creationism (Weld and McNew, 1999). In addition, many instructors feel pressure from parents and administrators to omit or downplay evolution, as well as to include "alternatives" (NSTA, 2005). In Louisiana, Texas, and Indiana, 60%, 55%, and 35% of biology teachers, respectively, spend 5 instructional days or less on biological evolution content. Some of the teachers in those studies reported explicit pressure from parents and/or other teachers regarding biological evolution (Aguillard, 1999; Donnelly and Boone, 2007; Shankar and Skoog, 1993).

What evolutionary content is being taught in the K-12system? In the K-12 system in the United States the amount and quality of information varies considerably from state to state. With respect to the teaching of evolution, a recent evaluation of state standards revealed that only 31 of the 50 areas (the District of Columbia was included, Iowa was not) earned a score of C (satisfactory) or better on an A-F grading scale(Lerner, 2000). Thirteen states received an F grade, largely due to the near total absence of evolutionary content from their science standards.

One might expect that state standards would be useful to biology teachers as they teach evolution. Unfortunately this is not necessarily this case. In many state standards, evolution does not play a prominent part in the life science section (Cavanagh, 2005; Gross, 2006). Special interest groups are largely responsible for this circumstance, thanks to their influence on both the public and state legislatures (Wallis, 2005).

One of the most comprehensive studies related to the teaching of evolution and creationism in high school biology is found in the work of Zimmerman (1987). Zimmerman produced a 19-item questionnaire that he used to survey Ohio high school biology instructors. Eighty-eight percent of the instructors surveyed offered some evolutionary component in their courses, meaning that 12% did not cover biological evolution at all. The written comments provided showed that approximately 18% were presenting creationism in a favorable light in their course(s). In a related study, Tatina (1989) found that 16% of biology teachers at high schools in South Dakota had creationism as a topic in their courses. Again, the comments revealed that creationism was presented favorably in at least 10% of the courses.

In a survey of recent high school graduates, approximately 30% reported that evolution was either not mentioned at all, or mentioned but not covered in their first high school biology course. Approximately 5% reported that their instructors emphasized creationism as the best way to explain the earth's diversity. On top of that, approximately 43% reported that their instructors gave equal time to both evolution and creationism in their first high school biology course (Bandoli, 2008). In a second survey, conducted across eight states, 30% of respondents reported that their high school biology class taught creationism (Bowman, 2008). Nearly 20% reported that Intelligent Design was also taught. One encouraging thing, however, is that almost 92% stated that biological evolution was taught. Of course, that means that 8% of classes did not teach biological evolution at all (Bowman, 2008).

Teacher education is one area that may help explain why instructors are failing at effective BEE. Fifty-two percent of Minnesota biology teachers surveyed stated that they felt their undergraduate studies did not prepare them to teach evolution in an effective manner (Moore and Kraemer, 2005).In Louisiana, while public high school biology teachers reported being predominantly certified in biology, those with lower levels of education in biology were teaching less biological evolution. Fifteen percent of survey respondents reported taking no college courses in which they were specifically exposed to evolution. Fifty-four percent had completed one to two college courses in evolution, 19% had completed three to four college courses in evolution, and 12% had completed five or more college courses in evolution. Fifty percent of teachers holding greater than a Bachelor's degree allocated five or fewer hours of instructional time to evolutionary theory as compared to 66% of biology teachers holding a Bachelor's degree only (Aguillard, 1999). The quantitative data presented by Aguillard show that teachers holding greater than a Bachelor's degree allocate more time to evolutionary theory than do teachers possessing only a Bachelor's degree.

A 2008 study of 939 high school biology teachers from across the US reported some distressing trends. Seventeen percent of respondents reported that they did not teach human evolution at all. Two percent reported not teaching evolution at all, as well as 9% reporting only spending 1 – 2 hours on the subject. Perhaps more disturbing is the 25% reporting that they spent class time devoted to teaching creationism or intelligent design. That 25% may be misleading however, as only half of that portion reported teaching creationism and/or intelligent design as a “valid scientific alternative to Darwinian explanations for the origin of species” (Berkman et al, 2008).

The Berkman et al. (2008) study reported two potential explanations for this: 1) the same relationship seen in Aguillard’s work where in time a teacher allocated to evolution and amount of education in biology/evolution the teacher had were correlated; and 2) that teachers’ personal beliefs are influencing their decisions. The data presented suggest that teachers who have completed a larger number of college-level biology courses (including at least one course in evolution) devote approximately 60% more time to evolution than those with fewer credit hours. Regarding teachers' personal beliefs, the study used the same question format that is used in the Gallup polls on personal beliefs on origins (Gallup, 2011). They found that teachers in their sample population were twice as likely to choose the "agnostic" option and 66% less likely to choose the "young earth creationism" option. Even so, 16% of the teachers surveyed reported agreeing with the statement "God created humans beings pretty much in their present form at one time with the last 10,000 years or so" (Berkman et al., 2008).

What about middle school students? State standards at this level vary wildly from state to state, but most biology courses cover mutation, natural selection, and variation from sexual reproduction. When tested over the material required in Washington State, students showed a marked improvement after instruction (Beardsley, 2004). While the improvement is to be commended (and likely due to the historical approach used, described below), we may still be expecting too much of these students. Only 25% of the students in the Beardsley study actually met the state standards set for them. Given that this was under ideal circumstances (methods emphasizing historical events, 10 days devoted to the content), it is not unreasonable to consider revising the middle school standards. Rather than understanding very little about a lot of evolutionary ideas, many argue that it would be better to know more in depth about selected aspects of evolution (Bishop and Anderson, 1990; Beardsley 2004).

If the expectations placed on middle school students are too high, what about those placed on undergraduates? Given the bias placed on microevolutionary processes in textbooks (Catley, 2006) students are likely at a disadvantage from the start when they are learning about macroevolution and deep time. Many researchers have noticed this problem (Baum, et al 2005; Catley, 2006; Dodick and

Orion, 2003; Catley and Novick, 2009) and have suggested that instructors should spend additional time on macroevolution and deep time.

Deep time is a difficult concept for humans to understand (Trend 1998; 2000; 2001a; 2001b). Given our relatively short life span and the limited amount of recorded history, we tend to think of time in extremely limited terms. To the average person the difference between one year and twenty years is vast. At the same time that person conceives of 100,000 years and 1,000,000 years as being "about the same". Events from that long ago are perceived to have no impact on an individual human's life, so we mentally compress that part of Earth's history (Trend, 2001a; 2001b).

The use of the historical context of evolution in the teaching of evolution has been suggested as one way to improve knowledge of evolution and to eliminate misconceptions (such as those regarding deep time) (Catley and Novick, 2009). An historical context approach might include discussions of alternative theories of evolution that were promoted prior to Darwin's theory, examples of historical experiments testing evolution, and presentation of Darwin's life history. Previous research has shown that using this history-based approach resulted in both an improvement in content knowledge and a significant decrease in misconceptions (Beardsley, 2004; Jensen and Finley, 1996).

What about the impact of the instructor on the students? Rutledge and Warden (1999) found that biology teachers' "acceptance or rejection of evolutionary theory as a scientifically valid explanation is potentially important to the role that evolution takes in the high school biology curriculum". Several studies found that teacher attitudes and views about subject matter can also influence their "curricular and instructional decisions". Teachers spent more time teaching evolution as their own acceptance and knowledge of evolution increased (Tatina, 1989; Rutledge and Warden, 1999). Helgeson, et al. (2002) found that among pre-service elementary school teachers introduced to evolutionary issues via a mock-trial activity, there was a slight increase in understanding of evolutionary principles, decreased acceptance of a literal interpretation of the Biblical creation story, and increased acceptance of the accuracy of evolutionary theory. Importantly, the pre-service teachers reported an increased recognition of the “difficulties involved in balancing evolution and creationism in science pedagogy”

We should also consider the potential social consequences of learning about and accepting evolution. These perceived social consequences were examined in college age men and women in 2002. The subjects (which included both those with creationist and evolutionist viewpoints) reported fearing a loss of their sense of purpose, an increase in racism, a lack of self-determination, increased selfishness, and decreased spiritual beliefs if people were taught evolutionary theory (Brem, et al., 2003).

The NOS and BEE

Previous research has shown that a person’s understanding and/or acceptance of biological evolution is correlated with certain aspects of the Nature of Science (NOS). Before we consider that research, it will be instructive to highlight some of the common NOS issues encountered when teaching science.

One of the best known issues is that of misunderstanding the scientific use of terminology. The word theory, for example, means something very different in a scientific context than it does in layman’s terms. When scientists call something a theory (e.g. The Theory of Gravity) they are referring to an evidence-based, internally consistent, well-tested, well-substantiated, body of work that can be used to both explain and predict the natural world. The average person, however, is used to thinking of the word theory in the way that they hear it used in daily life (e.g., “I have a theory about who ate my banana bread”).

Commonly found in tandem with this first misinterpretation of the word theory is a misunderstanding of how science progresses. It is not uncommon to find people who think that scientific certainty progresses linearly: Hypothesis -> Theory -> Law. This is in part due to a fundamental misunderstanding of the difference between a theory and a law in science. Compared to the definition of theory described above, a law is generally defined as a statement of a relation or sequence of phenomena invariable under the same conditions (e.g., Newton's three laws of motion, the law of conservation of mass, etc.). A theory may contain a set of laws, or a theory may be implied from an empirically determined law, but the two are not interchangeable terms. Theories do not become laws.

Science is a work in progress. This by definition means that its conclusions with respect to causal processes will always be tentative relative to the data currently available. This tentative nature of science leads some people to disregard scientific conclusions because they think they will just change again in the near future. In some cases this is reinforced in the classroom by differences between various editions of a textbook, or changes to the material covered from one year to the next. While some perceive this to be a weakness of science, it is actually its strength. It is not the case that a scientific conclusion is temporary filler until the real answer, comes along. More accurately, it is described as a willingness on the part of scientists to modify their ideas when presented with new evidence. Scientific conclusions are based on observations and interpretations of the natural world and are tentative only in the sense that they are open to later revision. In practice, once a given hypothesis has evidence to support it, it is considered a 'strong' hypothesis. To overturn it, one must have 'better' data in favor of an alternative hypothesis. This new evidence must far surpass prior evidence to move the field in question forward.

Sometimes people will disregard something in science because they think it cannot be tested or because it was not examined under experimental conditions. It is a common misconception that all science is done via controlled experiments. Many areas of science rely partly or largely on observation and observational data. Astronomy is one example of an area of science that relies almost entirely on observation. It is not feasible for an astronomer to do an experiment where he/she creates two solar systems and then waits billions of years for them to form planets so they can compare the similarities and differences. Both observation and experimentation add to how we understand the natural world, and scientific knowledge based on either is equally valid.

Confusion about deductive and inductive reasoning adds to this misconception about the nature of science. Induction is typically described as moving from specific premises to a general conclusion, while deduction begins with general premises and ends with a specific conclusion. Arguments based on experience on observation are best expressed inductively, while arguments based on laws, rules, or other widely accepted principles are best expressed deductively.

People are often told, both in school and in the media, that there is one way to do science. That every scientist follows the same method of: Observation - Hypothesis – Experiment – Results – Conclusions. While it is certainly the case that some scientists behave in this (or nearly this) fashion when they do science, not every scientist does nor would it be appropriate for them to do so. Not every scientist starts with an observation, some start with results or conclusions from previous work. Still others (e.g., the astronomers previously mentioned) do not do anything that could be considered an experiment. Sometimes a scientist will cycle back and forth between two of the steps, such as hypothesis and observation, before attempting to setup an experiment. This concept of one "scientific method" also risks reinforcing both the Hypothesis ->Theory -> Law misconception and the observation/experimentation misconception. Since both this and the Hypothesis ->Theory -> Law misconception are based on a concept of science being a unidirectional process (moving from one step to the next without going back), there is a potential for overlap and reinforcement. The placement of observation at the start and experimentation later in the "scientific method" may reinforce the misconception that experimentation is more important than observation as observation may be seen as simpler/easier since it is at the beginning.

Part of the fear held by some in the religious community (and others) is that people who do science do not believe in the possibility of supernatural causation. This is reinforced by surveys of scientists that show professional scientists have a much lower percentage of personal belief in god than the general public. When members of the National Academy of Science were surveyed only 7% reported having a personal belief in god, while 72.2% reported a personal disbelief (atheism) (Larson and Witham, 1998). While a majority of professional scientists do not believe in the possibility of supernatural causation, but that does not mean that this lack of belief is an inherent aspect of being a scientist.. This perspective is a result of confusing philosophical naturalism and methodological naturalism. In philosophical naturalism (sometimes referred to as metaphysical naturalism), a person believes nothing exists but natural elements, principles, and relations that are studied by the natural sciences. Methodological naturalism, by contrast, refers exclusively to the methodology by which humans do science. Metaphysical naturalism states that everything in existence is reducible to natural cause and natural phenomena. It completely rejects the supernatural concepts and explanations that make up most religious mythos. Methodological naturalism makes no explicit statements regarding what does and does not exist, it is merely the limiting idea that all scientific endeavors must be explained and tested using natural causes and natural phenomena. This provides an effective framework where scientists can study of the laws of nature. Some scientists use methodological naturalism when they are doing science but then accept and believe in supernatural causation in their personal lives (Ecklund, 2010).

This does not mean that the fear of science turning people toward a rejection of the supernatural is unjustified. The available data clearly support the conclusion that more scientific accomplishment is correlated with less belief in the supernatural (Larson and Witham, 1998). In other words, religiously minded folks are correct in their concern: a deeper understanding of science commonly leads to a questioning of non-materialist explanations for phenomena. This can and does threaten some of the underpinnings of religion, which are supernaturally-based and thus fundamentally opposed to the methods of science. For example, some religions make testable claims about the nature of the universe. These claims are regularly shown to be false or impossible to be taken literally.

Research suggests that biology teacher preparation programs should, therefore, place a high priority on developing a comprehensive understanding of evolution and the nature of science (NOS) in their students (Rutledge and Warden, 1999; Rutledge and Mitchell, 2002). Some research suggests that a robust understanding of the NOS is not only helpful but is required for both students and faculty to effectively learn and teach biological evolution (Bell et al., 1998; American Association for the Advancement of Science, 1993; Clough, 1994; Farber, 2003; National Academy of Sciences, 1998; Johnson and Peeples, 1987; Smith, 2010).

In the science education community, there is little question as to whether an understanding of evolution and an understanding of the NOS are positively correlated (Alters and Nelson, 2002). The questions being posed now are of the specific “how” and “what” variety. For example, what specific elements of the NOS hold the most sway over a students’ understanding of evolution?

Some of the difficulties in student understanding of fundamental evolutionary concepts can be traced to science instruction that is based on philosophical conceptions of science that are no longer viewed as accurate. It has been suggested that the primary difficulties center around issues of metaphysics (the nature of existence) and scientific method, aspects of the NOS sometimes ignored in science education. Previous researchers have suggested that incorporation of these elements of scientific practice to structure teaching and education research in evolution may improve student understanding of both the NOS and evolution (Rudolph and Stewart, 1998).

Some in the academic community have already begun integrating explicit instruction in the NOS into their biology courses. Alles (2001) reported including the NOS as a significant component of his non-majors biology course. While he did not generate any data on the relative effectiveness of his course as far as improvement in knowledge of or attitude toward evolution, he does have evaluations of his course by his students. On a scale of 1 to 5, the course overall has been rated a 3.85

on average and over a 4.0 regarding the intellectual challenge specifically. So at the very least, these students seem to enjoy a course where the NOS is covered explicitly, which eliminates one potential barrier to its inclusion.

Is it enough to understand science without accepting it? Few studies have explicitly looked for a correlation between a person's acceptance of a scientific concept and their understanding of science. One area where acceptance and understanding have been shown to be correlated is global climate change (Antilla 2005; Lorenzoni et al., 2007). Additionally, in a study with 989 Indiana public school teachers, Rutledge and Mitchell (2002) found a significant association between teachers' acceptance of evolution and their exposure to biology, evolution, and nature of science issues.

It would appear that any comprehensive investigation into a group's understanding and acceptance of biological evolution must include a portion on the NOS. To ignore the NOS is to risk missing a large piece of the puzzle of BEE.

Study Rationale

Many groups have been surveyed in recent years with respect to their understanding of and acceptance of biological evolution, including introductory biology students, upper level biology students, high school biology teachers, pre-service secondary instructors, Christian clergy, and many others. (Ingram and Nelson, 2006; Verhey, 2005; Brem et al., 2003; Colburn and Henriques, 2006;Barnesetal, 2009; Losh and Nzekwe, 2010) But one group that has received little attention is faculty at universities and colleges.

Faculty members at major research institutions are not only involved in the instruction of undergraduate students, but many are also active researchers at the forefronts of their chosen fields. Given the amount of trust that parents put in universities and colleges that they will provide the best possible education for their children, one might expect there would be at least a few studies on faculty and their understanding of biological evolution. We could find only one recent study in which faculty were the population of primary interest (Paz-y-Mino and Espinoza, 2011b). In this study the authors were interested in measuring the views of college faculty on biological evolution, as well as their views on several related topics (e.g. creationism and I.D.) While it is an interesting data set, like all studies it has limitations. First, it does not differentiate what types of faculty were responding to the survey. Their data cannot be partitioned into theistic groups, or by areas of expertise which severely limits the conclusions can be drawn. Second, the survey purported to be able to accurately measure faculty "views about evolution, creationism, and intelligent design, their understanding of how the evolutionary process works, and their personal convictions" concerning both the evolution and/or creation of humans and degree of religiosity in only 11 questions. Several of the questions required either a forced choice with no option of a "none of the above" response, or a forced choice between five incorrect answers. It is clear that the existing data from faculty populations is insufficient to answer the myriad questions remaining about their understanding and acceptance of biological evolution and the NOS.

To properly understand the relationship between faculty personal views, their area of expertise, their knowledge of biological evolution, and specific demographic factors one must assess these variables simultaneously from a single population. Faculty members at colleges and universities come from many disparate fields of expertise and divergent educational backgrounds (e.g. biology psychology, art). Faculty are also arguably the individuals with most the educational experience of any potential study group. Students have been studied extensively, but what is unknown from those data is how much of their response is influenced by the faculty they encounter. If the instructors do not understand the material or have significant misconceptions, then they may be passing those misconceptions to students. This can be true even for faculty who do not teach in the biological sciences. The average person ascribes a level of intellect and understanding to a person who has an advanced degree (e.g., a doctorate) regardless of the specific field. When television shows bring in an expert for a discussion, almost invariably the expert has an advanced degree. But the question that remains unanswered is: Do these experts actually know what they are talking about? By learning more about what faculty members understand about biological evolution, what misconceptions they have, and how those are related to their personal views, their area of expertise, and other factors, we will begin to understand what we can do to make improvements that lead to a better education for the students.

Certainly one reason to examine faculty understanding and acceptance of biological evolution and the NOS is that they are a group that has not been studied in detail and would fill an important gap. This is not, however, the only reason, nor is it sufficient. Faculty at colleges and universities are among the most highly educated members of our society. They have received significantly more instruction, not only in their field of study but also in other areas of knowledge. Previous work has shown that the general population, high school teachers, and college students all hold serious misconceptions about the NOS. It is reasonable to predict that college faculty should be on average more likely to understand science content (such as biological evolution) and to understand what science is (the NOS) than non-faculty. But what if this is not the case? What if even the most educated among us are failing to comprehend science? What if even those who have spent years (or decades) doing science hold serious misunderstandings of science and science content? That would be a severe condemnation of the educational systems they are a product of. Having the data collected in this study will allow comparisons with previously studied groups, as well as with any groups studied in the future.

It is also reasonable to predict that those faculty who expressly seek out careers in science would understand more about science topics and the NOS than those that do not. Even though not every science faculty member will be well-versed in biological evolution, there is some overlap in the underlying information (e.g. deep time, random processes, etc.). These science faculty should also have the best understanding of the NOS, not only compared to non-scientist faculty, but also to the general public. These are reasonable assumptions, but so far there are no data that support or refute them. It is entirely possible (if not expected) that a non-scientist faculty member has a better understanding of both biological evolution (and accepts it) and the NOS than a science faculty member. What if this is the case on a larger scale? What would it say about the quality of the science programs that produced these scientists if they lack a basic understanding of what science is and what science isn't? How could we expect students to understand the nature of science if the very faculty in charge of their instruction do not understand it?

It is clear from a review of the available data that many people do not accept biological evolution as either good science or as a viable explanation for the diversity of life on earth. It also seems many people (both scientists and non-scientists) assume that if you are a scientist (particularly a biologist) then you are much more likely to accept biological evolution. Yet no data exist to support this assumption. While it certainly appears reasonable on the surface, until scientists are explicitly examined we cannot be sure. It may very well be the case that some non-scientists (e.g., business faculty) accept biological evolution at a higher rate than some scientists (e.g., chemists).

Any individual may hold any number of the misconceptions about biological evolution and science described above in any combination. Some previous research (see above) has shown some misconceptions to be more common in some populations than in others. Given that faculty are a highly educated population, what misconceptions have persisted in their minds? Again, it is reasonable to predict that scientists (and those with biological training in particular) would hold fewer misconceptions compared to non-scientists, but this may not be the case. It could be that life scientists (faculty with training in the biological sciences) actually hold more misconceptions about biological evolution than their compatriots in other sciences (e.g., physicists).

But what good is all of this information? Knowledge for knowledge's sake is fine in some circumstances, but science education is facing a serious problem. How can understanding university faculty help address this issue? As was described above, previous work has found correlations between a person's understanding of biological evolution and their acceptance of biological evolution, between their understanding of biological evolution and their understanding of the NOS, as well as between their acceptance of biological evolution and their understanding of the NOS. This suggests that if we want to address shortcomings in a population's understanding of evolution, or if we want to properly teach biological evolution, we must also address their acceptance of biological evolution and the understanding of the NOS. It also suggests several potential models for organizing how knowledge of biological evolution, acceptance of biological evolution, and understanding of the NOS are related (Figure 2).

The question then, is which of all the possible models best represents the overall relationship between knowledge of biological evolution, acceptance of biological evolution, and understanding of the NOS. If the overall relationship resembles model C for example, then we would see a sub-relationship between knowledge of biological evolution and understanding of the NOS, and one between understanding of the NOS and acceptance of biological evolution, but no sub-relationship between knowledge of biological evolution and acceptance of biological evolution. We suggest that all three factors are intimately intertwined (Figure 2B) and that therefore the best option is to measure and consider them together in any research project on this topic. In this model, we see an interaction between all variables. This means that for each variable of interest (knowledge, acceptance, and understanding) each variable is affecting the other two and is being affected by them as well. This could result in an interactive feedback effect where, for example, a change in a person's knowledge of biological evolution leads to a change in their acceptance of evolution which then leads to a change in their understanding of the NOS, which then leads to a change in their knowledge of biological evolution. The five models described here are very basic, and to not attempt to discern any directionality to the effects being measured. If appropriate data are collected on each factor from one population of interest (in this case faculty), then an effective predictive model can be constructed to

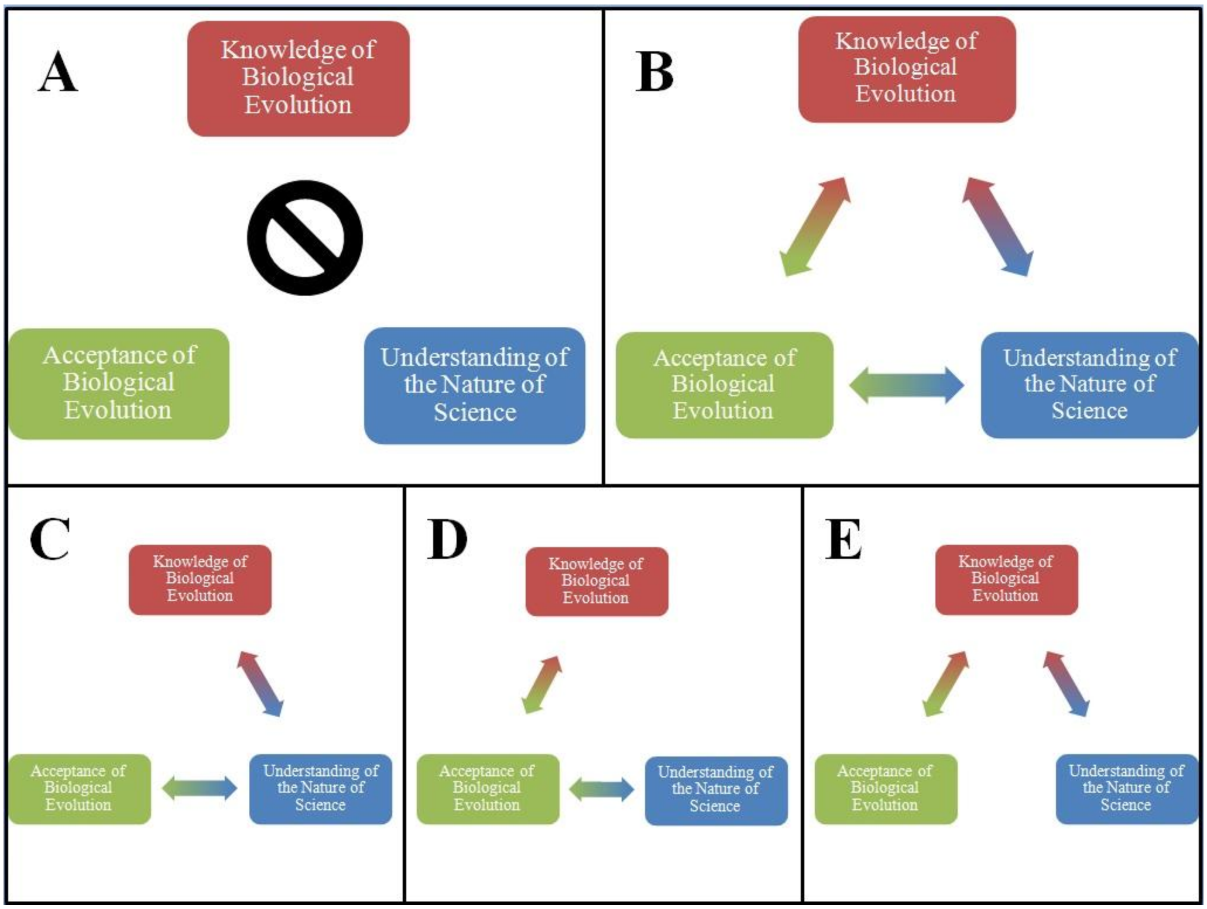

Figure 2: Five models of the potential overall relationship between knowledge of biological evolution, acceptance of biological evolution, and understanding of the NOS. A: Bidirectional dual input interaction between all variables resulting in interactive effect. B: Interaction between all variables resulting in a feedback loop. C: No interaction between knowledge of biological evolution and acceptance of biological evolution. D. No interaction between knowledge of biological evolution and understanding of the NOS. E. No interaction between acceptance of biological evolution and understanding of the NOS.

represent how changes in one factor will likely impact the others. Constructing a model of this type will help balance the relative investment in each factor when attempting to improve them.

There are three primary pieces of this model that need to be considered. First, what is the strength of the correlation (if any) between each factor. Second, given a correlation, what is its directionality (positive or negative)? Finally, in what cases (e.g., subdivisions of the population) are their differences from the overall model?

We can expect that if strong positive correlations between each of the factors are detected, we can then infer that effective instruction in biological evolution must incorporate coverage all three factors; understanding of evolution, acceptance of evolution, and understanding of the NOS. Conversely, if no correlation or a negative correlation is detected between any of the factors, then we will have evidence that it is not necessary for instructors to invest time and energy addressing a factor if improvement in another factor is their primary goal.

Since faculty have a direct impact on the educational experience of their students, and since some of those students will go on to become K-12 teachers or faculty themselves, we need to be aware of the risk of a self-feeding cycle of misconceptions. It is reasonable to predict that a student who graduates from college with a poor understanding of science and then proceeds to become a science teacher will have a high likelihood of imparting their misconceptions to their students. Some of their students may become teachers themselves, perpetuating the cycle. Since some faculty are a link in this cycle, it is important that we quantify the misconceptions they hold. If we can make improvements in one or more steps in the cycle (e.g. students and in-service teachers via their faculty instructors) then we may be able to convert it into one that gives a positive result (such as improved science learning).

Specifically, the following work was designed to answer these questions:

1. What understanding of, and acceptance of, biological evolution do faculty members across various disciplines have?

2. How, if at all, does faculty member understanding of biological evolution differ between members of different disciplines?

3. How, if at all, does faculty member acceptance of biological evolution differ between members of different disciplines?

4. What is the relationship, if any, between faculty member theistic position and both their understanding of, and acceptance of, biological evolution?

5. What is the relationship, if any, between faculty member demographic responses and both their understanding of, and acceptance of, biological evolution?

6. What understanding of the NOS do faculty members across various disciplines have?

7. How, if at all, does faculty member understanding of the NOS differ between members of different disciplines?

8. What is the relationship, if any, between faculty member understanding of the NOS and both their understanding of, and attitude towards, biological evolution?

9. What is the relationship, if any, between faculty member theistic position and both their understanding of the NOS?

10. What is the relationship, if any, between the amount of science education claimed by faculty members and their understanding of the NOS?

11. What is the relationship, if any, between faculty member demographic responses and their understanding of the NOS?

12. What model best describes the relationship between understanding of biological evolution, acceptance of biological evolution, and understanding of the nature of science?

With answers to these questions we should be able to better prepare for the next step in improving BEE, by better understanding what changes need to be made, and to what degree they need to be made.

CHAPTER 3:

University Faculty: Knowledge and Acceptance of Biological Evolution

Introduction

The modern theory of biological evolution is an integral part of understanding the natural world. Yet, polls consistently find that large portions of the public do not accept that evolution has occurred and is continuing to occur (Miller et al, 2006). It is an unfortunate fact that in our education system many students (in both high school and college) are: 1) not being given adequate instruction in biological evolution; 2) being taught inaccurate conceptions of biological evolution; and 3) being explicitly taught non-science material (e.g., creationism and intelligent design) in their science classes (Bandoli, 2008; Beardsley, 2004; Bowman, 2008; Cavanagh, 2005; Gross, 2006; Wallis, 2005).

Adding to the problem is that there are not just one or two common misconceptions about biological evolution, but many. These misconceptions include: 1) Biological evolution explains the origin of life; 2) Biological evolution is an entirely random process; 3) Knowledge of biological evolution will lead a person to become an atheist/act in an immoral fashion; 4) That there is a controversy in the scientific community regarding the validity of biological evolution; 5) That Biological evolution is not observable/testable; 6) That Lamarckian evolution occurs; 7) That the phrase “survival of the fittest” means those that are strongest, fastest, etc.; 8) That individual organisms undergo biological evolution; 9) That there is a positive directionality to the process of biological evolution; and 10) That our knowledge of biological evolution is incomplete means that biological evolution is incorrect.

Scientists, educators and science educators have known about the problem surrounding biological evolution education (BEE) for decades. The misconceptions held by members of the public are not new, but within the last decade various events have drawn greater attention to the issue. There has been an increase the number of publications on the topic, more funds are available for new research, and new journals and conferences have been created as specific venues for BEE research. While all of these developments are welcome, and will hopefully lead to real improvements in BEE, there is still considerable work remaining.

Many groups have been surveyed in recent years, including introductory biology students, upper level biology students, high school biology teachers, pre-service secondary instructors, Christian clergy, and many others (Ingram and Nelson, 2006; Verhey, 2005; Brem et al., 2003; Colburn and Henriques, 2006;Barnesetal, 2009; Losh and Nzekwe, 2010). These studies have provided valuable insight into how these groups view and understand biological evolution, and suggest some avenues for addressing the issue. One group that has so far received little attention is the faculty at universities and colleges.

Faculty members at major research institutions are not only involved in the instruction of undergraduate students, but many are also active researchers at the forefronts of their chosen fields. Given the amount of trust that parents put in universities and colleges that they will provide the best possible education for their children, one might expect there would be at least a few studies on faculty and their knowledge of biological evolution. We could find only one recent study of this group, (Paz-y-Mino and Espinoza, 2011b). In this study the authors were interested in measuring the views of college faculty on biological evolution, as well as their views on several related topics (e.g. creationism and I.D.). They used a newly developed eleven question survey that they claim accurately measures faculty "views about evolution, creationism, and intelligent design, their understanding of how the biological evolution works, and their personal convictions". Given previous work done in this field (Alters and Alters, 2001; Johnson and Peeples, 1987; Miller et al., 2006; Moore and Kraemer, 2005; Moore et al., 2009; Nehm and Schonfeld, 2007; Rice et al., 2011;

Rudolph and Stewart, 1998; Sinatra et al., 2003; Sinclair and Pendarvis. 1998; Van Koevering and Stiel, 1989; Verhey, 2005; Zimmerman, 1987) we find this claim to be unlikely.

For instance, while Paz-y-Mino and Espinoza (2011) provide an interesting data set, it has limitations that do not allow one differentiate what types of faculty were responding to the survey. The type of faculty that respond to a survey will significantly impact the conclusions can be drawn from the resulting data. It is not clear whether the 244 respondents were non-biologists, biologists, or some mixture of both. Second, several of the questions examining viewpoints used a forced choice between answers with no option of a “none of the above” response, while one question on knowledge used forced choice between five incorrect answers. Neither of these survey question formats is appropriate if accurate estimation of participant views or knowledge of a topic is the goal (Hawkins and Coney, 1981; Tull and Hawkins, 1993). Therefore, we still have insufficient data on faculty and what they know about biological evolution, understand about the NOS, and accept about biological evolution.

But why should educators care what faculty at colleges and universities think about biological evolution? Do you have to understand biological evolution to be a “good” faculty member? From a big picture perspective, biological evolution is important because ties the field of biology together. Not only is it ***the*** unifying concept of the biological sciences, knowledge of biological evolution can provide a useful context from which to consider the natural world. From a medical perspective, biological evolution informs our of how we are subject to natural selection, our understanding of the origin of disease, resistance to antibiotics, viral function, and how we can more effectively deal with current and future pathogens. Conservation, agriculture, environmental change, and forensics are just a few examples of other ways biological evolution informs our modern world.

Understanding the views and knowledge of faculty is of particular importance for several reasons. First, understanding the relationship between faculty personal views, their area of expertise, their knowledge of biological evolution, and specific demographic factors will allow us to answer several important questions about BEE. Faculty members at colleges and universities come from many disparate fields of expertise and divergent educational backgrounds (e.g. biology, sociology, business). It would be informative to know what impact those disparate experiences may have had on their current views.

While both the public as a whole, and college students specifically have been studied in some detail, there exists little information regarding any potential influence faculty may be exerting. If the instructors in charge of providing a college education do not understand the material or have significant misconceptions about it, then they may be passing those misconceptions to students. This can also be true for faculty outside of the biological sciences. It is reasonable to assume that the typical student will ascribe a level of intellect and understanding to someone who has earned an advanced degree (e.g., a doctorate) or is in charge of a college course, regardless of their area of expertise. But do these “experts” actually know what they are talking about? If we can learn what typical faculty members understand about biological evolution, what misconceptions they have, and how those are related to their personal views, their area of expertise, and other factors, we will begin to understand what we can do to make improvements that lead to a better education for the students.

It is also reasonable to predict that those faculty who expressly seek out a career in the biological sciences would understand more about biological evolution. Even though not every life science faculty member will be equally well-versed in biological evolution, there is likely to be overlap in the basic elements they understand, such as heritability. It should be these faculty who exhibit the best knowledge of biological evolution, compared to non-scientist faculty, the general public, and students. This is a reasonable assumption, but currently there are no data that support or refute it. It is entirely possible that a non-scientist faculty member could have a better knowledge of biological evolution (and accept it) than a science faculty member. What if this is actually the case across a large population? It would be a very damning indictment of the science programs that produced these biologists if they lack a basic knowledge of what biological evolution is. How could we expect students to understand biological evolution if the instructors do not understand it?

It is clear that a large portion of people in various groups do not accept biological evolution as either good science or as a viable explanation for the diversity of life on earth. It also seems many people (both scientists and non-scientists) assume that there is a direct correlation between being a scientist (particularly a biologist) and accepting biological evolution. No data yet exist, however, to support this assumption. It may very well be that non-scientists (e.g., business faculty) accept and/or understand biological evolution at a higher level than scientists (e.g., chemists).

Some previous research has shown some misconceptions to be more common in some populations than in others. It is reasonable to predict that scientists (biologists in particular) would hold fewer misconceptions about biological evolution, but this may not be the case. It could be that life scientists hold more misconceptions about biological evolution than their compatriots in other sciences (e.g., physicists) or even non-scientists.

Previous work has also found correlations between a person's knowledge of biological evolution and their acceptance of biological evolution (Lawson and Worsnop, 1992; Rice et al., 2011; Scharmann et al., 2005). This suggests that if we want to address shortcomings in a population's knowledge of evolution, or if we want to properly teach biological evolution, we must also address their acceptance of biological evolution. We should also consider potential models for organizing how knowledge of biological evolution and acceptance of biological evolution are related to other factors of potential influence (Figure 1).

There are three primary pieces that need to be considered. First, what is the strength of the correlation (if any) between knowledge of biological evolution and acceptance of biological evolution? Second, given a correlation, what is its directionality? Finally, given a correlation, what factors (e.g., subdivisions of the population) are driving differences from the overall model?

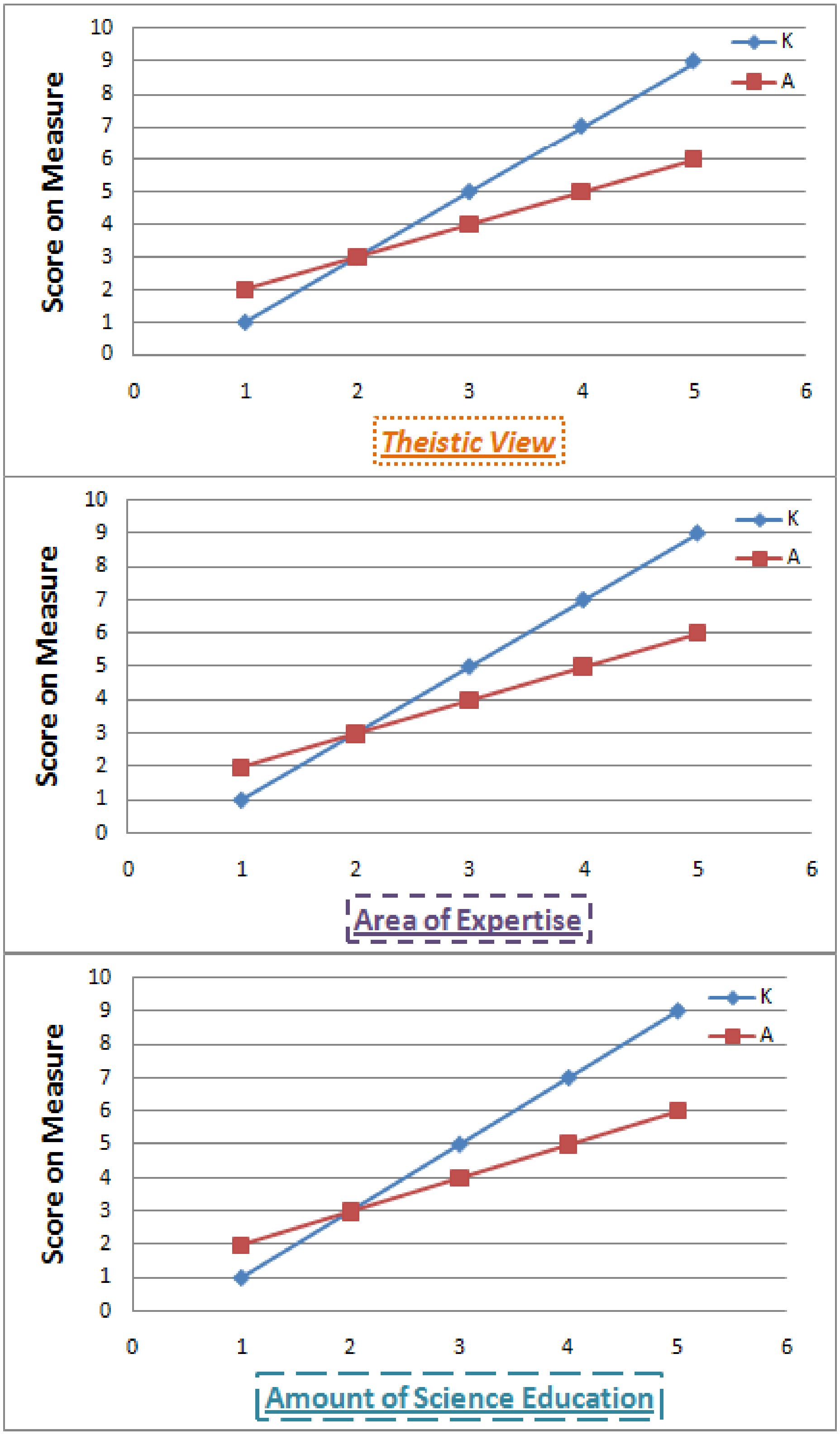

Figure 3: Models of potential relationship between knowledge of evolution, acceptance of evolution and three variables of interest.

We can expect that if strong positive correlations between the variables are detected, we can then infer that knowledge of evolution and acceptance of evolution are related in an additive manner. This may mean that effective instruction must incorporate both. Conversely, if no correlation or a negative correlation is detected then we will have evidence that it is not necessary for instructors to invest time and energy addressing one variable if improvement in the other is their primary goal.

Faculty have a direct impact on the educational experience of their students, and some of those students will go on to become K-12 teachers or faculty themselves. It is thus important to investigate the possibility of a perpetual cycle of misconceptions. Students who graduate from college with a poor knowledge of biological evolution and then become biology instructors will likely impart their misconceptions to their students. Some of those students may become teachers themselves, which then perpetuates the cycle. Understanding what misconceptions are common in university faculty, particularly those responsible for instruction in biological evolution may allow us to make improvements in one or more steps in the cycle.

Specifically, the following work was designed to answer these questions:

1. What knowledge of, and acceptance of, biological evolution do faculty members across various disciplines have?

2. How, if at all, does faculty member knowledge of biological evolution differ between members of different disciplines?

3. How, if at all, does faculty member acceptance of biological evolution differ between members of different disciplines?

4. What is the relationship, if any, between faculty member theistic position and both their knowledge of, and acceptance of, biological evolution?

5. What is the relationship, if any, between faculty member demographic responses and both their knowledge of, and acceptance of, biological evolution?

6. What model best describes the relationship between knowledge of biological evolution and acceptance of biological evolution?

The purpose of this study is to investigate the relationship between faculty personal views, their area of expertise, their knowledge of biological evolution, their acceptance of biological evolution, and several demographic factors. Faculty members from many disparate fields of expertise were included to allow for comparisons between participants with divergent educational backgrounds (e.g. biologists with engineers).

Study Context and Methods

Study Site

Faculty member participants were recruited for participation from the full list of employees that were considered faculty at a major, public, Midwestern university during the 2010 – 2011 academic year. This definition was at the discretion of the Office of Institutional Research at the research site, and included 1595 potential participants. Faculty members were contacted via email where they were directed to voluntarily proceed to an online survey.

Data were kept anonymous; however participants were given the opportunity to submit another email contact for use in a random drawing for one of ten $50.00 gift cards to a local bookstore. Data were collected over several months, with two reminder emails being sent to the potential participants. Relevant demographic data for the population as a whole was obtained from the Office of Institutional Research at the study site.

Survey Instrument

The variables of interest in this study are participant knowledge of biological evolution, acceptance of biological evolution. In order to accurately measure both of those variables, distinct sets of questions are required.

We used an unmodified Knowledge of Evolution Exam (KEE) to measure participant knowledge of evolutionary concepts. The KEE has been used in previous studies and has been shown to be both a reliable and valid measure of a participant's knowledge of biological evolution for several different groups (Moore et al., 2009). The ten questions on the KEE cover content on biological evolution that students in an introductory college biology course would be familiar with.

For acceptance of biological evolution we used an unmodified version of the Measure of Acceptance Toward Evolution (MATE). The MATE has also been used in previous studies measuring acceptance of biological evolution and has been shown to be a valid and reliable measure (Rutledge and Sadler, 2007; Moore and Cotner, 2009a; Moore and Cotner, 2009b). The twenty questions on the MATE examine the participants views on whether humans and other animals have evolved, whether biological evolution is science, how old the earth is, whether biological evolution is testable, and other related views.

There was also a section of the survey devoted to measuring participant understanding of the nature of science (NOS). Understanding of NOS has been previously show to be related to an individual's knowledge and acceptance of biological evolution, and thus was also of value in addressing the issues at hand. This portion of the survey was based on the Student Understanding of Science and Science Inquiry (SUSSI) and had significant alterations (Liang et al., 2008). This section was placed at the beginning of the survey so as to avoid any potential negative bias associated with a discussion of biological evolution. This portion of the survey and how it relates to the results of the rest of the survey is discussed in Chapter 4.

In total the survey used here consisted of 54 multiple-choice questions and 7 text response questions. Besides the KEE, MATE, and SUSSI sections, three other questions examined participant views of educational policies, public acceptance/rejection of biological evolution, and their personal theistic view. Five questions at the end of the survey were of a demographic nature (gender, age, area of expertise, employment level, and amount of science education received). Of the seven text response questions, three are relevant to this work while the remaining four were part of the nature of science section and will be discussed in Chapter 4.

309 complete surveys from the 1595 faculty members contacted were received. Various factors led to an additional 139 incomplete surveys also being collected; however none of these responses reached a level of completeness to be useable in our analyses.

The resulting sample was examined both as a whole and in specific subgroups. The demographic and theistic view questions allowed the sample to broken down into our specific divisions of interest: participant area of expertise, participant theistic view, and participant amount of science education. Participants were grouped for area of expertise according to their response to the question: “What is your area/field of work? (e.g. Chemistry, History, etc.)”. Based on the responses participants were grouped together into the following categories: Social Science (responses such as Economics, Psychology, Education, and History), Physical Science (responses such as Physics, Chemistry and Geology), Business (responses such as Finance, Marketing, and Accounting), Applied Science/Engineering (responses such as Civil Engineering, Aerospace Engineering, and Industrial Engineering),Life Science (responses such as Agronomy, Cell Biology, Genetics, and Horticulture), Humanities (responses such as Music, Theatre, English, and Philosophy), Veterinary Medicine, and those that did not answer. Some responses were collected that did not fit in this categorization scheme and were also too few in number to warrant inclusion as their own group (e.g. Information Systems, Statistics). Such responses were not used in the analysis.

For participant theistic view, the survey provided several possible categories: Young Earth Creationist, Old Earth Creationist, Theistic Evolutionist, Agnostic Evolutionist, Atheistic Evolutionist, and a not answered/other group. This categorization scheme is based on a similar set of categories described in Scott (2005). During analysis, these six categories were grouped together using three distinct categorization schemes.

Schema A used Young Earth Creationist, Old Earth Creationist, and Theistic Evolutionist as one group, Agnostic Evolutionist and Atheistic Evolutionist as a second group, and the not answered/other participants as a third group. Schema B used Young Earth Creationist and Old Earth Creationist as one group, Theistic Evolutionist, Agnostic Evolutionist and Atheistic Evolutionist as a second group, and the not answered/other participants as a third group. Schema C treated Young Earth Creationist and Old Earth Creationist as one group, Theistic Evolutionist as a second group, Agnostic Evolutionist and Atheistic Evolutionist as a third group, and the not answered/other participants as a fourth group. Every statistical test that was performed that used participant theistic view was carried out three times, once for each Schema.

The amount of science education the participants reported was used as the set of categories for comparisons. Participants could choose from the following four choices: 9 or more science courses, 5-8 science courses, 1-4 science courses, or no science courses. The results from the KEE and MATE portions of the survey were summed into percentage scores for the analyses reported below, unless otherwise noted.

Statistical Analyses

In this study, we were interested in measuring the relationship between knowledge of biological evolution and acceptance of biological evolution in several contexts. Various statistical analyses were performed to address specific hypotheses. These are outlined below.

Statistical Analyses Part 1: Tests on the Knowledge – Acceptance relationship

In order to assess the overall relationship between knowledge of biological evolution and acceptance of biological evolution, we used a simple linear regression comparing the percentage scores of all the participants on the knowledge of biological evolution measure to their percentage scores on the acceptance of evolution measure. In addition, we performed an ordination analysis to obtain a graphical visualization of the patterns present in the data. For this, we first created a distance matrix among individuals by calculating pairwise Jaccard's distance between individuals, based on participant responses to *each* question. We then used principal coordinate analysis (PCoA) to generate an ordination of the response data space. Individual participants were then color-coded by grouping variables to provide a visual examination of whether or not a particular group displayed similar responses to the questionnaire.

One-way ANOVAs were then used to examine several relationships. First, we tested for the presence of a significant relationship between the percentage scores for participant knowledge of biological evolution by their theistic view; their area of expertise; and the amount science education they reported. Second, we tested for the presence of a significant relationship between the percentage scores for participant acceptance of biological evolution by their theistic view; their acceptance of biological evolution; their area of expertise; and the amount of science education they reported.

Statistical Analyses Part 2: Tests of the impact of multiple factors

In order to identify potential interaction between the grouping factors of area expertise and theistic viewpoint, two-way ANOVAs were performed. These tests were used to examine whether the relationships described in the one-way ANOVAs were the same or different when another variable was considered. As with prior analyses, two-way ANOVAs were performed separately on survey questions relating to: 1) knowledge of biological evolution, and 2) acceptance of biological evolution. Mantel tests were also performed on separate distance matrices of the participant responses to the knowledge and acceptance portions of the survey to assess the degree of association between participant scores on the knowledge of evolution, acceptance of evolution, and the grouping variables of area of expertise and theistic view. Specifically, Mantel correlations were calculated between knowledge of biological evolution and acceptance of biological evolution across all participants; between knowledge of biological evolution and acceptance of biological evolution for those participants with differing theistic views (e.g. young earth creationist); and between knowledge of biological evolution and acceptance of biological evolution for each area of expertise (life science, humanities, etc.).

In order to identify potential interaction between the grouping factors of theistic viewpoint and amount of science education, two-way ANOVAs were performed. Again, these tests were used to examine whether the relationships described in the one-way ANOVAs were the same or different when another variable was considered. As with prior analyses, two-way ANOVAs were performed separately on survey questions relating to: 1) knowledge of biological evolution, and 2) acceptance of biological evolution. Mantel tests were also performed on separate distance matrices of the participant responses to the knowledge and acceptance portions of the survey to assess the degree of association between participant scores on the knowledge of evolution, acceptance of evolution, and the grouping variables of theistic view and amount of science education. In this case Mantel correlations were calculated between knowledge of biological evolution and acceptance of biological evolution across all participants; between knowledge of biological evolution and acceptance of biological evolution for those participants with differing theistic views (e.g., young earth creationist); and between knowledge of biological evolution and acceptance of biological evolution by how much science education participants reported.

One-way ANOVA tests were used to examine whether participant knowledge of biological evolution and acceptance of biological evolution were different between each category of interest (theistic view, area of expertise, amount of science education). Linear regression was also used to identify the relationship between variables such as between knowledge of biological evolution and acceptance of biological evolution for physical scientists.

Since we are interested in seeing which factors explain the variation we see in the data (e.g. does amount of science or theistic view have more impact on an individual's knowledge of biological evolution and acceptance of biological evolution), we used Akaike Information Criterion (AIC)to compare the fit of the resulting models. Specifically, we used AIC to compare models based on participant theistic view, area of expertise, or amount of science education regarding their fit to participant knowledge of biological evolution and acceptance of biological evolution. We also used permutation tests to examine whether the observed results from some specific tests were significantly different from a random result.

Finally, pairwise t-tests were used to compare the knowledge of biological evolution and acceptance of biological evolution of the participants between each area of expertise as well as within each area of expertise but between their theistic views (e.g. creationist business faculty compared to non-creationist business faculty). Additionally, each test that was performed that used participant theistic view was carried out three times, once with Schema A, once with Schema B, and once with

Schema C to allow us to see if there were any differences between the three ways of grouping and what those differences were.

All statistical computations and procedures were performed in R 2.12.1 (R Development Core Team, 2010).

Results

Quantitative Results

The participants in the resulting data sample aligned very closely with previously known information regarding the population as a whole. There were two points of difference that are worth noting. First, the participants were 47.4% female and 52.6% male, but the population of faculty at this study site are35.1% female and 64.9% male. This means a disproportionate number of female faculty members completely the survey compared to their male counterparts. No differences between any variable of interest were detected when gender was considered, but given that our sample was not gender-representative of the population those may not be accurate results. Second, less than 5% of the participants stated their area of expertise was in or related to Veterinary Medicine but approximately 11% of the faculty at this study site hold that specialty. Other areas of expertise were more accurately represented in the sample (Figure 2A).

The overwhelming majority (66.9%) of participants chose the Agnostic Evolutionist theistic view, with no other views exceeding 11% of the participants (Figure 2B). The majority (53.07%) of participants also stated that they had received a large amount (nine or more courses) of science education, with the next largest portion being those with a low amount (one to four courses) of science education (27.51%) (Figure 2C).The participants were largely tenured faculty (58.3%, tenure track: 18.7%, non-tenure track: 23%) as well as Caucasian (81.1%, Asian: 14.1%, All other options: 4.8%).

As a whole, the faculty scored an average of 68% correct on the knowledge of biological evolution portion of the survey (Figure 3). They scored an average of 86.8% agreement with statements measuring acceptance of biological evolution (Figure 4). Both measures are right-shifted toward the higher end of the scale, but approximately 45% of the knowledge of biological evolution scores lying to the right of the average, and approximately 60% of the acceptance of biological evolution scores lying to the right of the average. This means we should not have bias in our results from having a population with an unbalanced distribution of scores.

Results Part 1: Single Factor Tests

Using simple linear regression we found a significant association between knowledge of biological evolution and acceptance of biological evolution ($F_{1, 307} = 145.07$, $R^2 = 0.3204$, $p<0.001$; Pearson's $r = 0.566$) (Figure 5). High knowledge of biological evolution was strongly correlated with high acceptance of biological evolution. Likewise, a significant relationship between knowledge of biological evolution and acceptance of biological evolution was revealed using a Mantel test ($r = 0.469$; $p < 0.001$).

Tests by Theistic View. Analysis of variance revealed that faculty grouped by theistic views differed in their knowledge of evolution and acceptance of evolution, regardless of which grouping schema was utilized (Table 1). In all but one case participants with a more creationist theistic view had a lower average knowledge of biological evolution ($p<0.001$) (Table 2). In all cases participants with a more creationist theistic view had a significantly lower average acceptance of biological evolution ($p<0.001$) (Table 2).

Likewise a significant relationship between knowledge of biological evolution and acceptance of biological evolution was revealed using a Mantel test for each group in each Schema (Table 3). As above, the one exception in the case of knowledge of biological evolution was in

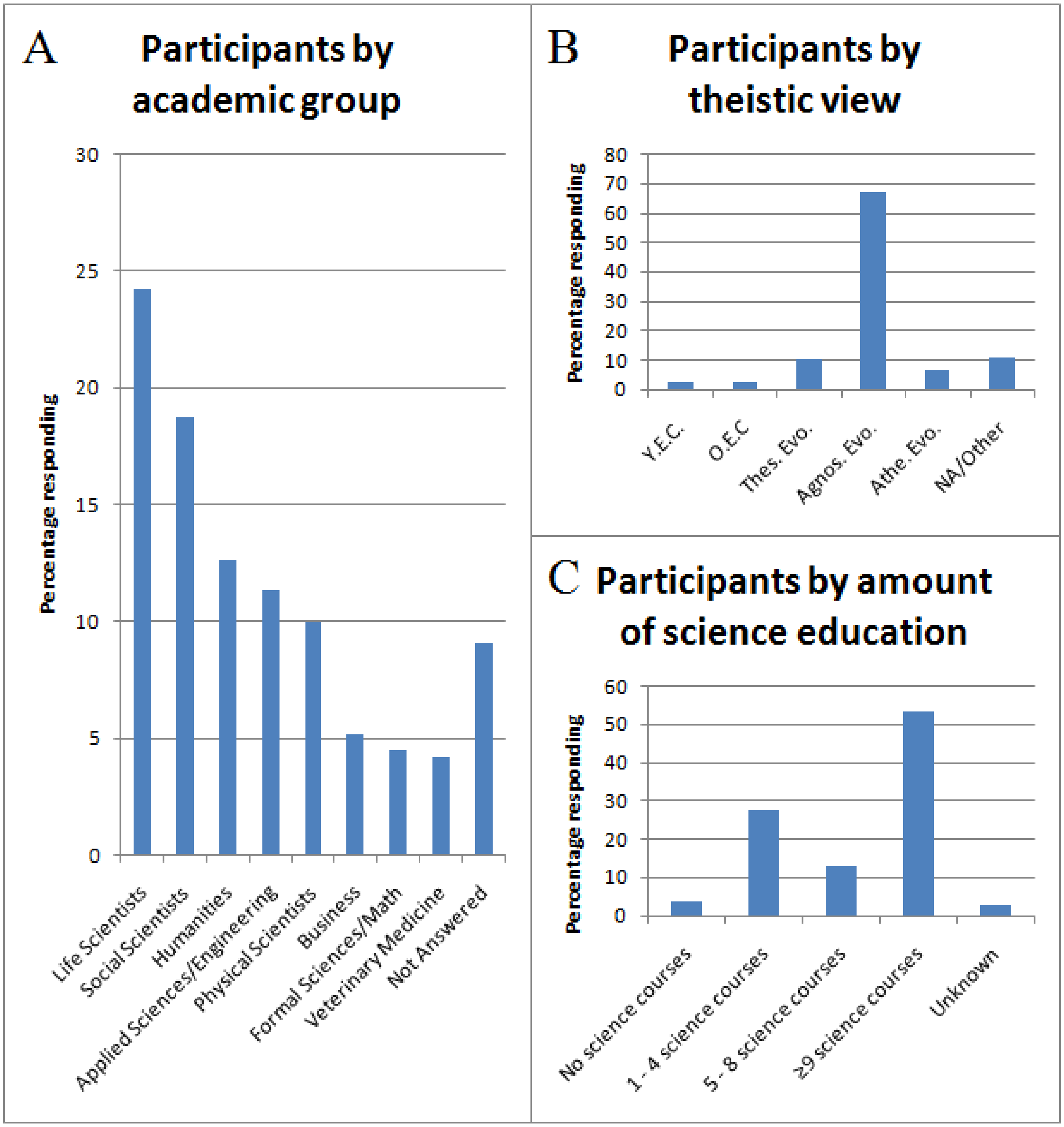

Figure 2: A: Percentages of participants categorized by their academic group B: Percentages of participants categorized by their theistic view C: Percentages of participants categorized by the amount of science education they reported receiving

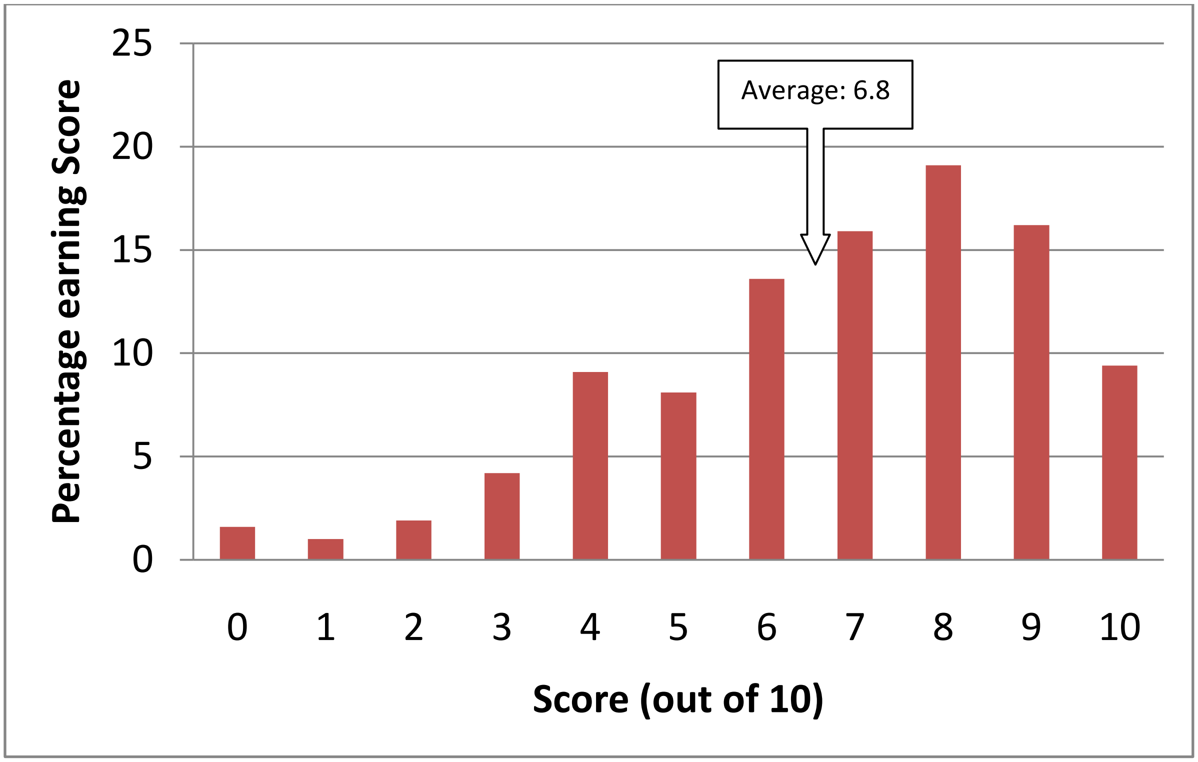

Figure 3: Distribution of participant scores on the measure knowledge of biological evolution (KEE)

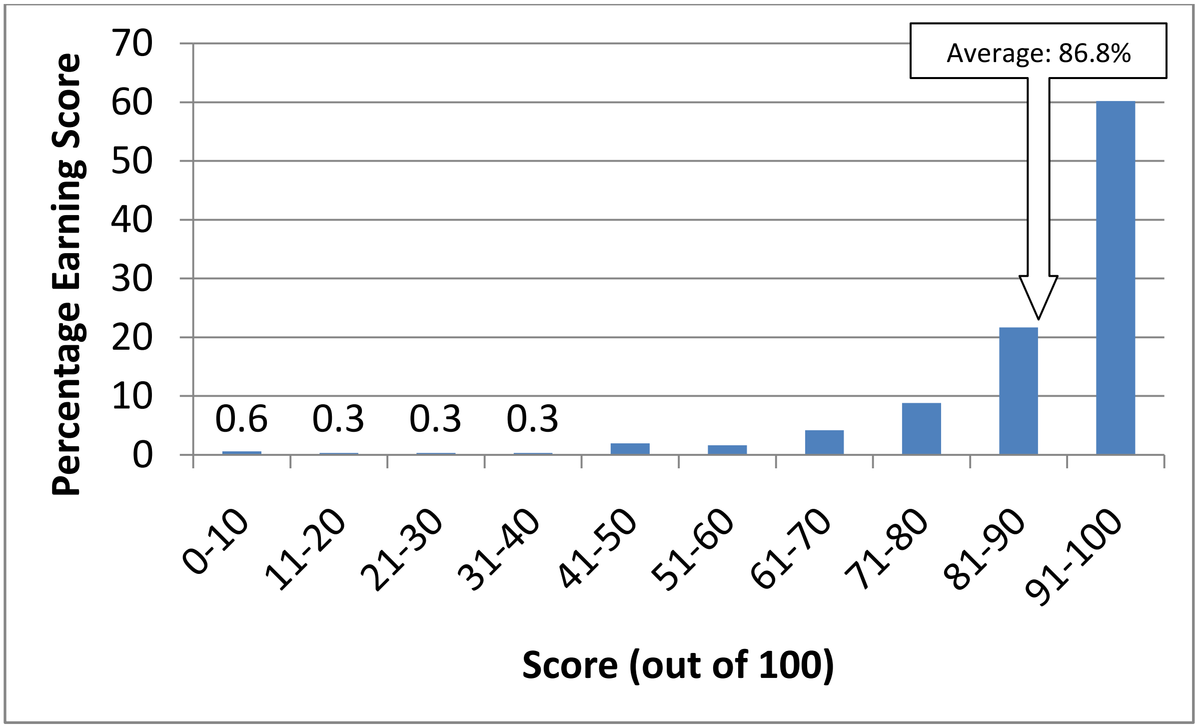

Figure 4: Distribution of participant scores on the measure of acceptance of biological evolution (MATE)

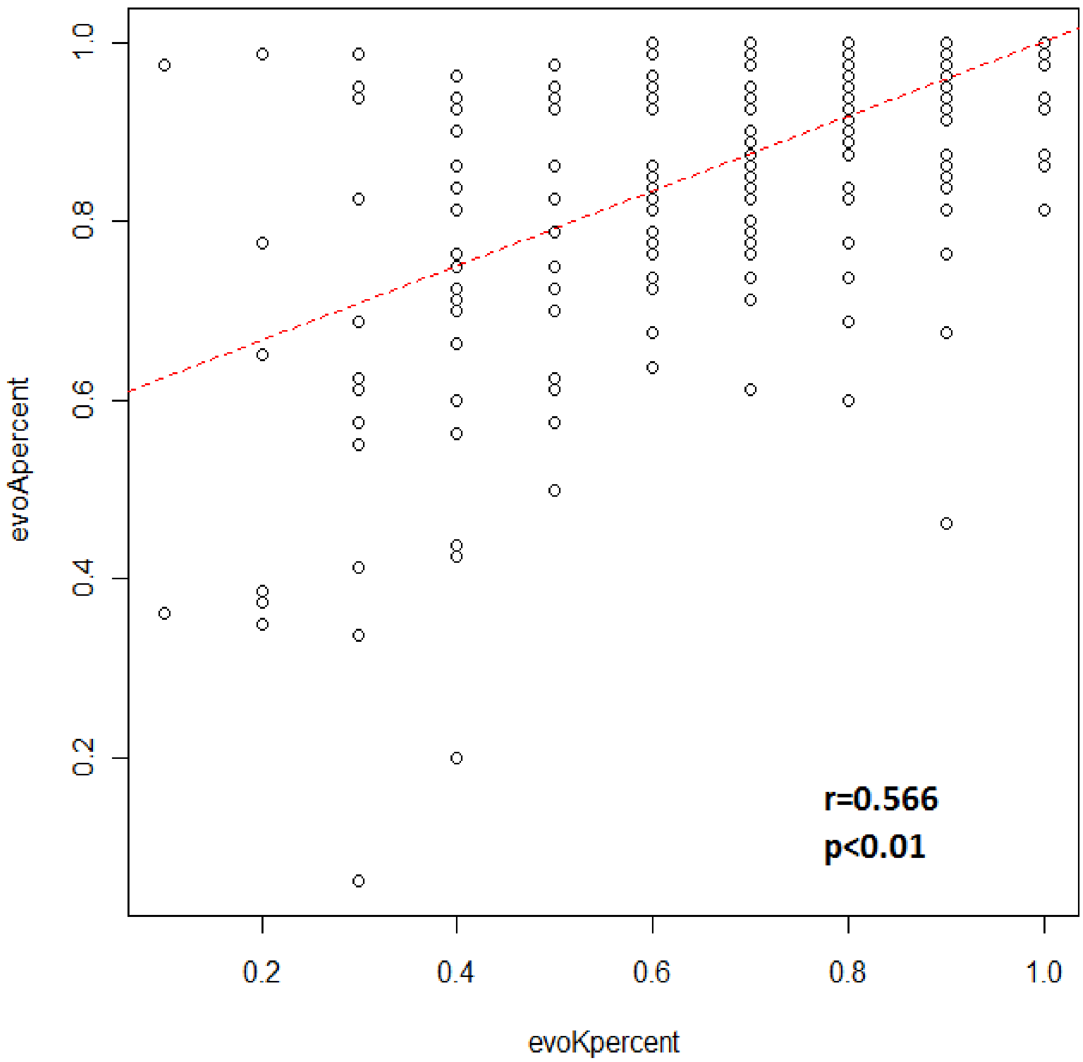

Figure 5: Simple linear regression of knowledge of biological evolution by acceptance of biological evolution. evoApercent = participant scores on the measure of acceptance of biological evolution as a percentage. evoKpercent = participant scores on the measure of knowledge of biological evolution as a percentage.

Table 1: Statistical results from ANOVA examining participant knowledge of biological evolution and acceptance of biological evolution by their theistic viewpoint using Schema A, B and C

	Knowledge of Biological Evolution	Significance	Acceptance of Biological Evolution	Significance
Theistic View: Schema A	$F_{1, 280} = 53.665$	$p<0.001$	$F_{1, 280} = 167.66$	$p<0.001$
Theistic View: Schema B	$F_{1, 280} = 27.791$	$p<0.001$	$F_{1, 280} = 176.82$	$p<0.001$
Theistic View: Schema C (All Groups)	$F_{2, 279} = 28.745$	$p<0.001$	$F_{2, 279} = 136.70$	$p<0.001$
Theistic View: Schema C (Creationist vs. Theistic Evolutionist)	$F_{1, 49} = 2.5928$	$p=0.1138$	$F_{1, 49} = 27.921$	$p<0.001$
Theistic View: Schema C (Theistic Evolutionist vs. Non-Creationist)	$F_{1, 263} = 28.904$	$p<0.001$	$F_{1, 263} = 71.344$	$p<0.001$
Theistic View: Schema C (Creationist vs. Non-Creationist)	$F_{1, 246} = 35.478$	$p<0.001$	$F_{1, 246} = 259.19$	$p<0.001$

Table 2: Mean percentage scores on measures of knowledge of biological evolution and acceptance of biological evolution by theistic view groupings used in Schema A, B, and C

	Mean Knowledge of Biological Evolution	Mean Acceptance of Biological Evolution
Creationists (Young Earth Creationists and Old Earth Creationists)	43.53%	39.12%
Theistic Evolutionists	54.12	60.82
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists)	72.68	73.53
Creationists + Theistic Evolutionists	50.59	53.59
Non-Creationists + Theistic Evolutionists	70.3	71.9

Schema C in the comparison between the participants with creationist views and the participants with theistic evolutionist views (Table 1). In that case no significant differences were detected in the knowledge of biological evolution between the participants ($F_{1, 49}$= 2.5928, p=0.1138).

Tests by Area of Expertise. Using one-way ANOVA to examine the relationship between the percentage scores for participant knowledge of biological evolution, acceptance of biological evolution, and their area of expertise, We found significant differences in their knowledge of biological evolution among faculty grouped by their area of expertise ($F_{8, 273}$= 2.3537, $p<0.05$) but no differences in their acceptance of biological evolution ($F_{8, 273}$= 1.7659, p=0.08376).

Using pairwise t-tests it was seen that the only significant difference in knowledge of biological evolution was between the participants who identified their area of expertise as “Life Science” who scored significantly ($p<0.05$) higher on the measure of knowledge of biological evolution than those who did not identify their area of expertise (Figure 6). The pairwise t-tests used to compare average scores of participants in each area of expertise with each other also revealed that while a one-way ANOVA was unable to detect any significant differences in participant acceptance of biological evolution between the areas of expertise, they did exist. Specifically, participants who identified as “Social Science” scored significantly ($p<0.05$) higher on the measure of acceptance of biological evolution than those who did not identify their area of expertise (Figure 7).

Using linear regression we found that knowledge and acceptance were significantly positively correlated for all areas of expertise (Table 4). Likewise a significant relationship between knowledge of biological evolution and acceptance of biological evolution was revealed using a Mantel test for each area of expertise except those participants who identified their area of expertise as Veterinary Medicine (Table 5).

Table 3: Correlations between participant knowledge of biological evolution and acceptance of biological evolution by theistic view groupings used in Schema A, B, and C (Mantel test using Jaccard's)

Group(s)	n	r value	*p* value
Creationists (Young Earth Creationists and Old Earth Creationists)	17	0.302	<0.005
Theistic Evolutionists	34	0.2406	<0.01
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists)	231	0.3457	<0.001
Creationists + Theistic Evolutionists	51	0.3687	<0.001
Non-Creationists + Theistic Evolutionists	265	0.3972	<0.005

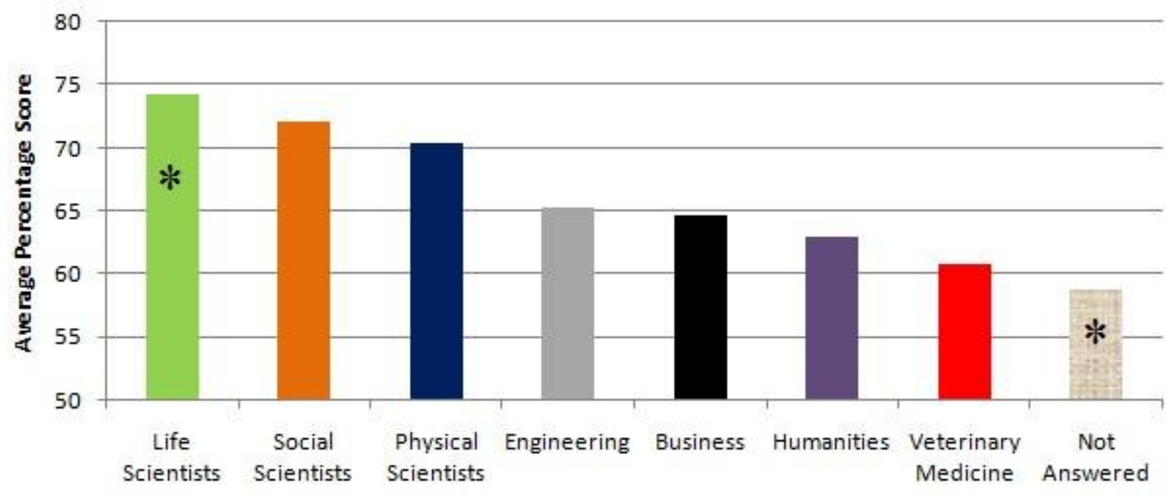

Figure 6: Average participant knowledge of biological evolution grouped by area of expertise. * indicates a significant difference ($p<0.05$) using pairwise t-tests.

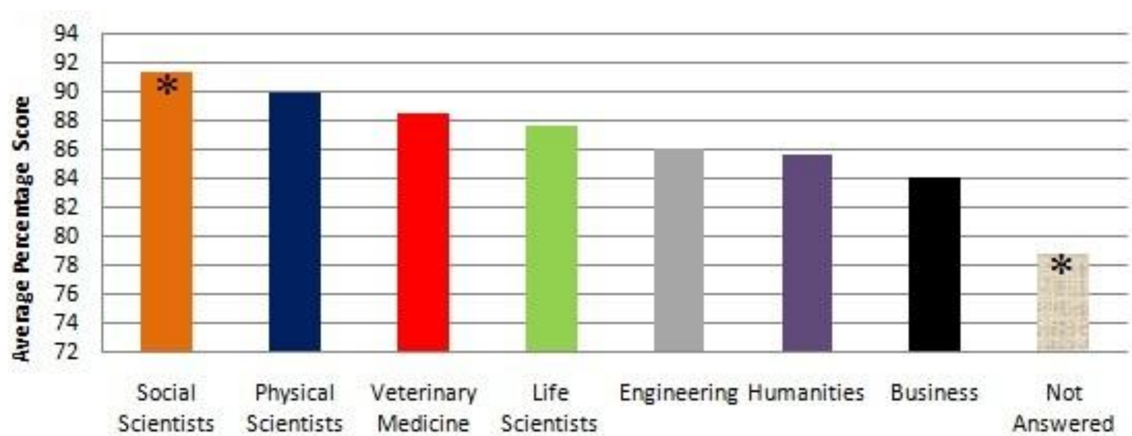

Figure 7: Average participant acceptance of biological evolution grouped by area of expertise. * indicates a significant difference ($p<0.05$) using pairwise t-tests.

Table 4: Correlation between participant knowledge of biological evolution and acceptance of biological evolution by area of expertise (one-way ANOVA and simple linear regression).

	r value	*df*	Sum Sq	Mean Sq	F value	*p*
Life Science Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.4257	1	0.12185	0.121851	16.596	<0.001
Residuals		75	0.55067	0.007342		
Physical Sciences Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.4344	1	0.08270	0.082702	6.9774	<0.05
Residuals		30	0.35559	0.011853		
Social Science Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.5084	1	0.23591	0.235906	19.524	<0.001
Residuals		56	0.67665	0.012083		
Humanities Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.3619	1	0.032832	0.032832	5.5786	<0.05
Residuals		37	0.217758	0.005885		
Engineering Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.5070	1	0.085588	0.085588	11.416	<0.01
Residuals			0.247401	0.007497		
Business Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.7829	1	0.13045	0.13045	22.166	<0.001
Residuals		14	0.082394	0.005885		
Veterinary Medicine Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.5909	1	0.030829	0.0308292	5.9016	<0.05
Residuals		11	0.057463	0.0052239		

Table 4: Continued

Not answered Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.5217	1	0.044536	0.044536	8.6021	<0.01
Residuals		23	0.119080	0.005177		

Table 5: Correlation between participant knowledge of biological evolution and acceptance of biological evolution by area of expertise (Mantel test using jaccard).

Area of Expertise	r value	*p* value
Life Science	0.6085	<0.001
Physical Sciences	0.4668	<0.001
Social Science	0.5211	<0.001
Humanities	0.4115	<0.001
Engineering	0.3457	<0.005
Business	0.6721	<0.001
Veterinary Medicine	-0.09546	= 0.584
Not answered	0.357	<0.05

Tests by other Demographic Variables. One-way ANOVAs were used to examine the relationship between the percentage scores for participant knowledge of biological evolution, acceptance of biological evolution and the various demographic variables that were measured. We found no significant relationships except in the case of the amount of science education participants reported (Table 6). While both participant age and employment level were weakly related to participant acceptance of biological evolution, the strength of the relationship was not large enough to warrant further investigation.

Tests by Amount of Science Education. Pairwise t-tests revealed that those participants that reported a high level of science education (nine or more courses) scored significantly higher on the measure of knowledge of biological evolution than those who reported a low level of science education (one to four courses) (Figure 8). The pairwise t-tests using average scores of participants by their amount science education also revealed that participants that reported a high level of science education (nine or more courses) scored significantly higher on the measure of acceptance of biological evolution. This is compared to either those who reported a moderate level of science education (five to eight courses) or a low level of science education (one to four courses) (Figure 9).

One-way ANOVA tests were then used to examine how knowledge of biological evolution and acceptance of biological evolution were related for each amount of science education participants reported. Using linear regression calculate the magnitude and direction of the correlation between variables (such as between knowledge and acceptance of biological evolution for those reporting a high amount of science education), we found that knowledge and acceptance were significantly positively correlated for all groups except those that reported no science education (Table 7).

Mantel tests between knowledge and acceptance of biological evolution by how much science education participants showed that there are significant positive correlations between

Table 6: Statistical results from ANOVA examining participant knowledge of biological evolution by several demographic responses and participant acceptance of biological evolution by several demographic responses.

	df	Sum Sq	Mean Sq	F value	*p* value
Gender (Response: Knowledge of Biological Evolution)	1	0.0019	0.001930	0.0426	=0.8366
Residuals	280	12.6795	0.045284		
Gender (Response: Acceptance of Biological Evolution)	1	13	13.074	0.0826	=0.774
Residuals	280	44337	158.347		
Age (Response: Knowledge of Biological Evolution)	3	0.2714	0.090483	2.0269	=0.1104
Residuals	278	12.4100	0.044640		
Age (Response: Acceptance of Biological Evolution)	3	1254	418.11	2.6971	<0.1
Residuals	278	43096	155.02		
Employment Level (Response: Knowledge of Biological Evolution)	3	0.2326	0.077532	1.7314	=0.1608
Residuals	278	12.4489	0.04478		
Employment Level (Response: Acceptance of Biological Evolution)	3	2237	745.67	2.9224	<0.1
Residuals	278	42113	151.49		
Amount of Science Education (Response: Knowledge of Biological Evolution)	3	0.7112	0.237079	5.506	<0.01
Residuals	278	11.9702	0.043058		
Amount of Science Education (Response: Acceptance of Biological Evolution)	3	1643	547.71	3.5653	<0.01
Residuals	278	42707	153.62		

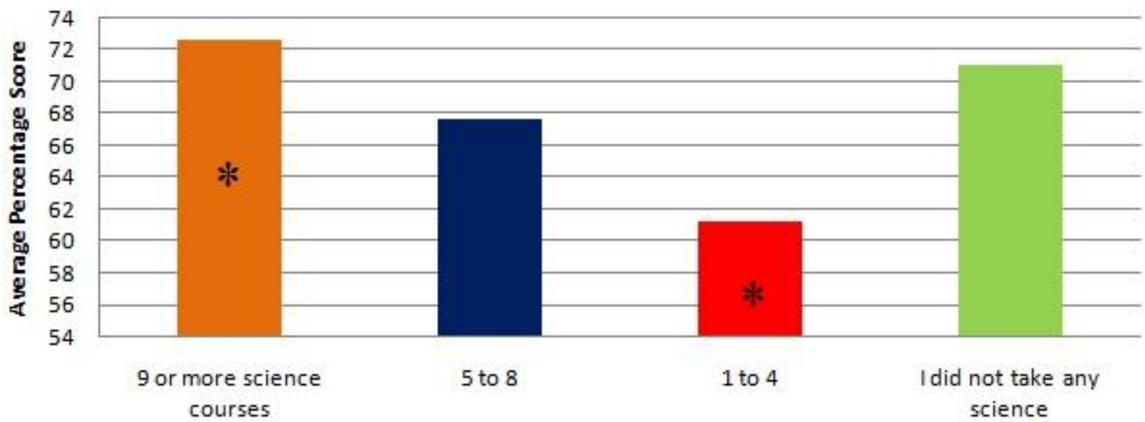

Figure 8: Average participant knowledge of biological evolution grouped by amount of science education reported. * indicates a significant difference (p<0.05) using pairwise t-tests.

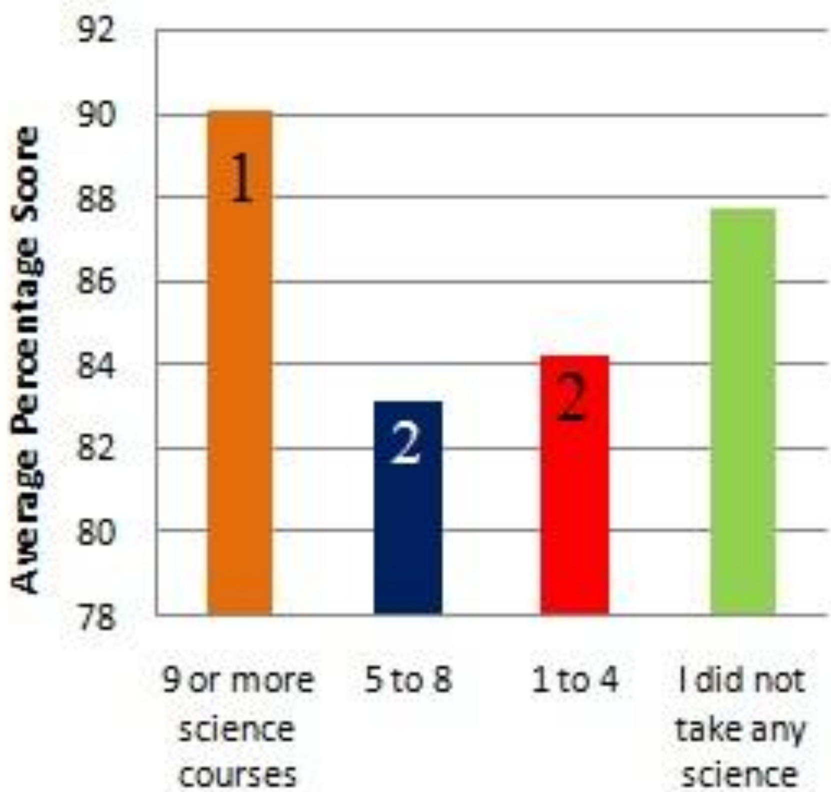

Figure 9: Average participant acceptance of biological evolution grouped by amount of science education reported. Different numbers in collumns indicate a significant difference (p<0.05) using pairwise t-tests.

Table 7: Correlation between participant knowledge of biological evolution and acceptance of biological evolution by amount of science education reported (one-way ANOVA and simple linear regression).

	r value	*df*	Sum Sq	Mean Sq	F value	*p* value
High Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.4490	1	0.41177	0.41177	42.175	<0.001
Residuals		167	1.63047	0.00976		
Moderate Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.4734	1	0.060363	0.060363	11.264	<0.01
Residuals		39	0.208993	0.005359		
Low Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.4671	1	0.16923	0.169228	23.727	<0.001
Residuals		85	0.60626	0.007132		
None Knowledge of Biological Evolution (Response: Acceptance of Biological Evolution)	0.2546	1	0.011449	0.011449	0.6932	0.4245
Residuals		10	0.165151	0.016515		

knowledge and acceptance for high, moderate and low amounts of science education (Table 8). This corroborates the results from the one-way ANOVA and linear regression described in Table 7.

Principle Coordinates Analysis. The pattern seen in the PCoA of participant responses on knowledge and acceptance measures (Figure 10) displayed a distinct shape and curve. The distinct shape of the plot suggested that some other variable might be driving accounting for the variation seen along axis PCoA 1 (35% of the variation, PCoA 2 explains 7% of the variation). When participant responses were color coded by their response to other questions on the survey (theistic view, opinion of teaching ID, gender, etc) one label appeared to fit with the greatest variation being along the PCoA 1 axis, participant theistic view (Figure 10).

Labeling of the separate knowledge of biological evolution and acceptance of biological evolution PCoA plots by participant responses to other survey questions revealed a similar pattern. In both cases, variation in participant theistic view appeared to align well with axis PCoA 1 compared with other potential labels such as amount of science education or area of expertise (Figure 11A - F). In the case of participant knowledge of biological evolution (Figure 11D - F) axis PCoA 1 explains 21% of the variation; while for participant acceptance of biological evolution (Figure 11A - C) axis PCoA 1 explains 57% of the variation. This implies a general pattern of difference and corroborates the conclusion that participant theistic view is having major influence on both their knowledge of biological evolution and their acceptance of biological evolution.

Results Part 2: Tests of the impact of multiple factors

Tests by Theistic View and Area of Expertise. Using two-way ANOVAs, we found theistic view had a far more pervasive effect on participant knowledge of biological evolution than area of expertise (Table 9). This was also the case for participant acceptance of biological evolution (Table 10).

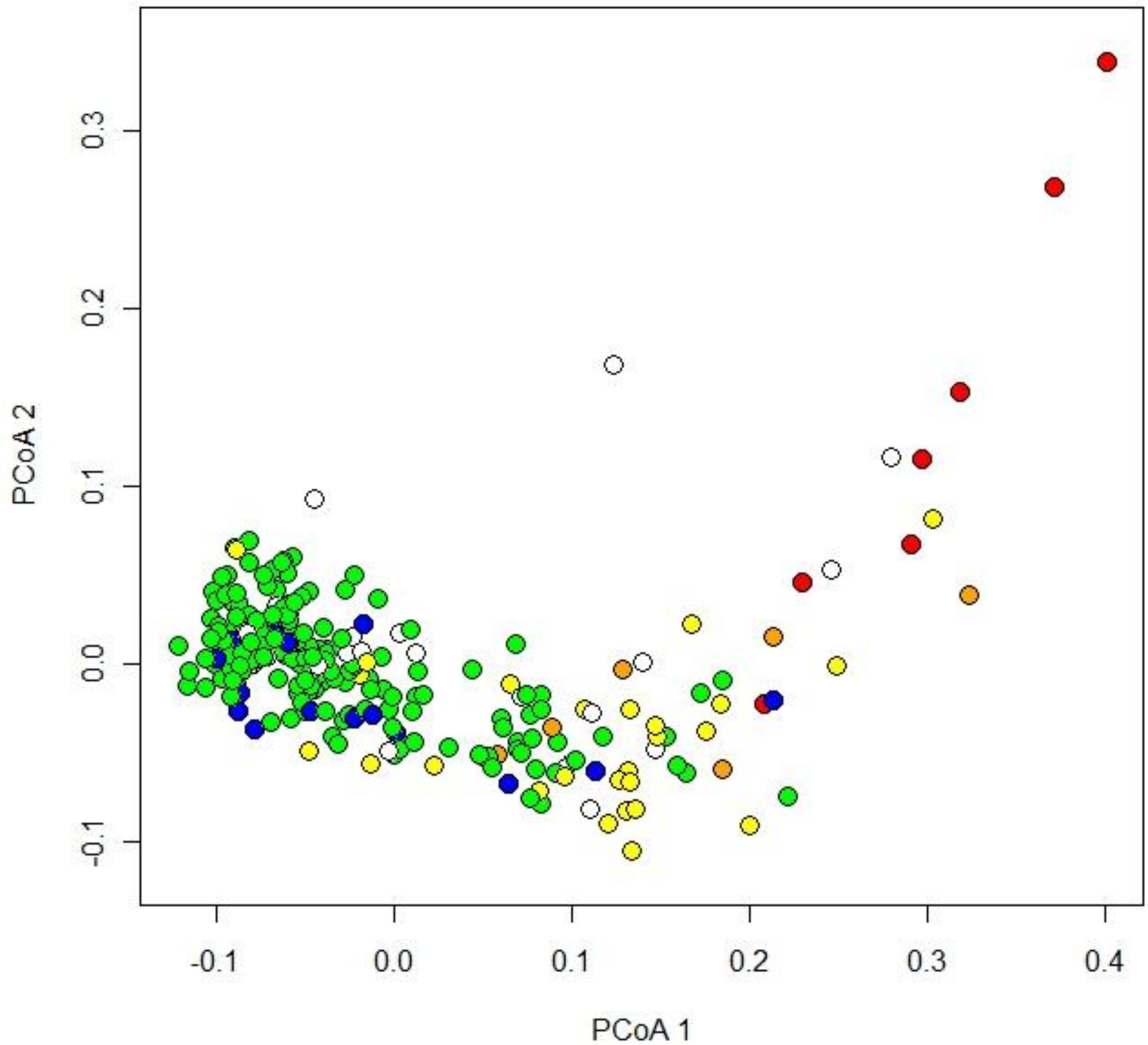

Figure 10: PCoA of participant scores on a measures knowledge and acceptance of biological evolution, color coded by participant theistic view. Legend: red = Young Earth Creationist, orange = Old Earth Creationist, yellow = Theistic Evolutionist, green = Agnostic Evolutionist, blue = Atheistic Evolution, white = NA/Other.

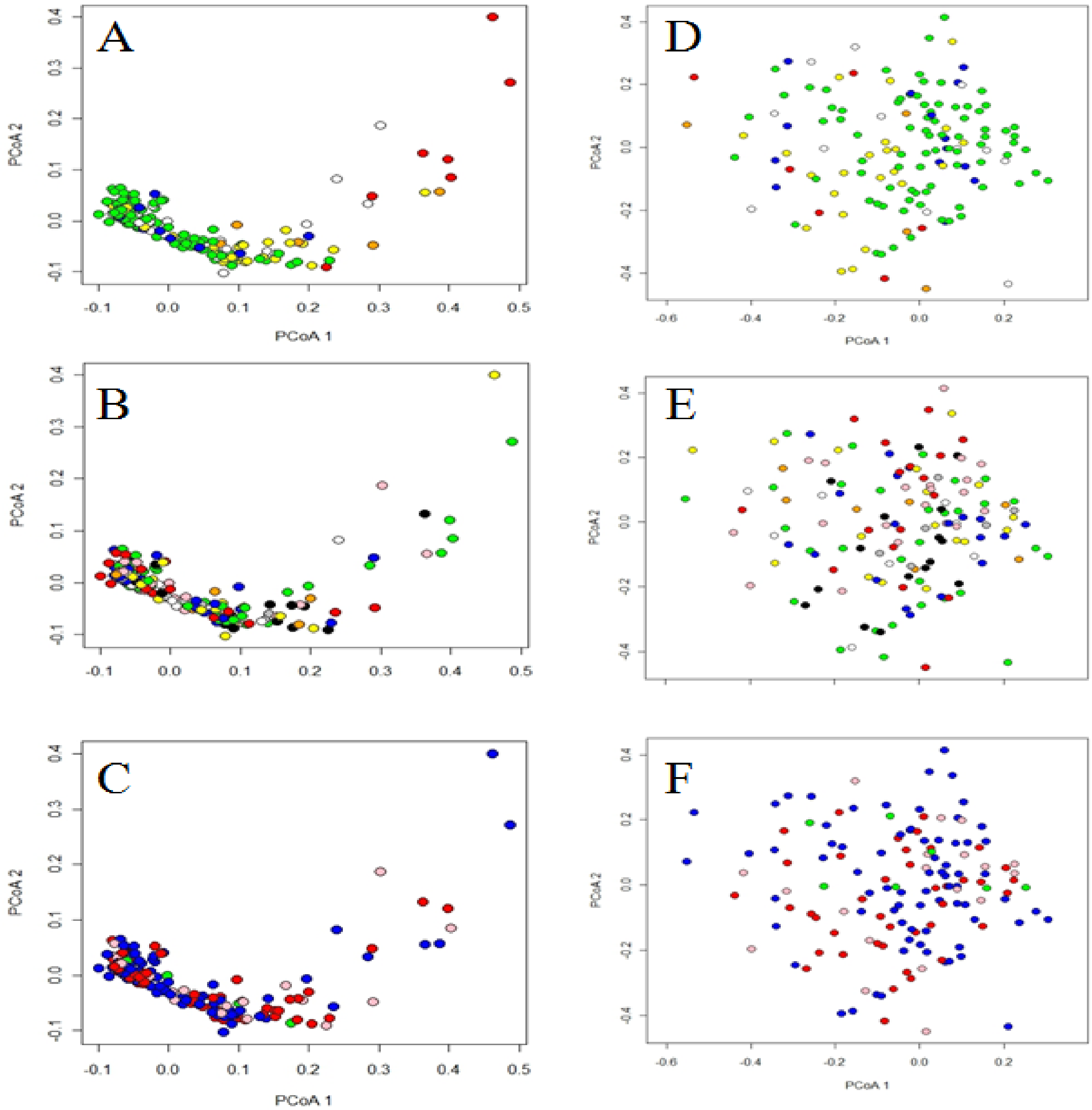

Figure 11: A: PCoA of participant acceptance of evolution scores coded by theistic view. B: PCoA of participant acceptance of evolution scores coded by area of expertise. C: PCoA of participant acceptance of evolution scores coded by amount of science education. D: PCoA of participant knowledge of evolution coded by theistic view. E: PCoA of participant knowledge of evolution coded by area of expertise. F: PCoA of participant knowledge of evolution coded by amount of science education. Legend: Figures A and D: red = Young Earth Creationist, orange = Old Earth Creationist, yellow = Theistic Evolutionist, green = Agnostic Evolutionist, blue = Atheistic Evolution, white = NA/Other; Figures B and E: pink = Social Science, red = Physical Science, orange = Business, yellow = Applied Science/Engineering, green = Life Science, blue = Humanities, white = Veterinary Medicine, gray = Formal Science/Math, black = Not Answered; Figures C and F: pink = 5-8 science courses, red = 1-4 science courses, green = no science courses, blue = 9 or more science courses.

In the case of acceptance of biological evolution, the significant interaction term for theistic view and area of expertise was detected and represents that acceptance of biological evolution does change by theistic view, but only for those participants who identified as “other”. If those participants are removed then no interaction term is detected.

Tests by Theistic View and Other Variables. Two-way ANOVAs also revealed that participant theistic view has a more pervasive effect on participant knowledge of biological evolution than their amount of science education reported (Table 11). This was also the case for participant acceptance of biological evolution (Table 12). Again, in the case of acceptance of biological evolution, a significant interaction term for theistic view and amount of science education was detected and represents that acceptance of biological evolution does change by theistic view, but only for those participants who reported “none” for their amount of science education. If those participants are removed then no interaction term is detected.

When these two-way ANOVAs are performed using Schema B or Schema C for theistic view, the resulting patterns are the same. In both Schema B and Schema C theistic view had a far more pervasive effect on participant knowledge of biological evolution than either area of expertise or amount of science education. Theistic view also had a more pervasive effect on participant acceptance of biological evolution than either area of expertise or amount of science education. As with Schema A, in the case of acceptance of biological evolution, the significant interaction term for theistic view and area of expertise was detected and represents that acceptance of biological evolution does change by theistic view, but only for those participants who identified as “other”. If those participants are removed then in both Schema B and Schema C no interaction term is detected.

Using pairwise comparisons, when participant area of expertise is broken into those with creationist and non-creationist theistic views (Schema A), those participants with non-creationist theistic views scored significantly higher on both knowledge and acceptance measures than those participants with creationist theistic views in all cases except for Business and Veterinary Medicine (Table 14).

If Schema B is used, most of the creationist groups become too small for statistical comparison (Table 15). In Schema B, participants who held non-creationist views from life science, engineering, and the not answered group scored significantly higher on both the knowledge and acceptance measures than those with creationist theistic views. Participants who held non-creationist views from social science and humanities scored significantly higher on only acceptance of biological evolution than those with creationist theistic views.

The results from the pairwise t-tests using Schema C, were extremely varied. The primary likely cause for this is that when Schema C is used in conjunction with a division of the data by area of expertise, some of the resulting groups are too small to be used in statistical comparisons (e.g., there was only one participant from the physical science area of expertise that is grouped as a creationist using Schema C). Nevertheless, significant differences were detected between several groups, particularly between the creationist and non-creationist groups (Tables 16 and 17).

AIC Tests of Model Fit. Using AIC we compared which model (theistic view, area of expertise, or amount of science education was the best fit to the data (knowledge of biological evolution and acceptance of biological evolution) (Table 13). In both cases the model using theistic view was the best fit (smallest AIC).

Qualitative Results

Of the seven text response questions, four were part of the nature of science (NOS) portion of the survey, one was designed to elicit participant views on public education policy, one was designed

Table 8: Correlation between participant knowledge of biological evolution and acceptance of biological evolution by amount of science education (Mantel test using Jaccard).

Amount of science education reported	r value	*p* value
High	0.461	<0.001
Moderate	0.571	<0.001
Low	0.5069	<0.001
None	0.3223	=0.06

Table 9: Statistical results from two-way ANOVA examining participant knowledge of biological evolution (response variable) by both theistic view and area of expertise.

	df	Sum Sq	Mean Sq	F value	*p* value
Theistic View	1	2.0396	2.03963	55.0097	<0.001
Area of Expertise	8	0.7853	0.09816	2.6475	<0.01
Theistic View : Area of Expertise	8	0.0680	0.00851	0.2294	=0.985278
Residuals	264	9.7885	0.03708		

Table 10: Statistical results from two-way ANOVA examining participant acceptance of biological evolution (response variable) by both theistic view and area of expertise.

	df	Sum Sq	Mean Sq	F value	*p* value
Theistic View	1	16610.4	16610.4	178.4005	<0.001
Area of Expertise	8	1237.0	154.6	1.6607	=0.108186
Theistic View : Area of Expertise	8	1922.7	240.3	2.5813	<0.01
Residuals	264	24580.3	93.1		

Table 11: Statistical results from two-way ANOVA examining participant knowledge of biological evolution (response variable) by both theistic view and amount of science education.

	df	Sum Sq	Mean Sq	F value	*p* value
Theistic View	1	2.0396	2.03963	55.7704	<0.001
Amount of Science Education	3	0.5074	0.16913	4.6245	<0.01
Theistic View : Amount of Science Education	3	0.1138	0.03792	1.0369	=0.376658
Residuals	274	10.0207	0.03657		

Table 12: Statistical results from two-way ANOVA examining participant acceptance of biological evolution (response variable) by both theistic view and amount of science education.

	df	Sum Sq	Mean Sq	F value	*p* value
Theistic View	1	16610.4	16610.4	172.8039	<0.001
Amount of Science Education	3	600.9	200.3	2.0839	=0.10261
Theistic View : Amount of Science Education	3	801.4	267.1	2.7791	<0.05
Residuals	274	26337.6	96.1		

Table 13: Log-likelihood and AIC of models on knowledge of biological evolution and acceptance of biological evolution.

Model	log-likelihood	AIC	No. of parameters
Knowledge of Biological Evolution ~ Theistic View	61.93252	-117.8650	3
Knowledge of Biological Evolution ~ Area of Expertise	46.61274	-73.22549	10
Knowledge of Biological Evolution ~ Amount of Science Education	45.34678	-80.69356	5
Acceptance of Biological Evolution ~ Theistic View	-1047.150	2100.301	3
Acceptance of Biological Evolution ~ Area of Expertise	-1106.2	2232.4	10
Acceptance of Biological Evolution ~ Amount of Science Education	-1107.991	2225.982	5

Table 14: Statistical results from pairwise t-tests examining participant knowledge of biological evolution and acceptance of biological evolution by their theistic viewpoint grouped by area of expertise (Schema A).

Mean Knowledge of Biological Evolution	Life Science	Physical Sciences	Social Science	Humanities	Engineering	Business	Veterinary Medicine	Not answered
Creationist	57.6%	50%	48.3%	50%	40%	45%	50%	45%
Non-Creationist	79.5	74.4	75.2	65.7	68.9	67.7	63%	65.6
p value	<0.001	<0.01	<0.01	<0.05	<0.01	=0.21	=0.49	<0.05
Mean Acceptance of Biological Evolution								
Creationist	53.5	59	54.2	58.2	36.5	51.5	68	51.8
Non-Creationist	75.2	74.6	75.5	70.7	73.4	69.7	71.4	68.6
p value	<0.001	<0.001	<0.001	<0.01	<0.001	=0.11	=0.61	<0.001

Table 15: Statistical results from pairwise t-tests examining participant knowledge of biological evolution and acceptance of biological evolution by their theistic viewpoint grouped by area of expertise (Schema B).

Mean Knowledge of Biological Evolution	Life Science	Physical Sciences	Social Science	Humanities	Engineering	Business	Veterinary Medicine	Not answered
Creationist	55.7%	50%	55%	40%	25%	20%	-	20%
Non-Creationist	76.3	73.1	72.8	64.4	68	67.9	60.8	62.2
p value	<0.05	-	=0.23	=0.055	<0.001	-	-	<0.001
Mean Acceptance of Biological Evolution								
Creationist	41.3	40	53	45.5	18	28	-	37.5
Non-Creationist	73.2	73.1	73.8	69.9	72.2	70.1	70.8	65.3
p value	<0.001	-	<0.01	<0.01	<0.001	-	-	<0.01

Table 16: Statistical results from pairwise t-tests examining participant knowledge of biological evolution by their theistic viewpoint grouped by area of expertise (Schema C).

Mean Knowledge of Biological Evolution	Life Science	Physical Sciences	Social Science	Humanities	Engineering	Business	Veterinary Medicine	Not answered
Creationist	55.7%	50%	55%	40%	25%	20%	-	20
Theistic Evolutionist	59	50%	45	55%	55	70	50	53.3
Non-Creationist	79.5	74.4	75.2	65.7	68.9	67.6	63	65.6
p value Creationist ~ Theistic Evolutionist	=1	-	=1	=0.92	=0.391	-	-	=0.128
p value Theistic Evolutionist ~ Non-Creationist	<0.05	-	<0.01	=0.71	=0.995	-	=0.49	=0.568
p value Creationist ~ Non-Creationists	<0.05	-	=0.43	=0.13	<0.05	-	-	<0.05

Table 17: Statistical results from pairwise t-tests examining participant acceptance of biological evolution by their theistic viewpoint grouped by area of expertise (Schema C).

Mean Acceptance of Biological Evolution	Life Science	Physical Sciences	Social Science	Humanities	Engineering	Business	Veterinary Medicine	Not answered
Creationist	41.3	40	53	45.5	18	28	-	37.5
Theistic Evolutionist	62	63.8	54.8	64.5	55	75	68	56.5
Non-Creationist	75.2	74.6	75.5	70.7	73.4	69.7	71.4	68.6
p value Creationist ~ Theistic Evolutionist	<0.001	-	=1	=0.087	<0.001	-	-	=0.1496
p value Theistic Evolutionist ~ Non-Creationist	<0.001	-	<0.001	=0.7103	<0.05	-	=0.61	=0.1026
p value Creationist ~ Non-Creationists	<0.001	-	<0.001	<0.005	<0.001	-	-	<0.005

to provide additional context to participant theistic view choice, and one was designed to provide additional context on participant opinion regarding the American public's view of biological evolution. Participants did have a final text box at the end of the survey where they could fill in any additional comments they wished.

Analysis of the text responses to these questions revealed the presence of nearly every misconception about science and biological evolution for which the educational field is currently aware. Most common were statements that either implicitly or explicitly stated that biological evolution (or science) was a belief and thus equivalent to other beliefs (e.g. creationism).

"I believe it would take perhaps many sources of data and different "angles" of contradictory data before replacing an established scientific idea. That said, I do feel we sometimes hold too tight to old and out-dated ***belief systems****."* (Emphasis added)

"While we all have different ***beliefs****, I believe it is important to teach both views so college students are aware of both positions. They then need to make their own choices. (I don't have to* ***believe*** *in evolution but I do believe students should be aware of the variety of* ***beliefs****"* (Emphasis added)

Another misconception theme running through the text responses was confusion regarding how biological evolution works. Multiple participants stated that biological evolution includes (or is) an explanation for the origin of life. As has been pointed out in other publications (Rice et al., 2010) this not the case, but is a common misconception. Other participants stated that biological evolution was an entirely random/undirected process. Still others made inherently incorrect statements about how natural selection works.

"Both biological evolution and intelligent design/creationism should be taught in college science classes and given equal time with respect to discussions about ***how life originated on earth****.*

The aspects of biological evolution that would explain how life is changing today, which can and have been observed and experienced experimentally, should also be taught with an emphasis on understanding how human interactions with the environment we live in impacts the ecosystem" (Emphasis added)

"By neglecting the supernatural as a possibility, scientists have eliminated one possible explanation of the origins of the natural world. As a result, many when confronted with the overwhelming evidence that ***life could not have randomly*** *started on this planet, ascribe our presence here to extraterrestrial involvement."* (Emphasis added)

A third theme running through the text responses was a perceived/implied measure of superiority or elitism. Multiple participants gave text responses that implied that specific questions were faulty, that the investigators did not understand the NOS, Kuhnian Theory, and survey question formatting, just to name a few. On multiple occasions participants explicitly stated that they had intentionally not answered a question (choosing an unsure, other, simply leaving it blank).

"Arguing or even discussing ID or any other creationist perspective is about the same as arguing against the "flat Earth theory". It ain't(sic) *worth my time and doing so only gives such viewpoints credibility. So why bother to debate. It's over."*

"You need to talk to a philosopher or other humanities person to help you refine the wording of your questions! For example, why do you care what the American public "accepts" or does not "accept"? Scientific results are true, and should be taught as well as teachers can teach them. But it is not a requirement for citizenship in the United States that anyone have any particular scientific knowledge. The Constitution, yes--evolution, no."

"Your questions were much too vague. You asked to mark all that applied, and I thought / that four of the five were correct. The "all are correct" I did not want to use because I / do not

believe that ontonogyrecapulatesphylogony(sic). *You need a written answer to those / questions because they were confusing with what you meant by the words you used. Of course, / that is what the creationists do a lot."*

"Survey design is a bit myopic"

"Because of its ambiguity and imprecision I would be very skeptical of the results of this survey. On the other hand, perhaps you're really testing for some other factor, such as how many people can be coaxed into completing a survey on any topic. It's hard to believe that a PhD thesis would be based on the results of a survey such as this."

Another theme running through to text responses was the presence of some robust statements regarding the NOS. Based on some of the individual scores on the NOS portion and these text responses, there were clearly some participants that are well versed in the NOS.

"Science rests on things being testable, observable, replicable, and falsifiable. Supernatural explanations violate at least one (if not all four) of these requirements"

"Science by definition concerns those phenomena that can be rigorously and conclusively demonstrated and/or falsified. Supernatural forces thus, by definition, fall outside the domain of science. History is FULL of phenomena that were once believed to be the province of the supernatural (e.g., tornadoes, illness, genetic diseases, the "heavenly bodies") that are now easily understood by scientists. What scientists as PEOPLE believe is irrelavant(sic) *(they can believe in fairies and superheroes and God and whatever). The PROCESS of science is different, though."*

"Obviously, no human engineer (or an intelligent designer) would use the same opening to the environment and air intake and exhaust, but that is what we have. Why? Our ancestors and theirs had this set up and it worked well enough to allow them to survive and reproduce."

"I take issue with one of the questions that occurred earlier in the survey. One option to choose state that "natural selection causes variation to arise within a population" and was supposed to be an inappropriate response. However, it is documentably(sic) *true that disruptive selection increases the phenotypic variance within a population, so perhaps the question would have been better worded to indicate directional (linear) selection."*

Finally, there was little agreement from the participants regarding which "side" of the BEE issue the investigators were on. Some participants seemed convinced that the survey was designed with an inherent bias against people with creationist views and that the results would be used to attack and defame religion. Other participants appeared equally convinced that the investigators were on the "side" of the creationists and would use the results to attack the teaching of biological evolution. We take this result as evidence that the survey was not inherently biased to either "side".

"God" help us if you are teaching Intelligent Design as fact."

"I wish you the best in your research. I hope that you're trying to better understand why people misunderstand evolution, and how we can convince people of the truth (as empirically and scientifically determined)."

"Mentioned before. Glad to see it addressed and pray it is a true study. Curious to know what the study outcomes are for this study . . . / Bottom line, scientific community and Christian community have much the same in common. Just need to chill a bit. Don't make these results inflammatory no matter what you conclude about whatever it is you are studying.

"Evolutionists need to STOP trying to convince people that God is not involved, and simply teach the evidence for and against evolution like any other scientific theory. Evolution has become confounded with the scientists' worldview, i.e., they use evolution to try to "enlighten" people that God is not necessary, with the underlying implication that God does not exist."

"If you don't consider psychology a science, then I would suggest you're just as biased as the creationists who do consider creationism a science!"

"If you can use this to knock ID out of some peoples head's, it will make me happy."

Discussion

What is the driving force behind an individual's knowledge and acceptance of biological evolution? Some argue that an individual's exposure to science, particularly to content on biological evolution, has the greatest impact on their knowledge and acceptance of biological evolution. Others suggest that an individual's theistic view is the overriding determiner of their knowledge and acceptance of biological evolution. Determining the factors (and the strength of those factors relative to each other) that influence an individual's knowledge and acceptance of biological evolution is an important step in being able to properly address the current issues with Biological Evolution Education (BEE). The analyses described here provide several unique insights into the interplay of factors influencing knowledge and acceptance of biological evolution.

First, it is clear that knowledge of biological evolution and acceptance of biological evolution are inextricably linked together for university faculty. Higher knowledge of biological evolution positively correlates with higher acceptance of biological evolution across the entire population of university faculty. This is in agreement with previous work showing a relationship between knowledge and acceptance (Lawson and Worsnop, 1992; Rice et al., 2011; Scharmann et al., 2005).

This positive correlation is also present if the population is broken down into distinct theistic views (creationist and non-creationist viewpoints). This suggests that regardless of their theistic view, for university faculty higher knowledge of biological evolution positively correlates with higher acceptance of biological evolution. This relationship between knowledge, acceptance, and theistic view is important, because it may mean that a person's knowledge of biological evolution and acceptance of biological evolution can be improved in tandem regardless of their underlying personal beliefs.

When the population was subdivided by participant area of expertise, the positive correlation between higher knowledge of biological evolution and higher acceptance of biological evolution was present for all types of expertise except Veterinary Medicine. The simple linear regression (SLR) and Mantel tests were not in agreement, with the SLR showing the positive correlation and the Mantel test showing no correlation in either direction for Veterinary Medicine participants. This may be due to the fact that there were few Veterinary Medicine participants overall and that none of the Veterinary Medicine participants identified as young earth creationists, leaving a gap that could have biased the result. The presence of this positive correlation across areas of expertise suggests that despite a person's choice of academic specialty, their knowledge of biological evolution and acceptance of biological evolution can be improved together.

Higher knowledge of biological evolution also positively correlates with higher acceptance of biological evolution across different levels of science education. This is the case for high, moderate, and low levels, but not for those participants who stated they had received no science education in college. This result makes sense, as one would expect that a person who is exposed to a science would learn that science and be more likely to accept it as accurate. Since we did not require the participants to inform us regarding how much of their previous science was in the biological sciences, it is impossible to be certain about how much exposure they may have previously had to it.

These results were expected, but it is worthwhile to reinforce the point that knowledge and acceptance of biological evolution are positive correlated. If improving the public's acceptance of evolution is a goal of science educators, then this result adds several more pieces of support to the idea that effective instruction in biological evolution is the correct course of action.

Second, between the factors of theistic view, area of expertise, and amount of science education, it is theistic view that has the most influence on the knowledge and acceptance of biological evolution of university faculty. While all three factors showed significant differences between their levels and knowledge and acceptance of biological evolution, it is theistic view that has the more pervasive influence on both measures. In both the two-way ANOVA of theistic view and area or expertise and the two-way ANOVA of theistic view and amount of science education it was theistic view that showed the stronger significant relationship with knowledge and acceptance. The AIC measure of the different models also supports theistic view being the strongest influencer of both knowledge and acceptance of biological evolution, as the models using theistic view had the smallest AIC values (Figure 12). This result has clear ramifications for the future of BEE. Keeping in mind that knowledge and acceptance were positively correlated regardless of the participant's theistic view, it begs the question "Is the most effective way to improve BEE to address theistic views?" The data appear unambiguous on the matter. Whether such action is morally, ethically, or legally appropriate is a question left to be answered.

Another interesting result of this work is that for both measures of knowledge and acceptance of biological evolution, the more science education the participants reported receiving in college, the better they did on those measures. Those participants who stated that they had taken nine or more science courses in college scored significantly higher on both the measures of knowledge of biological evolution and acceptance of biological evolution, when compared to those participants who had received less. This is suggests that with effective instruction in the sciences (particularly biological evolution) knowledge and acceptance of biological evolution can be improved.

It is also important to note that none of the other demographic measures (gender, age, tenure level) showed any relationship to either knowledge of evolution or acceptance of evolution. No previous studies have shown these measures to be related to knowledge or acceptance of biological

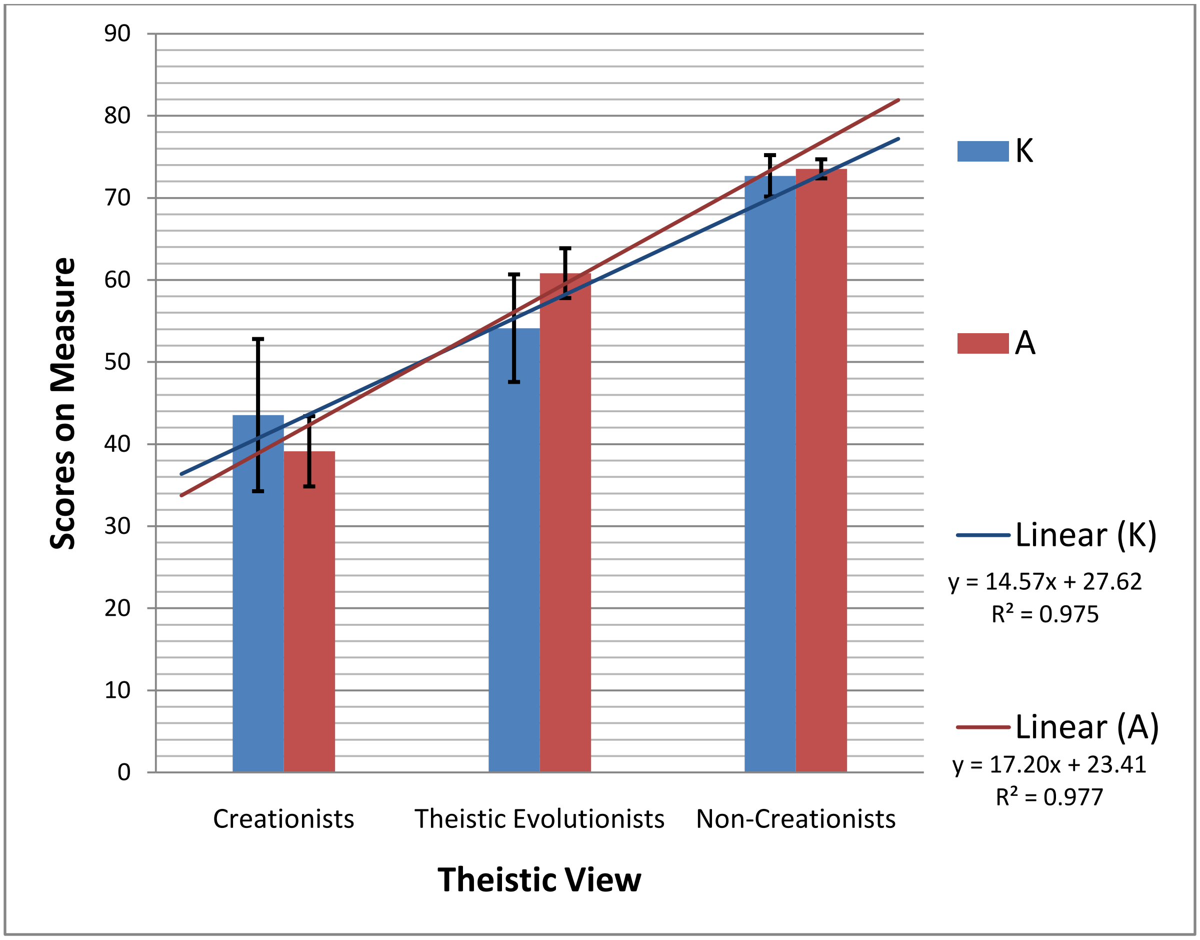

Figure 12: Best-fit model of participant average scores on knowledge of biological evolution measure (K) and acceptance of biological evolution measure (A) when grouped by theistic view Schema C. Linear K = Best-fit line and coefficient of determination (R^2 = 0.975) for knowledge of biological evolution. Linear A =Best-fit line and coefficient of determination (R^2 = 0.977) for acceptance of biological evolution. Bars = 95% C.I. around mean.

evolution, and there is no obvious reason to have thought they would be related. Regardless is it valuable to now have evidence that knowledge of biological evolution and acceptance of biological evolution are not related to an individual's age, gender, or tenure level While we do not suggest that future researchers ignore these factors entirely, given the lack of evidence of their importance their absence from future studies should not be seen as disqualifying. It is interesting to compare the results seen here to similar previously studied groups. For example, approximately 15% of the 309 participants in this study held creationist theistic positions, while previous work has shown 24% of Louisiana high school biology teachers, 30% of Minnesota high school biology teachers, and 62% of U.S. adults hold creationist theistic positions (Aguillard, 1999; Miller et al., 2006; Moore and Kramer, 2005). Clearly, university faculty at this study site have a lower rate of holding creationist views than these groups. They also exhibit higher levels of knowledge and acceptance of biological evolution compared to previously studied groups (Rutledge and Sadler, 2007; Moore et al., 2009; Moore and Cotner, 2009a; Moore and Cotner, 2009b). Given the higher average level of education earned by the participants in this study compared to previous studies, this result is not unexpected. It is interesting to note, however, that percentage of faculty who claim a personal belief in god is roughly twice that of the members of the National Academy of Sciences. This could be due to any number of factors, at personal, local, state, national, and/or international levels. For example, it could be that faculty who have creationist theistic positions see the state where this study site is located (Midwestern United States) as more favorable place to find a job than other areas.

Finally, the qualitative results from the participant text responses provide some valuable insight into the underlying thinking of university faculty. While it is apparent that some university faculty have serious misconceptions about biological evolution, not every response fell on the negative side of the ledger. Some participants demonstrated an extremely robust knowledge of not only biological evolution, but the issues surrounding BEE as well.

Conclusions

It is the hope of the investigators involved that the results presented have effectively answered some of the questions regarding faculty knowledge of and acceptance of biological evolution. Certainly the participants in this study had higher levels of knowledge and acceptance of biological evolution than those in other study populations the averages, however, are well below 100%. It is sobering that the average life science participant's score on the knowledge of biological evolution measure was only a 74.3% (a solid C in most college grading scales) and their score on the measure of acceptance was only 87.6%. These are the participants who self selected to study the biological sciences. If Dobzhansky's statement that "*Nothing in Biology makes sense except in the light of evolution*" is accurate, then how are these participants succeeding in their careers without a basic knowledge of biological evolution?

It is simultaneously encouraging and disappointing that the faculty in this study as a whole accept biological evolution at a moderately high level (86.8%). It is encouraging when you compare this result to two previous surveys looking at acceptance of biological evolution in the American public. Gallup polls consistently find that around 54% of the public accepts that biological evolution occurs. The highly popularized study by Miller, Scott, Okamoto found that only about 40% of the American public think that biological evolution is true (Miller et al., 2006).We expected that the faculty would score higher on average than the public, which they did (86.8%). Given that these are some of the most highly educated members of American society, and that previous work has shown only 7% of NAS members have a personal belief in god, we thought it reasonable to predict that they would hit over 90% acceptance. Even when the faculty are grouped by their theistic view, area of expertise, or amount of science education only those participants that identified as social science, physical science, or having had a high amount of science education scored at or above the 90% level.

Perhaps the most important result of this work is the evidence it provides that theistic view has a significant impact on both knowledge and acceptance of biological evolution. Additionally, it exerts more influence than either area of expertise or amount of science education. This is supported by the fact that the model using theistic view was the best fit according to the AIC measures used. The question remains, however, what do we do with this information? Should we as educators actively address our student's theistic views? Do the ends justify the means?

It is clear from these results that if educators want to effectively address their student's knowledge of biological evolution, they need to also address their acceptance of biological evolution. All of the participants in this study were someone's students at one time, just as today's students are the educators of tomorrow. Addressing the problem at the faculty level needs to be one part of a larger, multi-pronged effort to get BEE in America to the point it should have been decades ago.

Finally, it is the opinion of the authors that just examining knowledge and acceptance of biological evolution is actually insufficient for a robust understanding of how to address the problems of BEE. We suggest that any and all future research should include an effective measure of understanding of the nature of science (NOS). Some previous research on BEE has included a NOS portion, but typically the there is little consistency regarding the instrument used (AAAS, 1993;Alters and Nelson, 2002; Bell et al., 1998; Clough, 1994; Farber, 2003;Johnson and Peeples, 1987; NAS, 1998; Rutledge and Warden, 1999; Rutledge and Mitchell, 2002; Smith, 2010; Southerland and Sinatra, 2003). Some studies have shown knowledge of biological evolution to be correlated with understanding of the NOS while other studies have shown that acceptance of biological evolution is correlated with understanding of the NOS. What is needed now are studies where all three of these variables are measured simultaneously to see if they are correlated. If that is the case then it would be strong evidence that effective BEE *must* include content on biological evolution; it *must* address acceptance of biological evolution, and it *must* include content on *and* address issues of the NOS.

CHAPTER 4:

University Faculty understanding of the Nature of Science: What relationship do we see with Biological Evolution?

Introduction

Science literacy amongst citizens of the United States tends to be low (California Academy of Sciences, 2009; Miller, 2011). Certainly there are exceptions, but on average we don't seem know much about how the world around us works. The data supporting this conclusion are not difficult to find. Only 53% of adults surveyed in 2009 knew that it takes approximately365 days for the Earth to revolve around the sun, and only 59% knew that the earliest humans and dinosaurs did not live during the same time period (California Academy of Sciences, 2009). Recent work found that only 28% of American adults qualified as scientifically literate (Miller, 2011). That same study also found that only 77% agreed with the statement that "all plants and animals have DNA". If these results can be translated to the American public as a whole, then there are approximately 180 million American adults (or 72% of the nearly 250 million adults) over the age of 15 that are scientifically illiterate (Central Intelligence Agency, 2011). It seems safe to say that science literacy in the United States is below expectations.

Some would place the blame for this dismal state of affairs entirely on the K-12 system. Certainly there are improvements to be made at that level, particularly given the obligatory nature of student enrollment. The 2009 Trends in International Mathematics and Science Study (TIMSS) found that the 15-year-old students in the United States came in 17th out of 34 countries on a scale of science literacy. The TIMSS also found that only 47% of our 4thgrade students and 38% of our

8th grade students reach the “high” level international science benchmark for their respective grade (Institute of Education Sciences, 2007).

While there were approximately 50 million students enrolled in the K-12 system in 2008 (U.S. Department of Education, 2008) there were only around 11 million full time undergraduate students and under 3 million graduate students enrolled in various universities in the U.S. (U.S. Department of Education, 2009). Even though college-level education does not reach every citizen directly, it can impact them indirectly through interactions that college educated individuals have with non-college educated individuals. Additionally, while the knowledge of science content and the nature of science learned at the college level are both built upon that which was learned in the K-12 system, we should not ignore the importance of advances that can be made in science literacy at the college level regardless of a student’s starting point.

Previous studies have investigated various ways to improve the teaching of science and the nature of science(NOS), particularly at the middle and high school levels (Alters and Nelson, 2002; Abd-El-Khalick and Ledermann, 2000; Dagher and BouJaoude, 1997; Palmquist and Finley, 1997; Lederman, 1999; McComas et al., 1998; Nehmet al., 2009), but none have yet examined the understanding of the NOS of those people responsible for the teaching at the college level (particularly science courses). While understanding particular methods of NOS instruction are interesting and of value to instructors, it is difficult to imagine an instructor who can effectively use a proven teaching method if they themselves do not understand the underlying content. The question then becomes, what do college-level instructors know about the NOS?

Previous work has already shown that many groups (K-12 students, undergraduate college students, K-12 teachers) do not have a robust understanding of the NOS or the science used in the study of evolution (Eve and Dunn, 1990; Lawson and Worsnop, 1992; Ryan and Aikenhead, 1992; Johnson and Peeples, 1987; McComas et al., 1998; Nehm and Schonfeld, 2007; Nehmet al., 2009;

Scharmann et al., 2005; Sinclair and Baldwin, 1997; Zuzovsky, 1994). For example, students enrolled in a graduate-level science teacher curriculum showed that they held several specific misconceptions, including: theories become facts; evolution can't be "proven", and evolution is "just a theory" (Nehm and Schonfeld, 2007). Unfortunately little data exist on the understanding of the NOS held by instructors outside of the K-12 system. We already know that passive/implicit instruction in the NOS occurs whenever science content is taught, but also that active/explicit instruction is likely to be much more effective in developing NOS understanding (Smith and Scharmann, 2008). If we expect our college level instructors to be explicitly teaching aspects of the NOS then we had better be sure that they also understand the NOS.

In addition, understanding the NOS is of value in and of itself. A population educated in the NOS will be better able to understand and process much of the science and non-science related news and information that they encounter regularly. Having a robust understanding of the NOS can positively influence how well people understand science content as well. Of specific interest here is the research relating biological evolution and the NOS. It has been previously shown that the acceptance of evolution and the understanding of the nature of science are significantly related to each other (Johnson and Peeples, 1987; NAS, 1998; Southerland and Sinatra, 2003). Many people who do not understand why creationism and Intelligent Design (ID) are not considered scientific also do not understand the NOS (Hokayem and Boujaoude, 2008). Many students (both high school and college) do not understand the tentative aspect of the NOS, and thus expect science content such as biological evolution to be either 100% true or 100% false (Perry, 1981).

The available research suggests that instruction in the theory of biological evolution will benefit from the inclusion of a NOS component (Bell et al., 1998; Alles, 2001; Alters and Nelson, 2002; American Association for the Advancement of Science, 1993; Clough, 1994; Farber, 2003; National Academy of Sciences, 1998; Johnson and Peeples, 1987; Rudolph and Stewart, 1998;

Rutledge and Mitchell, 2002; Smith, 2010).Biologists, educators, and other scientists recognize biological evolution to be an integral part of our understanding of the natural world, and that it should be an explicit goal to ensure that appropriate instruction in the NOS is occurring to support understanding of biological evolution (AAAS, 2006;NABT, 2011; NRC, 1995; NSTA, 2003).

Since science faculty members at major research institutions are not only involved in the science instruction of their students, but are also active researchers in their chosen fields, it is reasonable to predict that they would have a robust understanding of science. Many students accept university faculty as authoritative on many subjects, even in topics outside their area of expertise. It is reasonable to expect then, that non-science faculty can also have an impact on the views of science held by their students, as science related topics could come up during class, or in a more casual setting.

Polls of the American public consistently find that large portions do not accept that biological evolution has occurred and is continuing to occur (Gallup, 2010; Miller et al, 2006). It seems clear that many students (in both high school and college) are: 1) not being given accurate instruction in biological evolution; 2) having their misconceptions about biological evolution reinforced; and 3) being explicitly taught non-science material (e.g., creationism and intelligent design) in their science classes (Bandoli, 2008; Beardsley, 2004; Bowman, 2008; Cavanagh, 2005; Gross, 2006; Wallis, 2005). It is also apparent that the public does not have a robust understanding of the NOS (Alters and Nelson, 2002).

Part of the larger problem is the presence of many misconceptions about biological evolution. For example, some people hold the misconception that biological evolution explains the origin of life (Paz-y-Miño and Espinoza, 2011a). Others think that biological evolution is an entirely random process (Shermer, 2008). Still others will argue that understanding biological evolution will lead them to become an atheist and/or act in an immoral fashion (Shermer, 2008). These are just a few examples of the many misconceptions about evolution that BEE researchers and educators encounter on a regular basis.

This is by no means a new problem. Within the last decade various events have drawn greater attention to the issue. We have seen an increase the number of publications on the topic, an increase in funds available for new research, and new journals and conferences have been created as specific venues for BEE research. These are welcome developments but, while we are hopeful that they will lead to real improvements in BEE, the task ahead is substantial.

Comprehending how faculty understanding of the NOS, knowledge of biological evolution, acceptance of biological evolution, and other potential factors of influence relate is of importance for several reasons. First, understanding the relationship between faculty personal views, their area of expertise, their understanding of the NOS, and their knowledge of biological evolution will allow us to answer several important questions about BEE. Faculty members at colleges and universities come from many disparate fields of expertise and divergent educational backgrounds (e.g. biology, engineering, history). It would be informative to know what impact those disparate experiences may have had on their current understanding.

Currently, there exists little information regarding any potential influence faculty may be exerting on student understanding of the NOS. If the instructors in charge of providing a college education do not understand the material or have significant misconceptions, then they may be passing those misconceptions to students. This can also be true for faculty outside of the biological sciences. It is reasonable to assume that the typical student will ascribe a level of intellect and understanding to someone who has earned an advanced degree (e.g., a doctorate) or is in charge of a college course, regardless of their area of expertise. But do these “experts” actually know what they are talking about? If we can learn what typical faculty members understand about science, what misconceptions they have, and how those are related to their personal views, their area of expertise, and other factors, we will begin to understand what we can do to make improvements that lead to a better education for the students.

It is also reasonable to predict that those faculty who expressly seek out a career in science would understand more about the NOS. Even though not every science faculty member will be equally versed in the NOS, is it reasonable to assume that there is overlap in the underlying information. It should be these faculty who exhibit the best understanding of the NOS, compared to non-scientist faculty, the general public, and students. This is a reasonable assumption, but currently there are no data that support or refute it. It is entirely possible that a non-scientist faculty member could have a better understanding of the NOS than a science faculty member. It would be a very damning indictment of the programs that produced these scientists if they lack a basic understanding of the NOS. How could we expect students to understand the NOS if the instructors do not understand it either?

Previous work on the NOS suggests that if we want to address shortcomings in a population's understanding of the NOS, we must also address biological evolution in some way. We can then consider some potential models for organizing how understanding of biological evolution and acceptance of biological evolution are related to each other (Figure 1) and to other variables of interest (Figure 2). We suggest that all three factors are intimately intertwined and that therefore the best option is to measure and consider them together in any research project on this topic. This sort of path-analysis model is best examined using Structural Equation Modeling (Shipley, 2002), which we use here.

Thus we consider which of the possible models best represents the relationship between understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution. If the overall relationship resembles model C for example, then we would see a sub-relationship between knowledge of biological evolution and understanding of the NOS, and one between understanding of the NOS and acceptance of biological evolution, but no sub-relationship between knowledge of biological evolution and acceptance of biological evolution. We suggest that all three factors are intimately intertwined (Figure 1B) and that therefore the best option is to measure and consider them together in any research project on this topic. In this model, we see an interaction between all variables. This means that for each variable of interest (knowledge, acceptance, and understanding) each variable is affecting the other two and is being affected by them as well. This could result in an interactive feedback effect where, for example, a change in a person's knowledge of biological evolution leads to a change in their acceptance of evolution which then leads to a change in their understanding of the NOS, which then leads to a change in their knowledge of biological evolution. Based on previous research showing the existence of each of the sub-relationships as well as our own anecdotal experience, this is the model we would predict is most accurate. However, other potential models must also be considered in case one of them is a better fit. The five models described here are very basic, and to not attempt to discern any directionality to the effects being measured. If appropriate data are collected on each factor from one population of interest (in this case faculty), then an effective predictive model can be constructed to represent how changes in one factor will likely impact the others. Constructing a model of this type will help balance the relative investment in each factor when attempting to improve them.

There are three primary pieces that need to be considered in order to effectively construct these models. First, what is the strength of the correlation (if any) between the variables? Second, given a correlation, what is its directionality? Finally, given a correlation, what factors (e.g., subdivisions of the population) are driving differences from the overall model? We can expect that if strong positive correlations between variables are detected, we can then infer that effective instruction must incorporate understanding the NOS, knowledge of biological

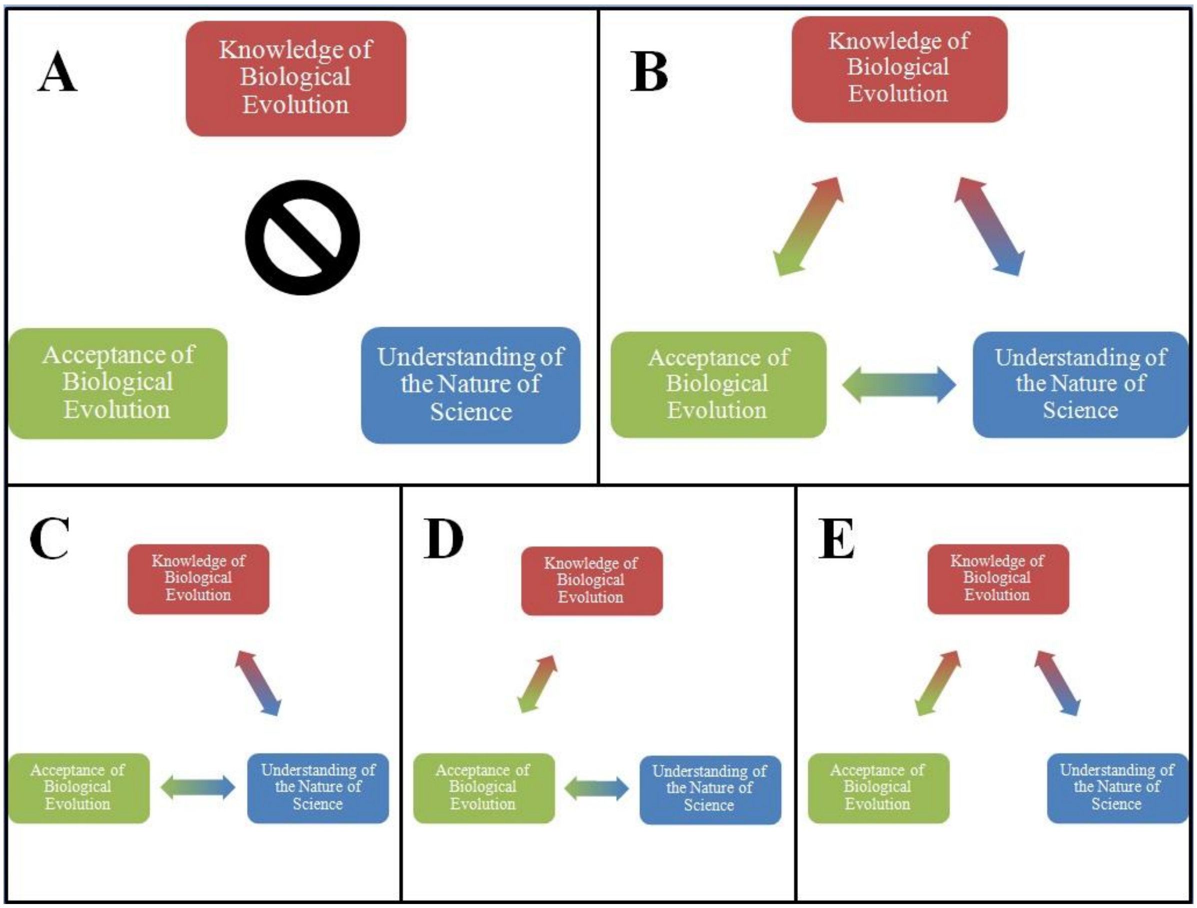

Figure 4: Five models of the potential overall relationship between knowledge of biological evolution, acceptance of biological evolution, and understanding of the NOS. A: Bidirectional dual input interaction between all variables resulting in interactive effect. B: Interaction between all variables resulting in a feedback loop. C: No interaction between knowledge of biological evolution and acceptance of biological evolution. D. No interaction between knowledge of biological evolution and understanding of the NOS. E. No interaction between acceptance of biological evolution and understanding of the NOS.

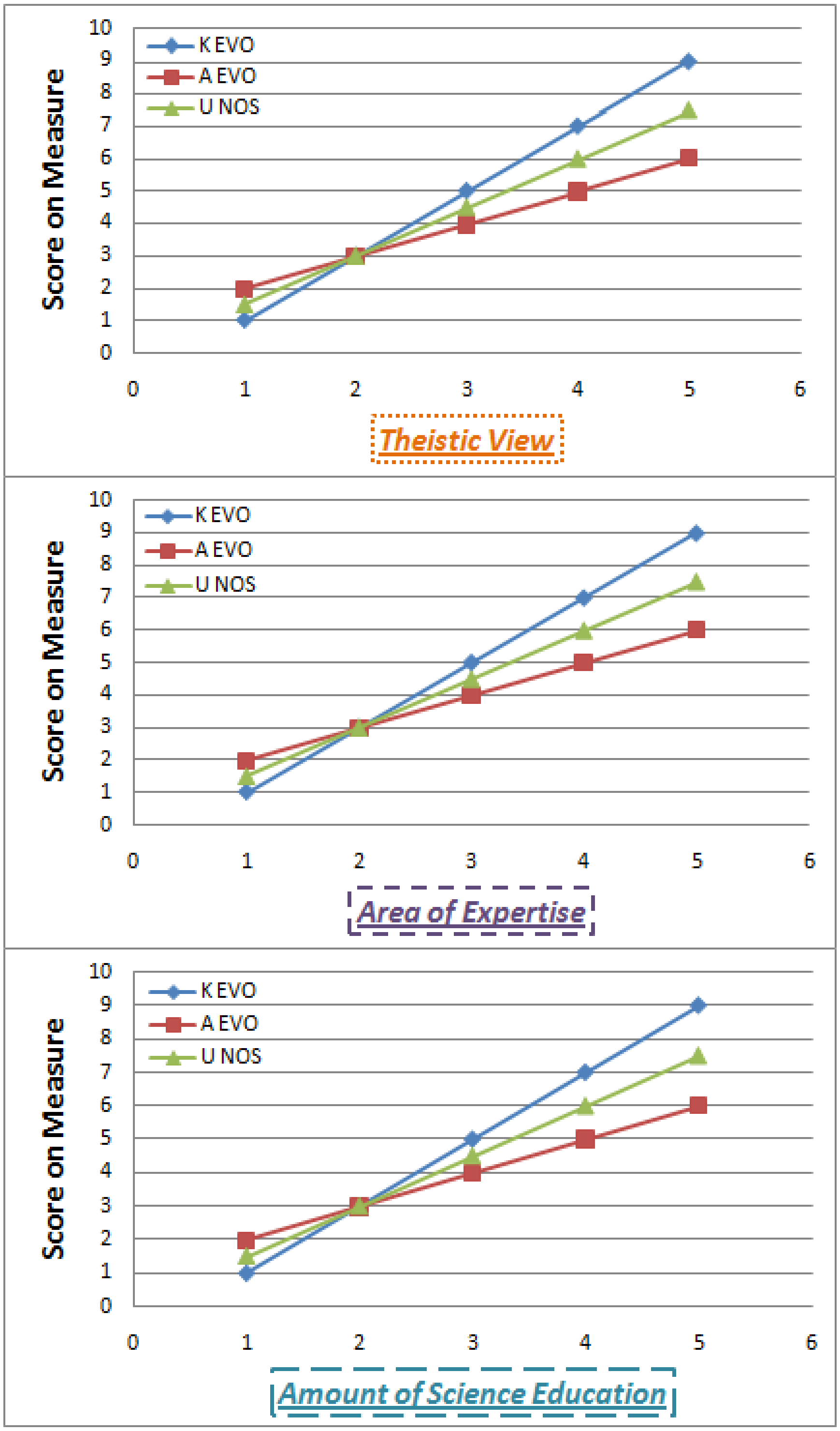

Figure 5: Models of potential relationship between understanding of the nature of science, knowledge of biological evolution, acceptance of biological evolution and three variables of interest.

evolution, and acceptance of biological evolution. Conversely, if no correlation or a negative correlation is detected then we will have evidence that it is not necessary for instructors to invest time and energy addressing one variable if improvement in one of the others is their primary goal.

The purpose of this study was to investigate the relationship between faculty understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution. Our goal is to comprehend what faculty members understand about the NOS, what misconceptions they have, and how those are related to their knowledge of and acceptance of biological evolution; as well as their personal views, their area of expertise, and other factors.

Specifically, this study was designed to answer the following questions:

1. What understanding of the NOS do faculty members across various disciplines have?

2. How, if at all, does faculty member understanding of the NOS differ between members of different disciplines?

3. What is the relationship, if any, between faculty member understanding of the NOS and both their understanding of, and attitude towards, biological evolution?

4. What is the relationship, if any, between faculty member theistic position and both their understanding of the NOS?

5. What is the relationship, if any, between the amount of science education claimed by faculty members and their understanding of the NOS?

6. What is the relationship, if any, between faculty member demographic responses and their understanding of the NOS?

Study Context and Methods

Study Site

All participants were recruited from the full list of employees that were considered faculty at a major, public, Midwestern university during the 2010 – 2011 academic year. This definition was at the discretion of the Office of Institutional Research at the research site, and included 1595 potential participants. Potential participants were contacted via email. The text of the email provided instructions to the voluntary online survey. Data were kept anonymous and no attempts to identify participants or non-participants was made. Participants were, however given the opportunity to submit another email contact for use in a random drawing for one of ten $50.00 gift cards to a local bookstore. This second email was used to select winners of the drawing only. Data were collected over several months, with two reminder emails being sent to the potential participants. Relevant demographic data for the population as a whole was obtained from the Office of Institutional Research at the study site.

Survey Instrument

The variables of interest in this study are participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution. In order to accurately measure all three of these variables, distinct sets of questions are required.

The section of the survey devoted to measuring participant understanding of the nature of science (NOS) was based on the Student Understanding of Science and Science Inquiry (SUSSI) (Liang et al., 2008). Since the SUSSI served only as a base for the format of the survey the resulting survey had significant alterations. New questions were designed and pilot tested on a population at a similar site (a major, public, Midwestern university). The pilot testing and post hoc testing showed that the modified SUSSI (mSUSSI) was a valid and reliable measure of the elements of the NOS that it was designed for. In the pilot testing the mSUSSI had an overall Cronbach alpha coefficient of 0.73 and an overall Cronbach alpha of 0.67 in the post hoc testing. No changes were made to the mSUSSI between pilot testing and post hoc testing. The Cronbach alpha is commonly used measure of an instrument's coefficient of reliability. It is typically used as a measure of the internal consistency or reliability of a psychometric test score for a set of participants (Cronbach, 1951). Coefficients of 0.73 and 0.67 are on the lower side of acceptable reliability (0.70 is generally considered the cutoff) and suggest that further modification of the survey may be needed to more accurately measure participant understanding of the NOS.

Validity of the mSUSSI was based on construct validity (Stangor, 2006), where each subsection (four total) of the mSUSSI was checked for their correlation with the others. In each pairing the subsections scored a correlation of at minimum 0.428 and was significant at minimum $p<0.01$.

Given the results of the reliability and validity testing the mSUSSI is considered valid and reliable enough to provide a statistically useful measure of the participant's understanding of the NOS for the purposes of the study presented here.

The mSUSSI was placed at the beginning of the survey so as to avoid any potential negative bias associated with the survey focused on biological evolution.

As is described in Chapter 3, an unmodified Knowledge of Evolution Exam (KEE) was used to measure participant knowledge of evolutionary concepts and the Measure of Acceptance Toward Evolution (MATE) was used to measure acceptance of biological evolution. The KEE has been used in previous work and has been shown to be both a reliable and valid measure of a participant's knowledge of biological evolution for several different groups (Moore et al., 2009). The ten questions on the KEE cover content on biological evolution that students in an introductory college biology course would be familiar with. The MATE has also been used in previous works measuring acceptance of biological evolution and has been shown to be a valid and reliable measure (Rutledge and Sadler, 2007; Moore and Cotner, 2009a; Moore and Cotner, 2009b). The twenty questions on the MATE examine the participants views on whether humans and other animals have evolved, whether biological evolution is science, how old the earth is, whether biological evolution is testable, and other related views.

The resulting three-part survey consisted of 54 multiple-choice questions and seven text response questions. In addition to the mSUSSI, KEE, and MATE sections, three other questions examined participant views of educational policies, public acceptance/rejection of biological evolution, and their personal theistic view (used previously in Rice et al, 2011). Five other questions at the end of the survey were of a demographic nature (gender, age, area of expertise, employment level, and amount of science education received).

Of the 1595 faculty members that were contacted 309 complete surveys were received. An additional 139 incomplete surveys were also collected; however none of these surveys reached a level of completeness to be useable in the analyses described here.

For some parts of the analysis the participants was examined as a whole and for other analyses in specific subgroups. We used the demographic and theistic view questions to break the participants into our specific divisions of interest: participant area of expertise, participant theistic view, and participant amount of science education. For area of expertise participants were grouped according to their response to the question: “What is your area/field of work? (e.g. Physics, Economics, etc.)”. These responses resulted the used of the following grouping categories: Social Science (responses such as Economics, Psychology, Education, and History); Physical Science (responses such as Physics, Chemistry and Geology); Business (responses such as Finance, Marketing, and Accounting); Applied Science/Engineering (responses such as Civil Engineering, Aerospace Engineering, and Industrial Engineering); Life Science (responses such as Agronomy, Cell Biology, Genetics, and Horticulture); Humanities (responses such as Music, Theatre, English, and Philosophy); Veterinary Medicine; and those that did not answer. Some of the responses to the question about area of expertise did not fit in this categorization scheme and were too few in number to warrant inclusion as their own group (e.g. Information Systems, Statistics). Such responses were not used in the analyses described below.

Answers to the survey question on theistic view provided the following categories for analysis: Young Earth Creationist, Old Earth Creationist, Theistic Evolutionist, Agnostic Evolutionist, Atheistic Evolutionist, and a not answered/other group. This categorization scheme is based on a similar set of categories described in Scott (2005). During analysis, these six categories were grouped together using three distinct grouping schemes. Schema A used Young Earth Creationist, Old Earth Creationist, and Theistic Evolutionist as one group, Agnostic Evolutionist and Atheistic Evolutionist as the second group, and the not answered/other participants as the third group. Schema B, by contrast, used Young Earth Creationist and Old Earth Creationist as one group, Theistic Evolutionist, Agnostic Evolutionist and Atheistic Evolutionist as the second group, and the not answered/other participants as the third group. The final grouping, Schema C, treated Young Earth Creationist and Old Earth Creationist as one group, Theistic Evolutionist as the second group, Agnostic Evolutionist and Atheistic Evolutionist as the third group, and the not answered/other participants as the fourth group. Every statistical test that was performed that used participant theistic view was carried out three times, once for each Schema.

The amount of science education the participants reported was also used as a set of categories for statistical comparisons. Participants could choose one of four choices: 9 or more science courses, 5-8 science courses, 1-4 science courses, or no science courses.

The results from the mSUSSI, KEE, and MATE portions were summed into percentage scores for each participant in the analyses below, unless specifically noted otherwise.

Statistical Analyses

For this study, we were interested in measuring the relationship between understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution in several contexts. In order to effectively assess these relationships, we performed a series of related analyses on one response variable relative to another, as well as on each grouping variable relative to the response variables. Mean scores are reported for various group comparisons to illustrate the differences between the groups. For example, The "Mean Understanding of the NOS of Theistic Evolutionists" is the average score (out of a possible 100%) of those participants who identified as theistic evolutionists on the measure of understanding of the NOS (the mSUSSI portion of the survey).

Statistical Analyses Part 1: Tests on the Understanding - Knowledge - Acceptance relationship

We used a simple linear regression (SLR) comparing the percentage scores of all the participants on the understanding of the NOS measure to their percentage scores on the knowledge of biological evolution measure in order to assess the overall relationship between understanding of the NOS and knowledge of biological evolution. SLR was also used to compare the percentage scores of all the participants on the understanding of the NOS measure to their percentage scores on the acceptance of evolution measure. In addition, we performed an ordination analysis to obtain a graphical visualization of the patterns present in the data. For this, we first created a distance matrix among individuals by calculating pairwise Jaccard's distance between individuals, based on participant responses to *each* question. Principal coordinate analysis (PCoA) was used to generate an ordination of the response data space. Individual participants were color-coded by grouping variables to provide a visual examination of whether or not a particular group displayed similar responses to the questionnaire. Finally, we ran a SEM-based path analysis comparing the models described in Figure 1 using covariance between variables as the connecting paths and Akaike Information Criterion (AIC) as the measure of model fit.

Statistical Analyses Part 2: Tests of the impact of multiple factors

In order to identify potential interaction between the grouping factors of area expertise and theistic viewpoint as the influence participant understanding of the NOS, two-way ANOVAs were performed. Mantel tests were also performed on a distance matrix of the participant responses to the mSUSSI portion of the survey to assess the degree of association between participant understanding of the NOS, knowledge of biological evolution and the grouping variables of area of expertise and theistic view. This was also done to assess the degree of association between participant understanding of the NOS, acceptance of biological evolution and the grouping variables of area of expertise and theistic view. Specifically, Mantel correlations were calculated between understanding of the NOS and knowledge of biological evolution across all participants; between understanding of the NOS and acceptance of biological evolution; between understanding of the NOS and knowledge of biological evolution for those participants with differing theistic views (e.g. young earth creationist); between understanding of the NOS and acceptance of biological evolution for those participants with differing theistic views (e.g. young earth creationist); between understanding of the NOS and knowledge of biological evolution for each area of expertise (life science, humanities, etc.); and between understanding of the NOS and acceptance of biological evolution for each area of expertise (life science, humanities, etc.).

In order to identify potential interaction between the grouping factors of theistic viewpoint and amount of science education, two-way ANOVAs were performed. As with prior analyses, two-way ANOVAs were performed the mSUSSI portion of the survey with theistic viewpoint and amount of science education. Mantel tests were also performed on separate distance matrices of the participant responses to the understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution portions of the survey to assess the degree of association between participant scores and the grouping variables of theistic view and amount of science education. In this case Mantel correlations were calculated as described above, but with amount of science education instead of area of expertise.

One-way ANOVA tests were used to examine how understanding of the NOS was related to knowledge of biological evolution for each category of interest (theistic view, area of expertise, amount of science education). Linear regression was also used to identify the relationship between variables such as between knowledge of biological evolution and acceptance of biological evolution for physical scientists. These one-way ANOVA tests and linear regressions were also done examining the relationship between understanding of the NOS and acceptance of biological evolution.

Since we are interested in seeing which factors (amount of science education, theistic view, or area of expertise) explain the variation we see participant understanding of the NOS, we used Akaike Information Criterion (AIC) to compare the fit of the resulting models. We also used permutation tests to examine whether the observed results from some specific tests were significantly different from a random result.

Pairwise t-tests were used to compare the understanding of the NOS and knowledge of biological evolution of the participants between each area of expertise as well as within each area of expertise but between their theistic views (e.g. creationist engineering faculty compared to non-creationist engineering faculty). Additionally, each test that was performed that used participant theistic view was carried out three times, once with Schema A, once with Schema B, and once with Schema C to allow us to see what differences, if any, between the three ways of grouping exist. These pairwise t-tests were used in a similar fashion to compare the understanding of the NOS and acceptance of biological evolution of the participants between each area of expertise as well as within each area of expertise, but between their theistic views.

Partial Mantel tests were used to compare distance matrices of the participant responses to the mSUSSI, KEE, and MATE portions of the survey to assess the degree of correlation between participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution when controlling for one of those variables.

All statistical computations and procedures were performed in R 2.12.1 (R Development Core Team, 2010).

Results

Quantitative Results

The participants in the resulting data sample aligned very closely with previously known information regarding the population as a whole. For specifics regarding the demographic makeup of the participants, please see Chapter 3.

As a whole, the participants scored an average of 56.3% correct on the understanding of the NOS portion of the survey (Figure 3).

Results Part 1: Single Factor Tests

Using SLR to compare the percentage scores of all the participants on the measures of understanding of the NOS and knowledge of biological evolution, we found a significant positive relationship ($F_{1, 307} = 85.731$, $R^2 = 0.218$, $p<0.001$; Pearson's $r = 0.467$) (Figure 4). High understanding of the NOS was strongly correlated with high knowledge of biological evolution. Likewise, a significant relationship between understanding of the NOS and knowledge of biological evolution was revealed using a Mantel test ($r = 0.275$; $p < 0.001$).

We also found a significant positive relationship between the percentage scores of all the participants on the measures of understanding of the NOS and acceptance of biological evolution using SLR ($F_{1, 307} = 94.482$, $R^2 = 0.235$, $p<0.001$; Pearson's $r = 0.485$) (Figure 5). Again, high understanding of the NOS was strongly correlated with high acceptance of biological evolution. A significant relationship between understanding of the NOS and acceptance of biological evolution was also detected using a Mantel test ($r = 0.178$; $p < 0.001$).

Using the results described in Chapter 3 for the relationship between knowledge of biological evolution and acceptance of biological evolution, SEM-based path analysis found that model B (Figure 1) was the best fit to the data. This was based on the relative AIC scores of each model (Table 1).

Tests by Theistic View. When the three methods of grouping the theistic views (Schema A, Schema B, and Schema C) were used with ANOVA, significant positive relationships were detected in all cases (Table 2). In all cases participants with a more creationist theistic view had a significantly lower average understanding of the NOS (Table 3).

A significant relationship between understanding of the NOS and knowledge of biological evolution was revealed using a Mantel test for some of theistic groups in each Schema (Table 4). The exceptions were the theistic evolutionists alone and the creationists plus theistic evolutionists group. Likewise a significant relationship between understanding of the NOS and acceptance of biological evolution was discovered in all but one group using a Mantel test (Table 5). The exception in this case was in Schema C where the participants with theistic evolutionist views were considered a separate group.

Tests by Area of Expertise. We found significant differences using one-way ANOVA to examine the relationship between the percentage scores for participant understanding of the NOS and their area of expertise ($F_{8, 273}= 2.3835$, $p<0.05$). Using pairwise t-tests only one significant difference between different areas of expertise in the knowledge of biological evolution was detected. This difference was between the participants who identified their area of expertise as "Physical Science" who scored significantly ($p<0.05$) higher on the measure of knowledge of biological evolution than those who did not identify their area of expertise (Figure 6).

Using linear regression we found that understanding of the NOS and knowledge of biological evolution were significantly positively correlated for all but one (Veterinary Medicine) of the areas of expertise (Table 5). A significant relationship was also detected between understanding of the NOS and knowledge of biological evolution using a Mantel test for each area of expertise except those participants who identified their area of expertise as Veterinary Medicine; Social Science; Humanities; Engineering; or Not Answered (Table 7).

We found that understanding of the NOS and acceptance of biological evolution were significantly positively correlated for all but three (Veterinary Medicine, Humanities, and Not Answered) areas of expertise using linear regression (Table 8). Likewise a significant relationship between understanding of the NOS and acceptance of biological evolution was revealed using a Mantel test for each area of expertise except those participants who identified their area of expertise as Veterinary Medicine; Humanities, or Not Answered (Table 9).

Tests by other Demographic Variables. We also found significant relationships between participant age and understanding of the NOS as well as between participant employment level and

Table 1: SEM-based path analysis AIC scores of each model described in Figure 1

Model	Description	AIC Score
A	Null Model (no connections between variables)	224
B	Full Model (all connections between variables present)	12
C	Reduced Model (no connection between acceptance of biological evolution and understanding of the NOS)	91
D	Reduced Model (no connection between understanding of the NOS and knowledge of biological evolution)	77
E	Reduced Model (no connection between knowledge of biological evolution and acceptance of biological evolution)	131

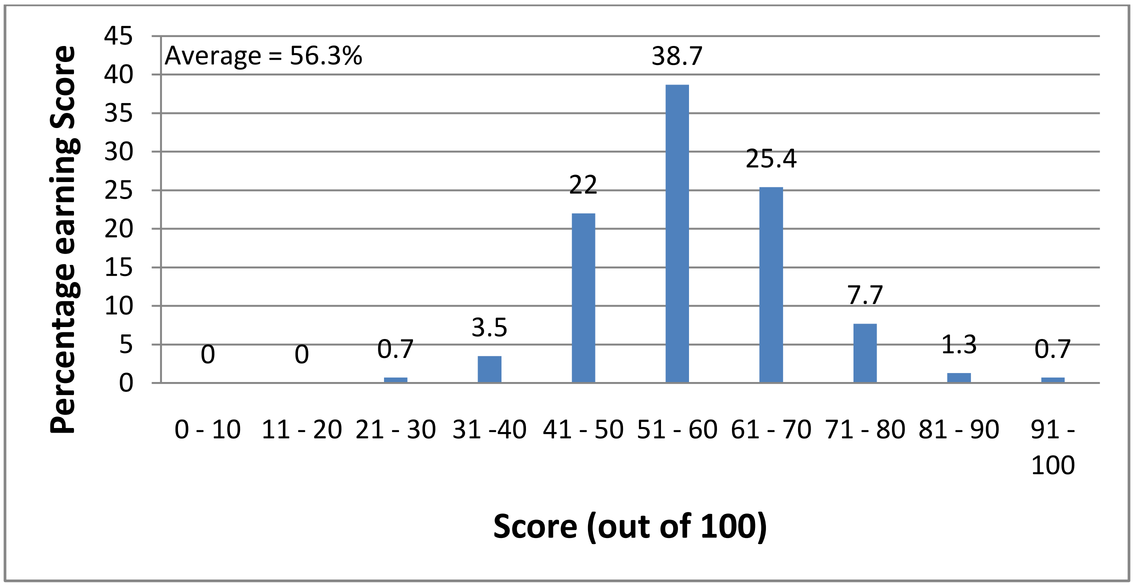

Figure 6: Distribution of participant scores on the measure of understanding of the NOS (mSUSSI)

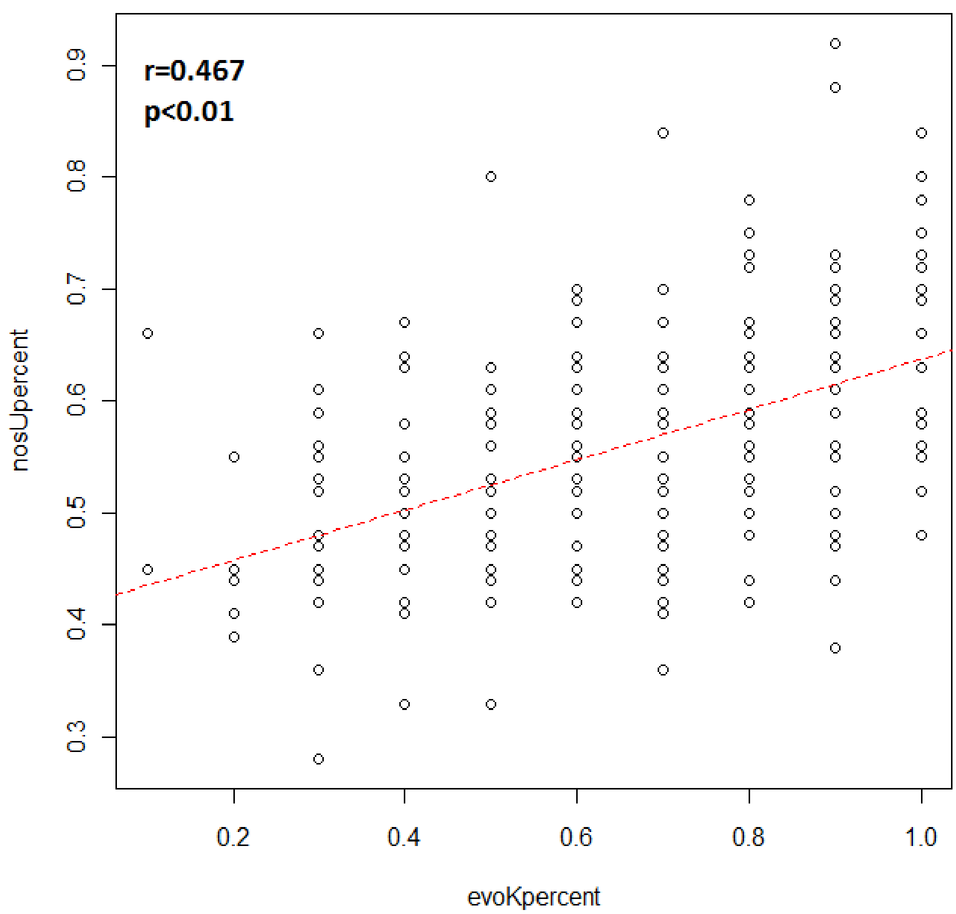

Figure 7: Simple linear regression of understanding of the NOS by knowledge of biological evolution evoKpercent = participant scores on the measure of knowledge of biological evolution as a percentage. nosUpercent = participant scores on the measure understanding of the NOS as a percentage.

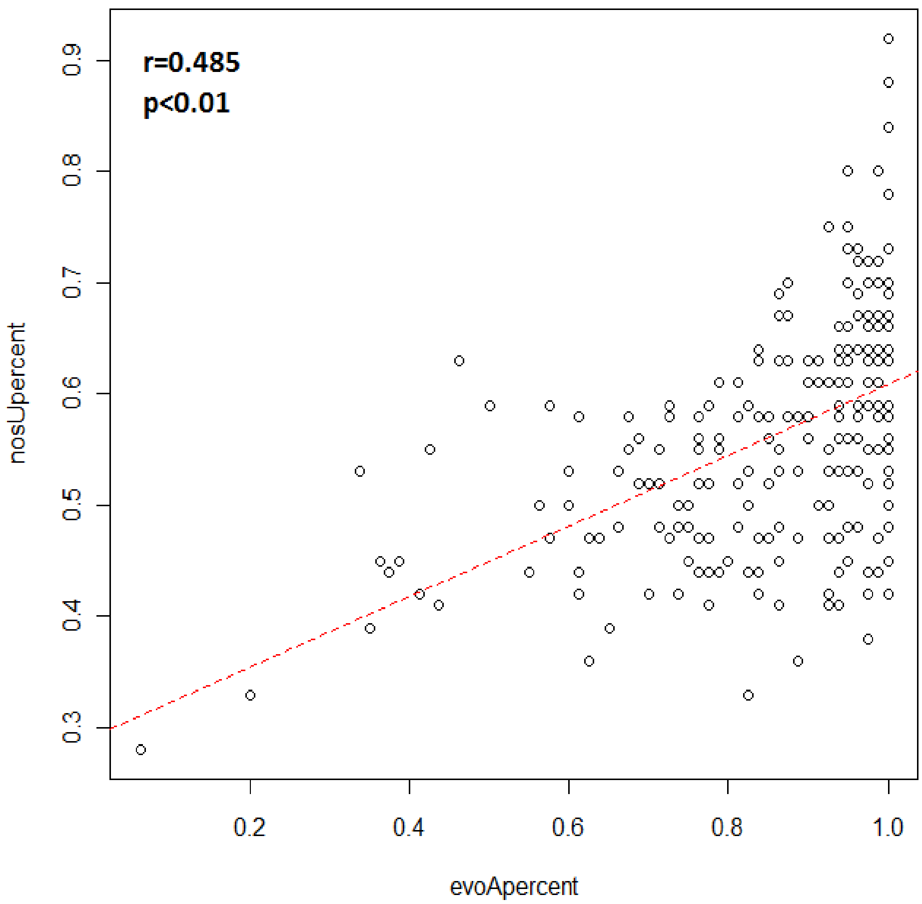

Figure 5: Simple linear regression of understanding of the NOS by acceptance of biological evolution. evoApercent = participant scores on the measure of acceptance of biological evolution as a percentage. nosUpercent = participant scores on the measure understanding of the NOS as a percentage.

Table 2: Statistical results from ANOVA examining participant understanding of the NOS by their theistic viewpoint using Schema A, B and C

	Understanding of the NOS	Significance
Theistic View: Schema A	$F_{1, 280} = 35.014$	$p<0.001$
Theistic View: Schema B	$F_{1, 280} = 27.791$	$p<0.001$
Theistic View: Schema C (All Groups)	$F_{2, 279} = 28.745$	$p<0.001$
Theistic View: Schema C (Creationist vs. Theistic Evolutionist)	$F_{1, 49} = 5.57$	$p<0.05$
Theistic View: Schema C (Theistic Evolutionist vs. Non-Creationist)	$F_{1, 263} = 15.502$	$p<0.001$
Theistic View: Schema C (Creationist vs. Non-Creationist)	$F_{1, 246} = 25.456$	$p<0.001$

Table 3: Mean percentage scores on measure of understanding of the NOS by theistic view groupings used in Schema A, B, and C

	Mean Understanding of the NOS
Creationists (Young Earth Creationists and Old Earth Creationists)	45.29%
Theistic Evolutionists	50.91
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists)	58.19
Creationists + Theistic Evolutionists	49.04
Non-Creationists + Theistic Evolutionists	57.25

Table 4: Correlations between participant understanding of the NOS and knowledge of biological evolution by theistic view groupings used in Schema A, B, and C (Mantel test using Jaccard's)

Group(s)	n	r value	*p* value
Creationists (Young Earth Creationists and Old Earth Creationists)	17	0.3042	<0.01
Theistic Evolutionists	34	0.0457	=0.301
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists)	231	0.1153	<0.01
Creationists + Theistic Evolutionists	51	0.0765	=0.191
Non-Creationists + Theistic Evolutionists	265	0.1544	<0.001

Table 5: Correlations between participant understanding of the NOS and acceptance of biological evolution by theistic view groupings used in Schema A, B, and C (Mantel test using Jaccard's)

Group(s)	n	r value	*p* value
Creationists (Young Earth Creationists and Old Earth Creationists)	17	0.6269	<0.001
Theistic Evolutionists	34	0.1166	=0.117
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists)	231	0.1648	<0.001
Creationists + Theistic Evolutionists	51	0.3536	<0.001
Non-Creationists + Theistic Evolutionists	265	0.1968	<0.001

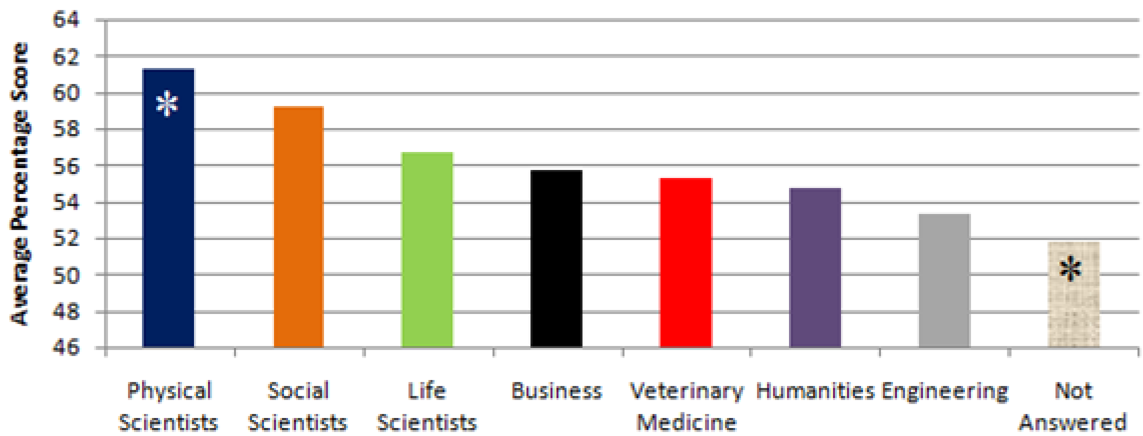

Figure 6: Average participant understanding of the NOS grouped by area of expertise. * indicates a significant difference (p<0.05) using pairwise t-tests.

Table 6: Correlation between participant understanding of the NOS and knowledge of biological evolution by area of expertise (one-way ANOVA and simple linear regression).

	r value	*df*	Sum Sq	Mean Sq	F value	*p* value
Life Science Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.6872	1	1.1356	1.1356	67.1	<0.001
Residuals		75	1.2693	0.01692		
Physical Sciences Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.6337	1	0.18592	0.185920	20.134	<0.001
Residuals		30	0.27703	0.009234		
Social Science Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.6194	1	0.40500	0.40500	34.867	<0.001
Residuals		56	0.65048	0.01162		
Humanities Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.4614	1	0.14608	0.146080	10.008	<0.01
Residuals		37	0.54005	0.014596		
Engineering Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.4805	1	0.30122	0.301222	9.908	<0.01
Residuals		33	1.00326	0.030402		
Business Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.7343	1	0.27306	0.273057	16.382	<0.01
Residuals		14	0.23335	0.016668		
Veterinary Medicine Knowledge of Biological Evolution (Response: Understanding of the NOS)	-0.1297	1	0.00465	0.0046541	0.1882	=0.673
Residuals		11	0.27195	0.0247233		
Not answered Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.5519	1	0.23625	0.236251	10.076	<0.01
Residuals		23	0.53929	0.023447		

Table 7: Correlation between participant understanding of the NOS and knowledge of biological evolution by area of expertise (Mantel test using jaccard).

Area of Expertise	r value	*p* value
Life Science	0.2002	<0.005
Physical Sciences	0.3054	<0.005
Social Science	0.1395	=0.052
Humanities	0.0753	=0.226
Engineering	0.1287	=0.095
Business	0.3827	<0.01
Veterinary Medicine	0.2002	=0.157
Not answered	0.0149	=0.439

Table 8: Correlation between participant understanding of the NOS and acceptance of biological evolution by area of expertise (one-way ANOVA and simple linear regression).

	r value	*df*	Sum Sq	Mean Sq	F value	*p* value
Life Science Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.5898	1	0.83645	0.83645	39.996	<0.001
Residuals		75	1.56852	0.02091		
Physical Sciences Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.4734	1	0.09822	0.098216	8.6643	<0.01
Residuals		30	0.34007	0.011336		
Social Science Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.5076	1	0.23510	0.235096	19.434	<0.001
Residuals		56	0.67746	0.012097		
Humanities Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.2919	1	0.021349	0.021349	3.4457	=0.071
Residuals		37	0.229241	0.006196		
Engineering Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.4652	1	0.072079	0.072079	9.1166	<0.01
Residuals		33	0.260910	0.007906		
Business Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.7334	1	0.114484	0.114484	16.295	<0.01
Residuals		14	0.098359	0.007026		
Veterinary Medicine Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.0730	1	0.000470	0.000470	0.0589	=0.813
Residuals		11	0.087822	0.007984		
Not answered Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.3655	1	0.021853	0.021853	3.5456	=0.072
Residuals		23	0.141763	0.0061636		

their understanding of the NOS (Table 10). Further investigation of the relationship between age and understanding of the NOS revealed that while there are significant differences in the mean understanding of the NOS between age groups, there is no significant correlation ($r = 0.087$) (e.g., participant understanding of science did not increase with increased age). The same is true for the relationship between employment level and understanding of the NOS ($r = -0.140$).

Tests by Amount of Science Education. Since amount of science education was a variable of high interest as far as its relationship to participant understanding of the NOS, pairwise t-tests were used for further investigation. The pairwise t-tests show that there are no significant differences in participant understanding of the NOS between the categories of amount of science education (Figure 7).

Using linear regression calculate the magnitude and direction of the correlation between variables we found that understanding of the NOS and knowledge of biological evolution were significantly positively correlated for all groups except those that reported no science education (Table 11).Mantel tests between understanding of the NOS and knowledge of biological evolution by how much science education participants showed that there are significant positive correlations between these variables for the high, moderate and none groups but not those participants who reported a low amount science education (Table 12).

Additionally, we found that participant understanding of the NOS and acceptance of biological evolution were significantly positively correlated for all groups except those that reported no science education (Table 13). The Mantel tests of the same variables showed that there are significant positive correlations between understanding of the NOS and acceptance of biological evolution for high, moderate and low amounts of science education but not for those reporting no science education (Table 14).

Table 9: Correlation between participant understanding of the NOS and acceptance of biological evolution by area of expertise (Mantel test using jaccard).

Area of Expertise	r value	*p* value
Life Science	0.3324	<0.001
Physical Sciences	0.3220	<0.05
Social Science	0.2964	<0.005
Humanities	0.1674	=0.082
Engineering	0.4012	<0.05
Business	0.3699	<0.05
Veterinary Medicine	0.1097	=0.288
Not answered	0.08904	=0.214

Table 10: Statistical results from ANOVA examining participant understanding of the NOS by several demographic responses.

	df	Sum Sq	Mean Sq	F value	*p* value
Gender (Response: Understanding of the NOS)	1	0.00304	0.0030416	0.2711	=0.603
Residuals	280	3.14158	0.0112199		
Age (Response: Understanding of the NOS)	3	0.19095	0.063649	5.9907	<0.001
Residuals	278	2.95367	0.010625		
Employment Level (Response: Understanding of the NOS)	3	0.13082	0.043608	4.0225	<0.01
Residuals	278	3.01380	0.010841		
Amount of Science Education (Response: Understanding of the NOS)	3	0.07409	0.024696	2.2359	=0.0843
Residuals	278	3.07053	0.011045		

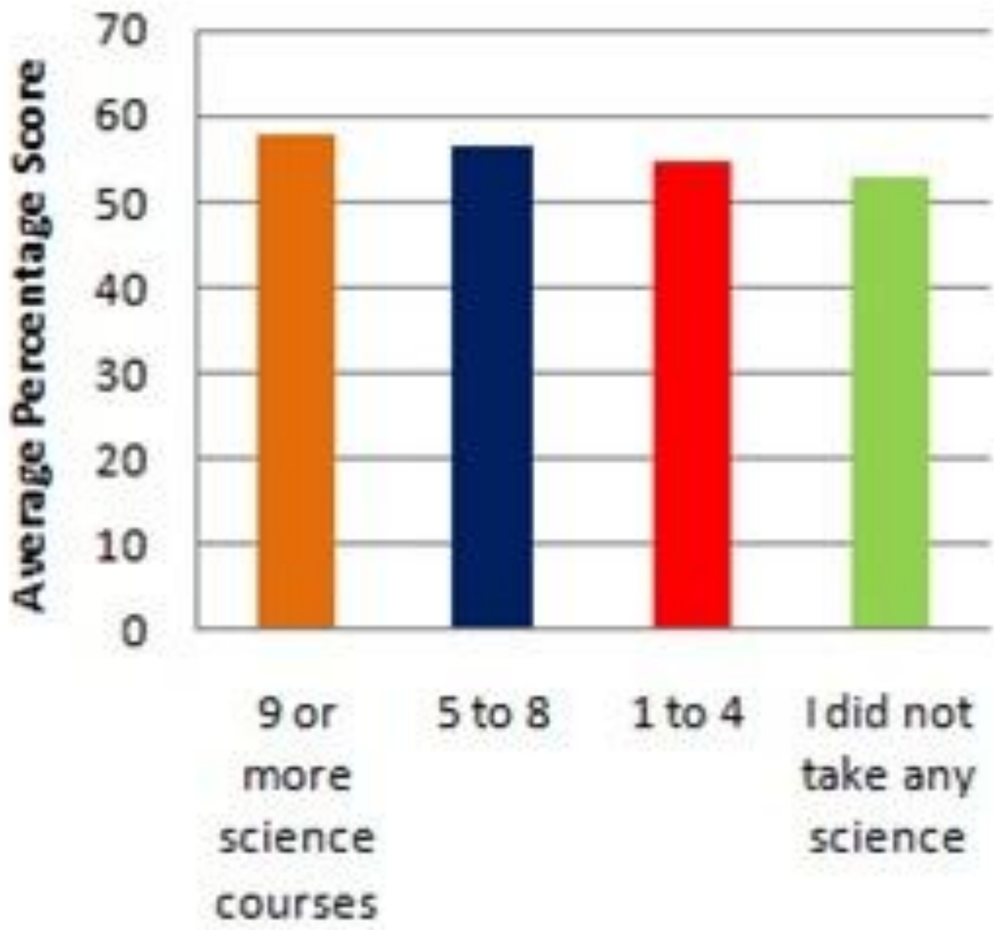

Figure 7: Average participant understanding of the NOS grouped by amount of science education reported. No significant differences detected using pairwise t-tests.

Table 11: Correlation between participant understanding of the NOS and knowledge of biological evolution by amount of science education reported (one-way ANOVA and simple linear regression).

	r value	*df*	Sum Sq	Mean Sq	F value	*p* value
High Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.4819	1	0.88493	0.88493	50.517	<0.001
Residuals		167	2.92539	0.01752		
Moderate Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.8090	1	0.88528	0.88528	73.891	<0.001
Residuals		39	0.46725	0.01198		
Low Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.5810	1	0.76026	0.76026	43.313	<0.001
Residuals		85	1.49199	0.01755		
None Knowledge of Biological Evolution (Response: Understanding of the NOS)	0.3111	1	0.015867	0.015867	1.0719	=0.3249
Residuals		10	0.148026	0.014803		

Table 12: Correlation between participant understanding of the NOS and knowledge of biological evolution by amount of science education (Mantel test using jaccard).

Amount of science education reported	r value	*p* value
High	0.2324	<0.001
Moderate	0.2346	<0.01
Low	0.08577	=0.094
None	0.3038	<0.05

Table 13: Correlation between participant understanding of the NOS and acceptance of biological evolution by amount of science education reported (one-way ANOVA and simple linear regression).

	r value	*df*	Sum Sq	Mean Sq	F value	*p* value
High Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.5015	1	0.51364	0.51364	56.115	<0.001
Residuals		167	1.52860	0.00915		
Moderate Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.4772	1	0.061359	0.061359	11.505	<0.005
Residuals		39	0.207997	0.005333		
Low Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.4712	1	0.17220	0.172204	24.263	<0.001
Residuals		85	0.60328	0.007097		
None Understanding of the NOS (Response: Acceptance of Biological Evolution)	0.3130	1	0.017301	0.017301	1.0861	=0.3219
Residuals		10	0.159299	0.015930		

Table 14: Correlation between participant understanding of the NOS and acceptance of biological evolution by amount of science education (Mantel test using jaccard).

Amount of science education reported	r value	*p* value
High	0.3771	<0.001
Moderate	0.2764	<0.01
Low	0.1407	<0.05
None	0.1311	=0.231

Table 15: Statistical results from two-way ANOVA examining participant understanding of the NOS (response variable) by both theistic view and area of expertise.

	df	Sum Sq	Mean Sq	F value	*p* value
Theistic View	1	0.34953	0.34953	36.5033	<0.001
Area of Expertise	8	0.17728	0.02216	2.3143	<0.05
Theistic View : Area of Expertise	8	0.08994	0.01124	1.1741	=0.315
Residuals	264	2.52788	0.00958		

Results Part 2: Tests of the impact of multiple factors

Tests by Theistic View and other variables. We found theistic view (Schema A) had a far more pervasive effect on participant understanding of the NOS than area of expertise using two-way ANOVAs (Table 15). Two-way ANOVAs also revealed that participant theistic view has a more pervasive effect on participant understanding of the NOS than their amount of science education (Table 16), however the interaction term was significant.

Using pairwise comparisons, when participant area of expertise is broken into those with creationist and non-creationist theistic views (Schema A), those participants with non-creationist theistic views scored significantly higher on the understanding of the NOS measure than those participants with creationist theistic views in all cases except for Business and Veterinary Medicine (Table 17).

The same patterns of significance result when these two-way ANOVAs are performed using Schema B or Schema C for theistic view. In both Schema B and C theistic view had a far more pervasive effect on participant understanding of the NOS than either area of expertise or amount of science education. Again, the interaction term for theistic view and amount of science education was significant in both Schema B and C.

The significant interaction term was examined using pairwise comparisons of the participants understanding of the nature of science by their theistic view in each amount of science education grouping. This analysis revealed that participants with non-creationist views scored significantly higher on the measure of understanding of the NOS in the high, moderate, and low amount of science education groups, but not in the “none” amount of science education group (Table 18). The same relationship was present when Schema B or Schema C was used.

Analysis with AIC showed that for understanding of the NOS, the model using theistic view was the best fit (smallest AIC) to the data compared to models using area of expertise or amount of science education (Table 19).

Partial Mantel tests revealed that participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution are significantly positively correlated with each other even when we control for one of the other measures (Table 20). This was not the case when the participants are grouped by theistic view, area of expertise, or amount of science education (Table 21, 22, 23). In some groupings strong positive correlations were detected, while in others no significant relationship was detected.

Qualitative Results

Four of the seven text response questions in this survey were part of the nature of science (NOS) portion of the survey. Of the remaining three, one was designed to elicit participant views on public education policy, one was designed provide additional context to participant theistic view choice, and one was designed additional context on participant opinion regarding the American public's view of biological evolution. Participants did have a final text box at the end of the survey where they could fill in any additional comments they wished.

Examination of the four NOS text response questions provided valuable context to participant responses the multiple-choice portion of the mSUSSI. In several instances participant understanding of the NOS score was modified (either positively or negatively) based on the information provided in the associated text response.

When the participants were asked about the reliability of scientific theories for example, they used terms like: replication; testing; evidence; prove; opinion; and belief. More specifically, the responses showed that some participants held one or more common misconceptions about scientific

Table 16: Statistical results from two-way ANOVA examining participant understanding of the NOS (response variable) by both theistic view and amount of science education.

	df	Sum Sq	Mean Sq	F value	*p* value
Theistic View	1	0.34953	0.34953	35.9767	<0.001
Amount of Science Education	3	0.04209	0.01403	1.4441	=0.23
Theistic View : Amount of Science Education	3	0.09097	0.03032	3.1210	<0.05
Residuals	274	2.66203	0.00972		

Table 17: Statistical results from pairwise t-tests examining participant understanding of the NOS by their theistic viewpoint grouped by area of expertise (Schema A).

Mean Understanding of the NOS	Life Science	Physical Sciences	Social Science	Humanities	Engineering	Business	Veterinary Medicine	Not answered
Creationist	48.94%	49.4%	48.5%	56.67%	43.25%	50%	45%	52%
Non-Creationist	59.13	63.68	60.63	54.32	54.75	56.62	57.4	57.5
p value	<0.001	<0.05	<0.05	=0.5	<0.05	=0.48	=0.06	<0.05

Table 18: Statistical results from pairwise t-tests examining participant understanding of the NOS by their theistic viewpoint grouped by amount of science education (Schema A).

Mean Understanding of the NOS	High	Moderate	Low	None
Creationist	47.65%	51%	47.67%	60%
Non-Creationist	59.40	58.33	56.44%	50%
p value	<0.001	<0.05	<0.001	=0.29

Table 19: Log-likelihood and AIC of models on understanding of the NOS.

Model	log-likelihood	AIC	No. of parameters
Understanding of the NOS ~ Theistic View	243.3523	-494.8786	3
Understanding of the NOS ~ Area of Expertise	250.4393	-466.7047	10
Understanding of the NOS ~ Amount of Science Education	237.1872	-464.3744	5

Table 20: Correlations between participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution (partial Mantel test using Jaccard's)

Comparison (control variable)	r value	*p* value
Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.4443	<0.001
Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.05769	<0.05
Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.2204	<0.001

Table 21: Correlations between participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution grouped by theistic view (partial Mantel test using Jaccard's)

Theistic View Comparison (control variable)	r value	*p* value
Creationists (Young Earth Creationists and Old Earth Creationists) Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.1499	=0.0999
Creationists (Young Earth Creationists and Old Earth Creationists) Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.1546	=0.087912
Creationists (Young Earth Creationists and Old Earth Creationists) Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.5892	<0.001
Theistic Evolutionists Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.2371	<0.01
Theistic Evolutionists Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.01833	=0.40460
Theistic Evolutionists Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1089	=0.13786
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists) Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.3334	<0.001
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists) Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.06306	=0.063936
Non-Creationists (Agnostic Evolutionists and Atheistic Evolutionists) Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.134	<0.001
Creationists + Theistic Evolutionists Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.3663	<0.001
Creationists + Theistic Evolutionists Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	-0.06192	=0.7992

Table 21: Continued

Creationists + Theistic Evolutionists Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.3511	<0.001
Non-Creationists + Theistic Evolutionists Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.3787	<0.001
Non-Creationists + Theistic Evolutionists Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.08467	<0.01
Non-Creationists + Theistic Evolutionists Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1494	<0.001

Table 22: Correlations between participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution grouped by area of expertise (partial Mantel test using Jaccard's)

Area of Expertise Comparison (control variable)	r value	*p* value
Life Science Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.5865	<0.001
Life Science Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	-0.002795	=0.52947
Life Science Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.2708	<0.005
Physical Science Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.4086	<0.005
Physical Science Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.1853	<0.05
Physical Science Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.2131	<0.05
Social Science Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.5073	<0.001
Social Science Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	-0.01838	=0.56144
Social Science Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.2647	<0.001
Humanities Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.4057	<0.001
Humanities Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.007134	=0.44056
Humanities Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1501	=0.11189

Table 22: Continued

Business Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.6181	<0.005
Business Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.1949	=0.076923
Business Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1647	=0.16983
Engineering Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.3237	<0.01
Engineering Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	-0.01163	=0.52248
Engineering Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.3834	<0.05
Veterinary Medicine Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	-0.1206	=0.63137
Veterinary Medicine Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.2129	=0.14286
Veterinary Medicine Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1321	=0.25774
Not Answered Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.3571	<0.05
Not Answered Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	-0.01811	=0.55045
Not Answered Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.08962	=0.19181

Table 23: Correlations between participant understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution grouped by amount of science education (partial Mantel test using Jaccard's)

Amount of Science Education Comparison (control variable)	r value	*p* value
High Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.3645	<0.001
High Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.08967	<0.05
High Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.317	<0.001
Moderate Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.5418	<0.001
Moderate Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.09738	=0.11089
Moderate Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1784	<0.05
Low Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.5016	<0.001
Low Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.01691	=0.37463
Low Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.1133	<0.05
None Knowledge of Biological Evolution ~ Acceptance of Biological Evolution (Understanding of the NOS)	0.299	=0.093906
None Understanding of the NOS ~ Knowledge of Biological Evolution (Acceptance of Biological Evolution)	0.2787	<0.05
None Understanding of the NOS ~ Acceptance of Biological Evolution (Knowledge of Biological Evolution)	0.0368	=0.39560

theories. Most common was the misconception that theories become laws (28 examples). Seven participants mentioned the phrase “just a theory”. Three participants claimed that science was a belief system.

“The word "theory" suggests that there is lack of evidence to substantiate a claim. A theory may be an educated or informed guess but still lacks enough proof to make the theory into law.”

“Because it's the definition of scientific theory. Things progress from hypothesis to theory to law. Examples: evolution, gravity (before it became a law)”

“Scientific theory is grounded in some sort of data or evidence, but not enough to guarantee beyond a doubt that the theory is an absolute fact or law. Evolution is a theory because we do not have a complete set of evidence that documents the evolutionary steps from the first living thing to humans, for example.”

“Theories are merely conjectures as to the possible causes or consequences of a given phenomenon.”

“The idea of a theory implies an opinion rather than a fact.”

“i think that currently "scientific" theories are among the most highly reliable ideas available. This is because the scientific belief system for the most part relies upon testability and repeatability of its theories and hypotheses. the scientific belief system also allows for the changing of laws when the new laws are better at predicting observed behaviors.”

Participant text responses regarding the tentative property of science showed very few clear examples of misconceptions. The most commonly participants referred to the need for replication of studies that contradict existing science (37 examples). Nine participants mentioned a concern regarding bias that researchers may have when they are doing science and how that bias might influence their results.

"It depends on the amount and validity of the contradictory data. If the new data can be replicated and substantiated, then the previously established science idea needs to be modified to utilize the new data."

"The process of scientific review needs time to review, replicate and determine the value of contradictory results. There needs to be a preponderance of evidence."

"Certainly a scientist needs to be certain that errors that arise do not emerge from errors in the experiment or at some other point in the scientific method, but often a bias that a well established idea is true can impact a researcher's ability to further his or her knowledge base. Take the Bering Strait theory of populating the Americas. Many scientists have great difficulty taking seriously data that demonstrated that Indigenous peoples populated the continents long before 12,000 BCE and simply disregard linguist evidence that demonstrates that they simply must have migrated early to develop the language diversity found in the Americas. Often innovative research can be blocked by this kind of bias."

The text responses regarding the equivalency of observational and experimental research elicited examples of one key misconception. Twenty-four participants made statements that implied experimental research was "better" and/or statements that experiments were the same as testing. Another less common (4 examples) misconception seen was that observational research was subjective while experimental research was objective.

"Experiments can be designed to distinguish between two scientific hypotheses. If one hypothesis is supported and one is not, then knowledge has been gained about the cause for the difference. Observational studies cannot distinguish between hypotheses."

"Experimental research is superior because more factors are controlled."

"Observation research can be somewhat subjective while quantitative research is used in statistical comparisons."

"This question cannot be answered as experimental research and observational research are objective versus subjective research modalities."

Various versions of the idea of "non-overlapping magisteria" (NOMA) appeared in the test responses about the use of supernatural cause with credible science (19 examples). Of those participants that wrote that science *should* use supernatural cause, they commonly referenced their faith and/or examples of currently unexplained phenomena (e.g., the Fatima "Miracle of the Sun" event or the existence of ghosts).

"I thnk(sic) *that science ass*(sic) *a discipline attempts to explain observational phenomenon. / Therefore scientific theories need to follow the accepted rules of science and scientiffic*(sic) *inquiry. I know many scientists, I believe Einstein and Steven J Gould are in that category, who hold a belief in God."*

"Science and religion have different domains and attempt to answer different questions. Never the twain shall meet. But there are lots of doctors/scientists at my church every week, and in my opinion it's silly to think science = atheism."

"The playing field should be level and it is not. Some physicist are adamant that there must be 10 or 11 dimensions, otherwise string theory does not hold. And if string theory does not hold, then the origins of the universe start look suspiciously supernatural. There is no distinction between the unsubstantiated claims of a physicist and the unsubstantiated claims involving the supernatural. Rather than "forcing" ideas to fit, scientists, educators, theologians, and others, should take things at face value. As the Buddhists say: cold is not bad--it is just cold. Hot is not good--it is just hot."

"dancing sun phenomena observed by thousands people at the same time in Fatima. How would you explain that?"

"Perhaps the toughest question of all. A scientist should be slow to conclude that a supernatural explanation is needed, for the obvious reason that natural explanations would never be discovered otherwise. To discover natural processes that explain observations can take significant effort. At the same time, the apriori conclusion that supernatural events cannot occur can force a scientist into accepting weak and incorrect explanations. I like to think of science as a pursuit of truth. The scientific method is one tool for discovering truth. For the vast majority of issues science faces, that tool is all that is needed. Problems happen, however, at the boundaries of science. A great example is the birth of the universe. How does one have an uncaused cause? Other tools that determine truth conclude this has to be from a supernatural source. Yet, those who insist on the modern science tool of ruling out any supernatural explanation are forced into ridiculous theories that not only can never be proven scientifically, but also lack any of the non-scientific evidence of the supernatural explanation. Thus, I believe scientists benefit when they are aware of the non-scientific evidence supporting a supernatural, and are not afraid to acknowledge that such explanations may indeed be the most likely truth for some events."

Finally, the results from the qualitative portion of the survey provide some insight into the underlying thinking of university faculty. It is apparent that some university faculty hold serious misconceptions about what science is and how science works, but there were some participants that demonstrated a robust understanding of the NOS:

"Scientific theories represent established knowledge; they are constantly changing as research develops, but usually only in small ways. They are usually well-tested through observation and experimentation. Because they are well-tested and represent the most up-to-date knowledge in a given area, I would consider them to be highly reliable ideas, although not 100% reliable, as they are

constantly subject to refinement. An example would be Newtonian physics, which served as a highly reliable description of the way the physical world worked until refined by Einsteinian(sic) *physics."*

"Science is always improving knowledge and technology is always improving such that scientists are able to learn more. It makes sense that scientific ideas will be reviewed and modified as new information comes to light. However, the scientific community should be very critical and skeptical of new ideas to ensure that they are indeed well-founded, well-tested, and well-grounded in previous scientific knowledge."

"I make no distinction between observational data and experimental data. I observe the planets motion in the sky. I don't do experiments with planets and 'try it out'. The two 'methods' are complimentary aspects to collecting data; I find the attempt to define a distinction here alien. When to do an experiment with controlled variables you are observing the results. If you observe results and can note the condition of the key variables, you do the same thing."

A more detailed discussion of the remaining text responses questions can be found in Chapter 3. However, some key misconceptions that were seen include: that biological evolution (or science) was a belief and thus equivalent to other beliefs (e.g. creationism); and that biological evolution includes (or is) an explanation for the origin of life.

Discussion

How are a person's understanding of the NOS, knowledge of biological evolution, and acceptance of biological evolution related? While previous studies have found correlations between pairs of these factors, this study shows that the relationship is much more complicated than previously thought.

For this set of participants overall, the three variables are significantly positively correlated with each other. Figure 8 summarizes the overall correlations detected between the three variables (values for correlations of knowledge of biological evolution with acceptance of biological evolution are taken from Chapter 3). The SEM-based path analysis reported here (Table 1) shows that the relationship between these variables is accurately represented by the full model (Figure 1B). Higher understanding of the NOS is significantly positively correlated with higher knowledge of biological evolution and with higher acceptance of biological evolution across the entire population of university faculty. This is also the case when one of the three variables is controlled for. We suggest that this trifecta that we have named the "Evolution Knowledge/NOS Understanding/Evolution Acceptance Trifecta" (KUAT) is an accurate representation of the relationship that exists between these variables. Future studies are clearly needed to see if the patterns observed in this study are present in other populations of interest (e.g., high school students). It seems certain that effective instruction in biological evolution must incorporate coverage all three elements: knowledge of biological evolution, acceptance of biological evolution, and understanding of the NOS.

However, when the participants are broken into sub-groups based on their theistic view, area of expertise, and amount of science education the relationship becomes much less clear. For example, we see the KUAT for the life and physical sciences groups, but not the other areas of expertise. Knowledge of biological evolution and acceptance of biological evolution are significantly positively correlated across every theistic view (Chapter 3), but understanding of the NOS is significantly positively correlated with knowledge of biological evolution across all but the theistic evolutionist and creationist + theistic evolutionist groups. Additionally understanding of the NOS and acceptance of biological evolution were significantly positively correlated for all theistic views except for theistic evolutionists. The KUAT was observed in the high amount of science education but not the other groups.

What do these inconsistencies in the KUAT mean? First, it means that factors other than pure knowledge, understanding, and acceptance are interacting with the KUAT. Clearly a person's life experiences and choices are having a significant influence. This is seen in several of the analyses reported above, but in all cases the factor having the most pervasive influence was theistic view. Both the two-way ANOVA of theistic view and area or expertise and the two-way ANOVA of theistic view and amount of science education it was theistic view that showed the stronger significant relationship all parts of the KUAT (Figure 10). The AIC measure of the different models also supports theistic view being the strongest influencer of the KUAT, as the models using theistic view had the smallest AIC values.

A surprising result of this work was that a larger amount of reported science education was NOT correlated with increased understanding of the NOS. Participants across all four amounts of science education were statistically indistinguishable from each other on their average understanding of the NOS. This unexpected result does not speak well of the science education the participants received. If understanding of the NOS is as uncorrelated with how much science education a person receives (as these results show), then we would suggest that is a serious failing of the education system that produced them.

Interestingly, understanding of the NOS varied significantly by both participant age and employment level. While there was no significant correlation detected in either case, an examination of the mean understanding of the NOS scores for each age group and each employment level showed where the differences were. Those participants who stated they were between the ages of 40 and 69 did significantly better on the measure of their understanding of the NOS than those who stated they were either younger than 39 or older than 70. For employment level it was the tenured participants that scored significantly higher than the tenure track, non-tenured, and other participants.

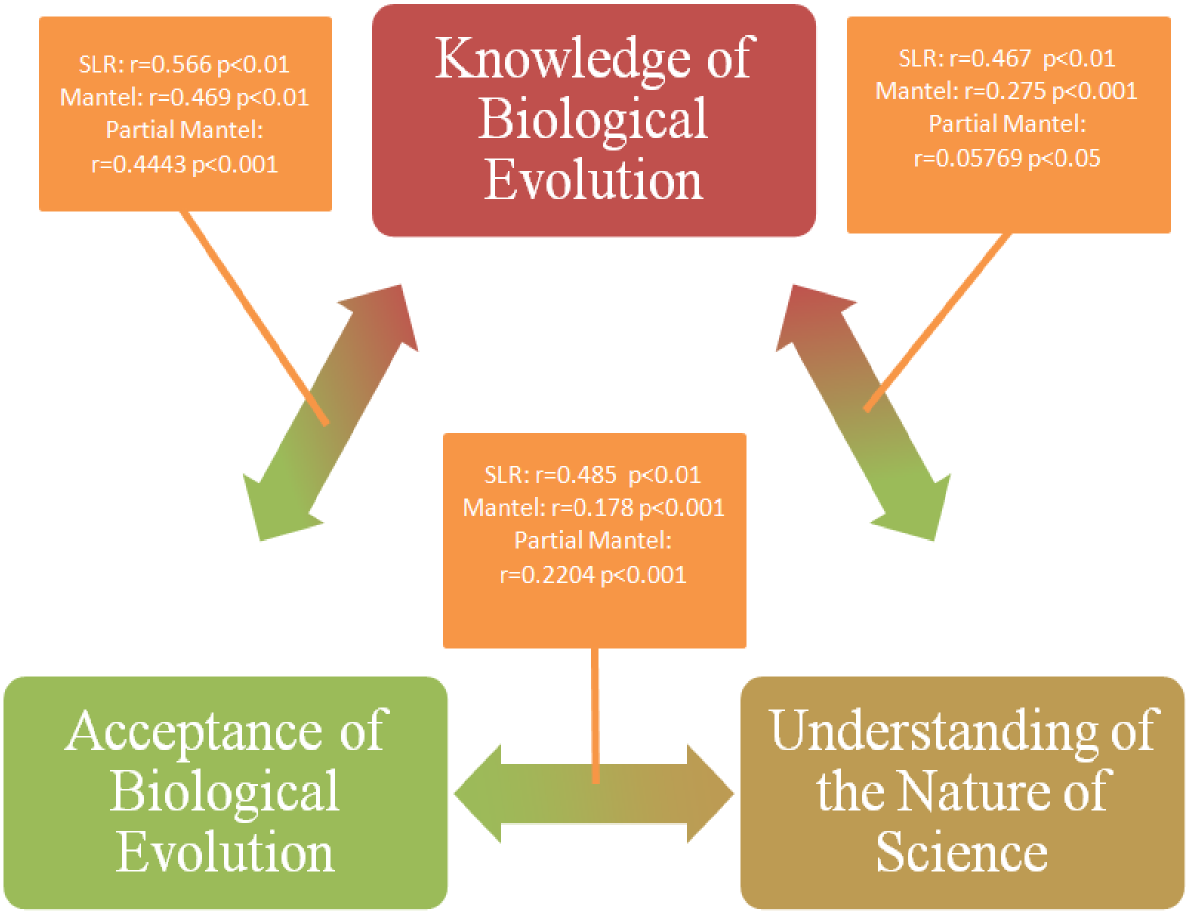

Figure 8: Correlations between knowledge of biological evolution, acceptance of biological evolution, and understanding of the NOS

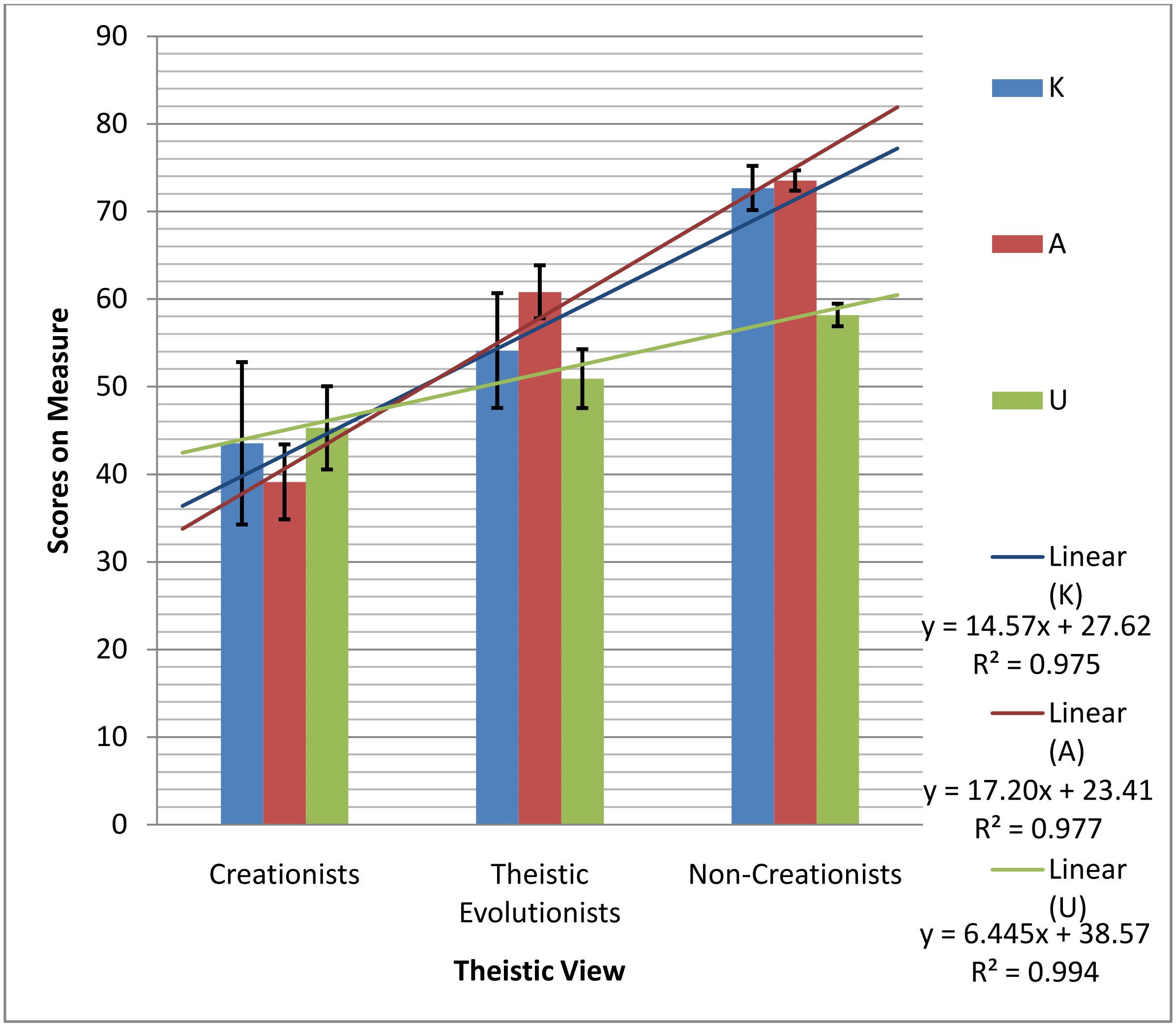

Figure 9: Best-fit model of participant average scores on the understanding of the NOS measure (U), knowledge of biological evolution measure (K) and acceptance of biological evolution measure (A) when grouped by theistic view Schema C. Linear U = Best-fit line and coefficient of determination (R^2 = 0.994) for understanding of the NOS. Linear K = Best-fit line and coefficient of determination (R^2 = 0.975) for knowledge of biological evolution. Linear A =Best-fit line and coefficient of determination (R^2 = 0.977) for acceptance of biological evolution. Bars = 95% C.I. around mean.

We should note that the other demographic measure of participant gender did not show any relationship to their understanding of the NOS. No previous studies have shown gender to be related to understanding of the NOS, and there is no obvious reason to have thought they would be related.

The qualitative portion of the survey provided valuable understanding into the apparent thinking of university faculty. It is clear that some university faculty hold serious misconceptions about what science is and how science works, yet other participants demonstrated a robust understanding of the NOS. Not all of the those participants with a high understanding were scientists, nor were those with a understanding only non-scientists. It is troubling that there are practicing scientists responsible for science teaching that hold fundamental misunderstandings of the NOS.

Conclusions

Studies such as the one described here are integral in determining the factors (and the strength of those factors relative to each other) that influence the KUAT. The primary result of the work presented here is the evidence in support of the existence of the KUAT. We hope that these results convince future researchers that if they wish to effectively address Biological Evolution Education (BEE) they need to consider all elements of the KUAT.

Given that the participants in this study (university faculty) did, on average, very poorly on the measure of understanding of the NOS (mSUSSI) we think that it is clear that significant changes need to be made to how we educate people in the NOS. The results presented here suggest that even though many of the participants may have been well versed in science content, they had failed to learn basic aspects of what science is and how science works. We found this to be the most surprising result of this work, as large portions of the participants are professional scientists. When highly educated, regularly practicing scientists do not score significantly better than non-scientists on a test of NOS understanding, there are two obvious explanations. Either the scientists have very poor understanding of the NOS or the non-scientists have an unusually robust one. Given the average score of 56.3%, and that only the physical science participants scored significantly higher than any other group, the available evidence seems to support the former. We had expected that those participants whose area of expertise was in some form of science would, on average, score higher levels of understanding of the NOS. In addition, no significant differences were detected between the science faculty and non-science faculty when they were grouped together and compared. One thing that remains to be explained is how the science participants are succeeding in their careers without a basic understanding of the NOS?

Since the instrument used in this study was heavily modified from the original (Liang et al., 2008) to suit the needs of the research, there are not any previous data that are directly comparable. There some indirect comparisons that may be useful to consider. Students enrolled in a graduate science teacher curriculum showed misconceptions about the term theory, the use of proof in science, and that theories become facts/laws (precise percentages not reported) (Nehm and Schonfeld, 2007). When presented with a multiple-choice question 69% of introductory college zoology students selected the correct definition of the term theory(Sinclair and Baldwin, 1997). Considering that the participants in this study scored on average 56.3% agreement with the correct NOS statements, it appears clear that they have an unacceptably low understanding of the NOS.

These results make it clear that if educators want to effectively address an element of their student's KUAT, they should address the other elements as well. Today's students are the educators of tomorrow, and we should be providing them with the best possible science education. Addressing the short-comings in BEE at the faculty level is only one part of the larger, multi-pronged effort needed to get BEE in America to the point it should have been years ago.

In conclusion, it is the opinion of the authors that just examining one aspect of the KUAT is insufficient when trying to understand of how to address the problems of BEE. We suggest that future research on BEE must include an effective measure of understanding of the nature of science (NOS) such as the mSUSSI. Previous research on BEE exists that included a measure of the NOS, but there is little consistency regarding the instrument used or the elements of the NOS being considered (AAAS, 1993;Alters and Nelson, 2002; Bell et al., 1998; Clough, 1994; Farber, 2003;Johnson and Peeples, 1987; NAS, 1998; Rutledge and Warden, 1999; Rutledge and Mitchell, 2002; Smith, 2010; Southerland and Sinatra, 2003). What BEE needs now are studies where the KUAT is examined in other populations of interest, such as college students. If evidence of the KUAT is found in other groups then it would support our claim that effective instruction in biological evolution *must* include content on biological evolution; it *must* address acceptance of biological evolution, and it *must* include content on *and* address issues of the NOS.

CHAPTER 5: Conclusions

“Nothing in biology makes sense expect in the light of evolution.” – Theodosius Dobzhansky

Dr. Dobzhansky’s oft used quote about evolution has been mentioned in many publications on this topic. It seemed a foregone conclusion to include it here, but given the breadth of research that has been done on biological evolution education (BEE), it seems insufficient. Some appropriate corollaries to Dobzhansky’s claim based on the research presented here might be:

1. Evolution doesn’t make sense except to those people that understand the nature of science.

and

2. Personal theistic viewpoints may block the “light of evolution” in some groups

The results of Chapters 3 and 4support the claim that highly educated adults (faculty at the university level) have a better understanding of biological evolution and a higher rate of acceptance of evolution if they also have a high understanding of the nature of science (NOS). Given the previous work in this area this finding is not entirely surprising. It is important, however, that this research has shown the three elements form a trifecta (the KUAT) of correlation. It is no longer sufficient to just claim that if we want to improve a person’s acceptance of biological evolution we only need to get them to understand biological evolution. As this research shows, we must also address their understanding of the NOS. We can infer from the research presented here that effective instruction in biological evolution must incorporate coverage all three elements; knowledge of evolution, acceptance of evolution, and understanding of the NOS.

We have shown this to be the case for highly educated individuals. University faculty have not had the same educational experience as the average American adult. Individuals who are employed as university faculty have spent a great deal of time becoming experts in their chosen field. They have been exposed to a college educational system and culture for multiple years. They have likely taken courses in diverse subjects not typically available to individuals with only a high school education. These and other differences make them a unique study population, as well as a study population of great importance for science education of the public. An important next step is to investigate the strength of the KUAT in other populations, particularly ones of interest such as college students.

How do we implement the KUAT in the educational system? The obvious solution would be to require the teaching of NOS material in biological science courses. The unfortunate problem with that seemingly simple solution is that we have no guarantee that the instructors in charge of those types of classes have a robust understanding of the NOS themselves. In fact, the data presented in Chapter 4 directly contradicts the claim that most science faculty have a robust understanding of the NOS. In addition, we know from experience that there will be push back from some instructors if we were to add NOS material to their courses. Some will argue that it doesn't belong in their class as it is not biology. Others will claim that their course is already full of biological content and thus there is no room to include anything else. Our response to both of these arguments would to ask: "If not here, then where?" It is clear from this and previous studies that many people, even scientists, are not receiving adequate instruction in the NOS. If having a robust understanding of the NOS is one our nation's educational goals (and we would argue that it should be) then we need to be providing quality NOS instruction. We are aware of no examples of NOS courses at the high school level and very few at the college level. As much as we might prefer that every student be required to take a course in the NOS, just as they are required to take a course in English, that is a more "big picture" or long term goal. At the moment, we see biology courses as the best option for getting the NOS to our students for several reasons not the least of which is that adding NOS instruction in biological science courses would have the added effect of aligning with the KUAT.

Since the university faculty in these studies accept biological evolution at a much higher rate (86.8%) than the general public, how do they account for the lack of public acceptance in the U.S.?

When they were asked to account for this the faculty selected a wide range of responses, the most frequent (21.5%) being a mix of three answers: 1) There is a lack of public understanding of science; 2) There are strong cultural influences acting on the public; and 3) There is a real conflict between science and religion. Those three answers were also commonly selected as individual responses (20.4%, 13.8%, and 12.1% respectively). It would seem that the faculty at this study site place the blame for the problem of evolution education squarely away from themselves.

Another telling piece of information from this question was that only 2.3% of the faculty selected the answer: “This is due to a lack of effort by the Scientific Community.” Why did so few select this? Did nearly 98% of the faculty think that current efforts being put forth by the scientific community are sufficient to combat this problem? It seems that one would be hard pressed to find many researchers in this field who think we don’t think we need to invest more effort. Do they think any additional effort would be ineffective? The research compiled on the subject disagrees with that conclusion. Instruction in evolutionary content does result in increased understanding and in some cases increased acceptance. So why don’t they place any of the blame on themselves or the colleagues?

One potential explanation depends on the nature of promotion and tenure at universities such as the one examined here. Efforts put forth by faculty members may not be valued as much as other work (e.g. scientific publications) during their tenure and promotion process. While there are certainly faculty for whom their work in education is an integral part of their tenure and promotion process, it is more typical at study sites such as the one used here that research output and grants attained are given higher priority/value. Some faculty may be able to invest time and effort in improving their pedagogy without a negative impact on their advancement, it is entirely possible a faculty member at a large research institution who invests a significant amount of time doing outreach programs, improving their lecture content, or attending conferences on BEE to the exclusion of their research scholarship will find that doing those activities may actually hurt their chances of earning tenure or a promotion. We would suggest that if we want to encourage participation by the larger scientific community in the issues of BEE, then we need to value these sorts of activities a great deal more than we currently do.

Another problem that appears in the additional questions was that 14.3% of the faculty participants stated that that both biological evolution and Intelligent Design/Creationism should be taught in public college science classes (Figure 1). This does NOT include anyone who stated that ID/creationism could be addressed in such a class to “educate students about the nature of science and why ID/creationism is not accepted by the scientific community (53.9%)”.

Compared to the 50% of K-12 biology science teachers that want some form of creationism included in their classes, this number is encouraging (Nehm and Schonfeld, 2007). Of that 14.3% of participants, 4% self identified as life scientists, 3% self-identified as social scientists, and the remainder was relatively evenly distributed between the other areas of expertise. While it is encouraging that 76.3% of the faculty participants selected answered that only biological evolution should be taught as science (includes the 53.9% mentioned above), it is not unreasonable to expect that number to be closer to 100%.Why do14.3% of the of the faculty think ID/creationism should be taught in public college science classes? The obvious explanation lies in the relationship between this belief and their theistic view. Over 15% of the overall set of faculty participants (15.4%) self-identified as holding one of the three types of creationist viewpoints; Young Earth, Old Earth, or Theistic Evolutionist. It seems beyond coincidence that these results would line up so well, however only 65% of those faculty participants that want ID/creationist taught were in one of the three creationist viewpoints groups. Why do those faculty who do not have creationist viewpoints want ID/creationism taught in public college science classes? An examination of their text responses provides some explanation. To quote one participant:

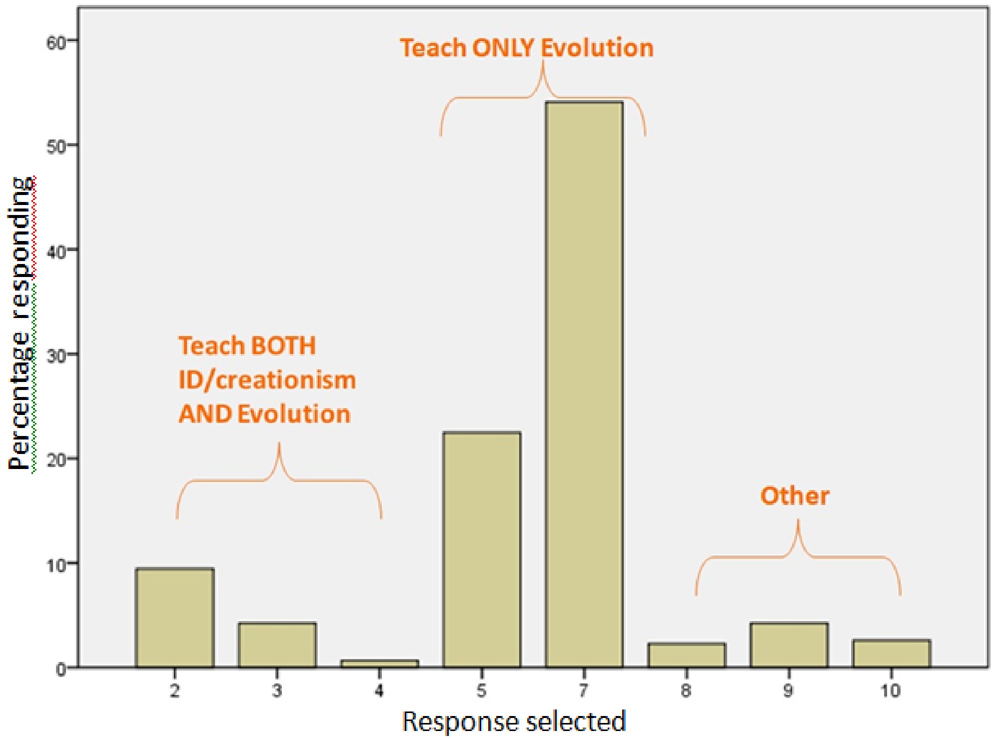

Figure 1: Participant opinion of public college science teaching policy

"While we all have different beliefs, I believe it is important to teach both views so college students are aware of both positions. They then need to make their own choices. (I don't have to believe in evolution but I do believe students should be aware of the variety of beliefs.)"

Another participant explained their choice this way:

"Students should have the chance to weigh the data for themselves and make their own decisions, perhaps in future they will test their own hypotheses and give weight to either side of the argument."

The first problem with these suggestions is that there is no scientific evidence supporting ID that can be compared to the amount of evidence supporting biological evolution. To teach both would be like saying an empty glass is the same as the Pacific Ocean. One has no water; the other has a preponderance of water. Thus, while perhaps it seems a 'democratic' or 'scholarly' suggestion to say "show the students the evidence on both sides and let them decide", that is a disingenuous suggestion, as there is no scientific data for one side of the issue (ID).

Additionally, we should consider if it is reasonable to expect students to be able to objectively evaluate the scientific merit of evolution, intelligent design, and creationism? We would argue that, frankly, it is not. The students being referred to in these examples are novices when it comes to science. Most will not have the proper mental tool set to judge what science is and what it is not. Compounding that problem is the lack of instruction that is typically provided to students regarding the NOS.

We did find it encouraging that 53.9% of the participants selected the option that ID/creationism could be addressed "educate students about the nature of science and why ID/creationism is not accepted by the scientific community". We argue that this is an effective and proper use of class time if it is done in an accurate manner. We personally have seen anecdotal evidence of the effectiveness of this strategy, and it was heartening to see that a majority of the participants agreed.

One might think it reasonable to expect that faculty who have devoted their lives to the study of the biological (and related) sciences would understand more about biological evolution than their non-biological science faculty compatriots. While the examination of the differences between participant's areas of expertise did show that the life scientists, on average, score the highest on the knowledge of evolution portion, they only scored significantly higher than those faculty who did not report their area of expertise.

Why did the life scientists score lower on average than expected on both the knowledge of and acceptance of evolution measures? One reasonable explanation is that, for many of these life science faculty, there is no direct benefit to their lives if they fully understand biological evolution. Many of the faculty in the life science group may not directly use any aspects of evolutionary biology regularly in their research or teaching. They may be out of practice or behind the curve in current advances in evolutionary knowledge. It does seem reasonable, however, that if any of these faculty are going to speak to the science of biological evolution, that those faculty *should* know as much as is practical/realistic.

Perhaps one of the most distressing, but not entirely unexpected results of this research, is that the amount of previous science education had showed zero relationship to average participant understanding of the NOS. This suggests that even though many of the participants may have been well versed in science content, they have failed to learn basic aspects of what science is and how science works. Given that a large portion of the study population are considered professional scientists, this result does not bode well for science education or the academic community as a whole.

Certainly one can be a good scientist (and thus be doing good science) without being an expert in the NOS. However the questions posed in this study are considered to be addressing basic elements of the NOS, rather than highly advanced ones. Even so, should we expect scientists to have a robust understanding of the NOS, or should that be left to scientific philosophers? Albert Einstein certainly saw value in having scientists that were versed in the NOS: "*I fully agree with you about the significance and educational value of methodology as well as history and philosophy of science. So many people today—and even professional scientists—seem to me like somebody who has seen thousands of trees but has never seen a forest. A knowledge of the historic and philosophical background gives that kind of independence from prejudices of his generation from which most scientists are suffering. This independence created by philosophical insight is—in my opinion—the mark of distinction between a mere artisan or specialist and a real seeker after truth*." (Einstein Archive 61-574, 1944).

We suggest that not just scientists, but all people should have a basic understanding of the NOS. As the data here (as well as other studies) show, current science education methods do not result in adequate NOS understanding. Certainly if we wish to reach the largest possible number of people, increasing the NOS content at the high school is one possible solution. We would also suggest that if and understanding of the NOS is something we expect in all of our students, then just as they take a required English course in college they should take a required NOS course.

To what extent do the attitudes and perspectives of faculty at the university level regarding biological evolution influence the students? Given that, at this study site, approximately 15% of the faculty stated they hold one of several different creationist positions, what effect might that have on their undergraduate students or their graduate students? Those same faculty were shown (Chapter 4) to have a poor understanding of the nature of science. What impact might that have on their students? How much of an impact do non-science faculty have on the attitudes and perspectives of their students regarding science? If a science undergraduate student takes a humanities course with a professor who holds a creationist viewpoint, does that impact their view of science topics (e.g., evolution)? How do science faculty address the NOS in their classes - if they address it at all? How much benefit would we see if undergraduates take a semester-long course that is devoted to and explicitly covers the NOS? Would their understanding of the NOS increase over time? These are, in our opinion, important questions that need to be addressed by future research.

It has been widely acknowledged in academic circles that the United States needs to drastically improve science education (U.S. Department of Education, 2011). Education in evolutionary content and the NOS are integral parts of that improvement. Recent funding initiatives by groups such as the National Science Foundation suggest that the country is moving in the right direction, however, this does not mean that we can afford to relax our efforts in any way. Not only do we need to reach out to our students about evolution and the nature of science, we need to reach out to everyone. From the university faculty to the public at large, everyone deserves to have a robust understanding of biological evolution and the nature of science. Science is how we understand the world around us. Evolution is among the most powerful explanations of natural phenomena on Earth. To teach this subject is a daunting challenge, though as President John F. Kennedy said when he addressed the National Academy of Sciences over 45 years ago: "The challenge, in short, may be our salvation."

Appendix: Survey Instrument

INFORMED CONSENT DOCUMENT

Investigators: Justin Rice, B. S., James T. Colbert, Ph.D.

This is a PhD Dissertation research study. Please take your time in deciding if you would like to participate. Please feel free to submit any questions using the information at the end of this form.

INTRODUCTION

The purpose of this study is to gain a better understanding of how well faculty understand the nature of science and some specific science content. You are being invited to participate in this study because you are currently employed at the Tenured, Tenure Track, or non-Tenure Track level.

DESCRIPTION OF PROCEDURES

If you agree to participate in this study, your participation will last approximately 20 minutes. During the study you will be presented with a survey form to complete. If you are uncomfortable at any time you may skip items or choose to quit at any time.

RISKS

While participating in this study you may experience the following risk: It is possible that participants may experience mild and short-lived discomfort associated with answering questions that may contradict their personal viewpoints.

BENEFITS

If you decide to participate in this study you will have the opportunity to submit your name in a random drawing for one of ten $50 gift certificates to the Iowa State University Book Store. It is hoped that the information gained in this study will benefit society by: 1) contributing new information to the existing body of literature; and 2) leading to improvements in science education at the college level.

COSTS AND COMPENSATION

You will not have any costs other than the donation of your time from participating in this study. You will not be directly compensated for participating in this study. You will have the opportunity to submit an email contact at the completion of the survey to enter into a drawing for one of ten $50 gift certificates.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information. To ensure confidentiality to the extent permitted by law, the following measures will be taken: Participants will be assigned ID numbers so that their names will not appear on data. Data will be stored on a password protected computer in a locked office. Only investigators and research assistants will have access to the data. If the results are published, your identity will remain confidential. QUESTIONS OR PROBLEMS You are encouraged to ask questions at any time during this study. For further information about the study contact Dr. James T Colbert at 294-9330. If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, Office for Responsible Research, (515) 294-3115, 1138 Pearson Hall, Ames, IA 50011.

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PARTICIPANT SIGNATURE Your electronic signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document, and that your questions have been satisfactorily answered. Since this is an online survey you may wish to print a copy of this informed consent document for your own files.

□ Yes, I agree to participate in this survey

□ No, I do not agree to participate in this survey

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by selecting the appropriate choice to the right of each statement. For text responses, simply type in the boxes provided.

Scientific Theories

Strongly Disagree / Disagree More Than Agree / Uncertain or Not Sure / Agree More Than Disagree / Strongly Agree

Scientific theories are well substantiated explanations for natural phenomena.

□ □ □ □ □

With enough supporting evidence, a scientific theory will become a scientific law.

□ □ □ □ □

A scientific theory is a speculative idea.

□ □ □ □ □

Well established scientific laws and well established scientific theories are different, but equally valid, forms of scientific knowledge.

□ □ □ □ □

Explain why you think scientific theories are OR are not highly reliable ideas and provide examples to support your answer.

Established Science Ideas

Strongly Disagree / Disagree More Than Agree / Uncertain or Not Sure / Agree More Than Disagree / Strongly Agree

Previously well supported and established science ideas are not easily abandoned by scientists, even in the face of contradictory data.

□ □ □ □ □

Scientists should not be so resistant to abandoning previously well supported and established ideas.

□ □ □ □ □

When data arises that contradicts a previously well supported and established science idea; that science idea is likely in need of modification or replacement.

□ □ □ □ □

When data arises that contradicts a previously well supported and established science idea; the problem likely lies not with the well supported and established idea, but somewhere else.

□ □ □ □ □

Explain why you think a previously well supported and established science idea should OR should not be abandoned when contradictory data arises, and provide examples to support your answer.

Methodology of Scientific Investigations

Strongly Disagree / Disagree More Than Agree / Uncertain or Not Sure / Agree More Than Disagree / Strongly Agree

Considering what scientists actually do, there really is no such thing as the scientific method.

□ □ □ □ □

Scientists basically follow the same step-by-step scientific method.

□ □ □ □ □

Scientific knowledge based primarily on observational data is as reliable as scientific knowledge based primarily on experimental data.

☐ ☐ ☐ ☐ ☐

Experiments are the most reliable way scientists develop valid scientific knowledge when they investigate the natural world.

☐ ☐ ☐ ☐ ☐

Explain why you think observational and experimental research are equally valid ways of understanding the natural world OR whether one is superior to the other, and provide examples to support your answer.

Science and the Supernatural

Strongly Disagree / Disagree More Than Agree / Uncertain or Not Sure / Agree More Than Disagree / Strongly Agree

The scientific community should be more open to the use of supernatural events or beings in scientific explanations . ☐ ☐ ☐ ☐ ☐

Supernatural explanations are potentially useful for helping scientists understand the natural world.

☐ ☐ ☐ ☐ ☐

Explaining natural phenomena without reference to the supernatural is necessary for advancing scientific knowledge. ☐ ☐ ☐ ☐ ☐

Scientists who will not use supernatural explanations when doing science can still believe in a supernatural being. ☐ ☐ ☐ ☐ ☐

Explain why supernatural explanations should OR should not be used in credible scientific ideas, and provide examples to support your answer.

Which of the following support the theory of evolution?

- artificial selection (also known as selective breeding), an analogue of natural selection
- comparative biochemistry, where similarities and differences of DNA among species can be quantified
- vestigial structures that serve no apparent purpose
- comparative embryology, where the evolutionary history of similar structures can often be traced
- all of the above provide evidence to support the theory of evolution

Resistance to a wide variety of insecticides has recently evolved in many species of insects. Why?

- mutations are on the rise
- humans are altering the environments of these organisms, and the organisms are evolving by natural selection

□ no new species are evolving, just resistant strains or varieties. This is not evolution by natural selection

□ humans have better health practices, so these organisms are trying to keep up

□ insects are smarter than humans

Which of the following is the most fit in an evolutionary sense?

□ a lion who is successful at capturing prey but has no cubs

□ a lion who has many cubs, eight of which live to adulthood

□ a lion who overcomes a disease and lives to have three cubs

□ a lion who cares for his cubs, two of whom live to adulthood

□ a lion who has a harem of many lionesses and one cub

How might a biologist explain why a species of birds has evolved a larger beak size?

□ large beak size occurred as a result of mutation in each member of the population

☐ the ancestors of this bird species encountered a tree with larger than average sized seeds. They needed to develop larger beaks in order to eat the larger seeds, and over time, they adapted to meet this need

☐ some members of the ancestral population had larger beaks than others. If larger beak size was advantageous, they would be more likely to survive and reproduce. As such, large beaked birds increased in frequency relative to small beaked birds

☐ the ancestors of this bird species encountered a tree with larger than average sized seeds. They discovered that by stretching their beaks, the beaks would get longer, and this increase was passed on to their offspring. Over time, the bird beaks became larger

☐ none of the above

Which of the following statements about natural selection is true?

☐ natural selection causes variation to arise within a population

☐ natural selection leads to increase likelihood of survival for certain individuals based on variation. The variation comes from outside the population

☐ all individuals within a population have an equal chance of survival and reproduction. Survival is based on choice

☐ natural selection results in those individuals within a population who are best-adapted surviving and producing more offspring

☐ natural selection leads to extinction

All organisms share the same genetic code. This commonality is evidence that

- evolution is occurring now
- convergent evolution has occurred
- evolution occurs gradually
- all organisms are descended from a common ancestor
- life began millions of years ago

Which of the following statements regarding evolution by natural selection is FALSE?

- natural selection acts on individuals
- natural selection is a random process
- very small selective advantages can produce large effects through time
- natural selection can result in the elimination of certain alleles from a population's gene pool
- mutations are important as the ultimate source of genetic variability upon which natural selection can act

A change in the genetic makeup of a population of organisms through time is

- adaptive radiation

- biological evolution
- LaMarckian evolution
- natural selection
- genetic recombination

Which of the following is the ultimate source of new variation in natural populations?

- recombination
- mutation
- hybridization
- gene flow
- natural selection

Which of the following best describes the relationship between evolution and natural selection?

- natural selection is one mechanism that can result in the process of evolution
- natural selection produces small-scale changes in populations, while evolution produces large-scale ones
- natural selection is a random process, while evolution proceeds toward a specific goal

□ natural selection is differential survival of populations or groups, resulting in the evolution of individual organisms

□ they are equivalent terms describing the same process

For each of the following statements indicate your agreement or disagreement using the following scale:

Strongly Disagree / Disagree More Than Agree / Uncertain or Not Sure / Agree More Than Disagree / Strongly Agree

Organisms existing today are the result of evolutionary processes that have occurred over millions of years

□ □ □ □ □

The theory of evolution cannot be tested scientifically

□ □ □ □ □

Modern humans are the product of evolutionary processes that have occurred over millions of years

□ □ □ □ □

The theory of evolution is based on speculation and not valid scientific observation and testing

□ □ □ □ □

Most scientists accept evolutionary theory to be a scientifically valid theory

☐ ☐ ☐ ☐ ☐

The available data are unclear as to whether evolution actually occurs

☐ ☐ ☐ ☐ ☐

The age of the earth is less than 20,000 years

☐ ☐ ☐ ☐ ☐

There is a significant body of data that supports evolutionary theory

☐ ☐ ☐ ☐ ☐

Organisms exist today in essentially the same form in which they always have

☐ ☐ ☐ ☐ ☐

Evolution is not a scientifically valid theory

☐ ☐ ☐ ☐ ☐

The age of the earth is at least 4 billion years

☐ ☐ ☐ ☐ ☐

Current evolutionary theory is the result of sound scientific research and methodology

☐ ☐ ☐ ☐ ☐

Evolutionary theory generates testable predictions with respect to the characteristics of life

☐ ☐ ☐ ☐ ☐

The theory of evolution cannot be correct since it disagrees with the Biblical account of creation

□ □ □ □ □

Humans exist today in essentially the same form in which they always have

□ □ □ □ □

Evolution theory is supported by factual historical and laboratory data

□ □ □ □ □

Much of the scientific community doubts if evolution occurs

□ □ □ □ □

The theory of evolution brings meaning to the diverse characteristics and behaviors observed in living forms

□ □ □ □ □

With few exceptions, organisms on earth came into existence at about the same time

□ □ □ □ □

Evolution is a scientifically valid theory

□ □ □ □ □

Read the statement provided, then read the answers provided and select the ONE that BEST represents your position. In the U.S. today there is a great deal of public debate over the teaching of biological evolution in public college science classes. Other ideas such as Intelligent Design/Creationism have been put forth as an alternative.

□ Neither biological evolution nor Intelligent Design/Creationism should be taught in College science classes

□ Both biological evolution and Intelligent Design/Creationism should be taught in college science classes and given equal time

□ Both biological evolution and Intelligent Design/Creationism should be taught in college science classes but Evolution should be given more time

□ Both biological evolution and Intelligent Design/Creationism should be taught in college science classes but Intelligent Design/Creationism should be given more time

□ Only biological evolution should be taught in public college science classes

□ Only Intelligent Design/Creationism should be taught in public college science classes

□ Only biological evolution should be taught as a valid scientific idea, but Intelligent Design/Creationism might be addressed to educate students about the nature of science and why Intelligent Design/Creationism is not accepted by the scientific community

□ I don't know enough about this subject to make a choice

□ None of these choices fits my basic viewpoint. (If you select this, please write what your viewpoint is in the space below)

□ A combination of choices fits my basic viewpoint. (If you select this, please write what your viewpoint is in the space below.)

What was your reasoning for choosing the response above? / What is your viewpoint?

Read the statement provided, then read the answers provided and select the ONE that BEST represents your position. Biological evolution is overwhelmingly accepted within the scientific community. It has been for decades. However, a majority of the American public does not accept the idea. How do you account for this?

- ☐ This is due to a lack of public understanding regarding what science is and how it works
- ☐ This is due to a lack of effort from the scientific community to educate the public
- ☐ This is due to a real conflict between science and religion
- ☐ This is due to a perceived conflict between science and religion
- ☐ This is due to strong cultural influences acting upon the public
- ☐ I don't know enough about this subject to make a choice
- ☐ None of these choices fits my basic view point. (If you select this, please write what your viewpoint is in the space below.)
- ☐ Or a combination of choices fits my basic viewpoint. (If you select this, please write what your viewpoint is in the space below.)

What was your reasoning for choosing the response above? / What is your viewpoint?

Please read all of the following options, then select the one that is closest to your perspective.

☐ The Earth is young (6,000 - 10,000 years), with each of the six days of Genesis/ Creation being 24-hour days. God created each kind of organism in its present form

☐ The Earth is ancient (many millions of years), with each of the six days of Genesis/Creation being long periods of time (thousands or millions of years). God created each kind of organism in its present form

☐ The Earth is ancient (many millions of years). Biological evolution occurs, but God has intervened at critical points. God created species through the laws of nature

☐ The Earth is ancient (many millions of years). Biological evolution describes a natural process that produces species without reliance upon intervention from God. Biological evolution neither supports nor denies the existence of God

☐ The Earth is ancient (many millions of years). Biological evolution occurs as a natural process to produce species. Biological evolution supports the idea that God does not exist

☐ None of these options fit my perspective. If you select this answer, please describe your perspective, in as much detail as you can, in the following text box

What was your reasoning for choosing the response above? / What is your viewpoint?

Your gender:

- ☐ Male
- ☐ Female

Your age group:

- ☐ 25 - 39
- ☐ 40 - 54
- ☐ 55 - 69
- ☐ 70 or older

What is your current level of employment?

- ☐ Tenured
- ☐ Tenure Track
- ☐ Non-Tenure Track
- ☐ Other

What is your current area/field of work? (e.g. Chemistry, History, Aerospace Engineering . . .)

Approximately how much science education did you receive in college?

- I did not take any science courses
- 1 - 4 science courses
- 5 - 8 science courses
- 9 or more science courses

Please use the following textbox to provide any additional comments or information

You have successfully completed the survey. Thank you for your time and your participation in this research project! You may now enter into a drawing for one of ten $50 gift certificates to the Iowa State University Book Store. If you wish to participate, please provide a contact email below. Winners will be announced prior to December 30th 2010. This information will be separated from your survey answers and will not be used other than to contact you if a prize is awarded.

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