THE EFFECT OF INSTRUCTION BASED ON THE NATURE OF SCIENCE AND ELIMINATING PRECONCEPTIONS ON UNDERSTANDING AND ACCEPTANCE OF EVOLUTION

by

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ABSTRACT

In this investigation, nature of science instruction was blended with evolution instruction that did not use words like *evolution* and *natural selection* for the purpose of increasing student understanding of evolution and the nature of science as well as increasing acceptance of the theory of evolution. Participants included 1 class of 20 7^{th}-graders and 1 class of 18 8^{th}-graders. Student learning and understanding were assessed with classroom summative tests, online surveys, and recorded interviews. Results revealed increased understanding of the nature of science and evolution, along with increased acceptance of evolution.

INTRODUCTION AND BACKGROUND

Project Background

For the past eight years I have been teaching sixth, seventh, and eighth grade science at North Woods Discovery School, a K-8 charter school located in Redding, California. Each grade level has a single instructor and in the middle school grades each instructor teaches a core subject and history, as well as other minor classes. I teach science to all three grades and history to grade six. At times I have taught art, technology, remedial math, reading, and other topics on a short-term basis. The school serves roughly 200 students in grades K-8. Our charter focuses on math, science, and technology, though realistically the primary grades have the traditional focus on language and math. Over 90% of the students identify as white, with 49% qualifying for free or reduced lunch according to our California Basic Educational Data System (CBEDS) data. North Woods is chartered by Gateway Unified School District, located in the City of Shasta Lake about ten miles north of Redding. Our current school site is north of the City of Shasta Lake in a rural area with dilapidated trailer parks on two sides. Redding is the largest city north of Sacramento with 90,000 residents and Shasta Lake has about 10,000. The rest of the county is sparsely populated, extending into the mountains in three directions.

Political affiliations and views affect this research because the topic is evolution, specifically utilizing certain approaches to maximize understanding. The residents of Shasta County are considered conservative. Democrats earned just 36% of the vote in the 2008 presidential election (Shasta County, 2008). Teaching evolution in this area has been challenging for me. Both the students and their parents frequently question the validity of evolution. Some parents have requested their child be removed from the classroom during instruction related to evolution. When I originally took the position in 2002, the director asked me how I would feel about teaching Intelligent Design alongside evolution, which I refused to do. At a California Science Teachers Conference I met Larry Flammer, who encouraged me with ideas and his web site (Evolution and the Nature of Science, 2011). The focus of the Evolution and the Nature of Science Institute group includes teaching the nature of science (NOS) as a critical prerequisite to evolution. Later I took some of the ENSI activities as well as others and designed an evolution curriculum that approached evolution differently. After understanding the NOS, students discover evolution through observations and models without being exposed to the word evolution. After learning about cells and genetics, the students learned about the way populations responded to change. They saw that genetic variation within a population meant differential survival depending on environmental pressure, resulting in changes in the phenotype of the population. Only then were they introduced to the word evolution.

Focus Questions

What is the effect of instruction based on the nature of science and initially avoiding the word *evolution* on student understanding and acceptance of evolution? This includes four sub-questions. First, does learning the process of evolution prior to using the word *evolution* affect acceptance and understanding of evolution? Second, how does understanding the definition of theory and the tentative nature of science affect acceptance of evolution? Finally, would experiencing a simulation of changes in organisms over Earth's history affect knowledge and acceptance of evolution?

CONCEPTUAL FRAMEWORK

Although scientists nearly universally accept evolution as an underlying theory of biology, in the United States there is significant public resistance to evolution (Kennedy, 2005). Recent survey results showed 38% of respondents accepted evolution as occurring with the guidance from God, and 13% accepted evolution without guidance from God (Coalition of Scientific Societies, 2008). From 1980 until today, public acceptance of evolution has remained steady, with 40 to 50% of Americans accepting evolution and the same percentage accepting a Biblical view of origins (Pew Research, 2005).

Evolution has primarily played out in the arena of public education where there is more uncertainty about how to best teach origins. A national survey showed that 32% of instructors were unsure about teaching creationism and 41% were doubtful about teaching intelligent design. However, only 22% expressed concern about teaching evolution. Fifty-three percent favored teaching evolution in public schools as opposed to 36% who favored teaching creationism. This has been interpreted as indicating that a majority of Americans support teaching evolution and even more may be open to it (Coalition of Scientific Societies, 2008).

In comparison, other Western nations post far more favorable reactions to evolution. Various surveys were examined for 34 nations, and 33 of them showed more acceptance of evolution than the US (Evolution, Creationism, Intelligent Design, 2008). The scientific community as a whole has no issues with accepting evolution and no acceptance of Intelligent Design (ID) or its predecessor creationism, as evidenced by rejections by scientific organizations such as the American Association for the Advancement of Science, which rejected ID in 2002 (Pennock, 2003). Evolution is deeply accepted by the scientific community (Cavallo & McCall, 2008). All theories are tentative, but one of the strongest scientific theories is evolution (Nelson, 2000). The National Research Council (1996) declared evolution biology's unifying concept, and it is considered a key element for all life science (Haury,1996). Often statements of evolution being the foundation of biology went uncited in recent research articles, apparently due to the near universal acceptance of its importance and acceptance. Evolution was deemed to be a core biological concept with many current advances (Science, Evolution, and Creationism, 2008).

There are many possible reasons for the lack of acceptance of evolution in the general population of the United States. According to Lac and Himelfarb (2010), the primary predictor of acceptance of evolution or ID is educational attainment. Low educational attainment predicts greater rejection of evolution. This study also showed significant differences in many demographics, from gender and race to religion and political ideology. The best predictor of pro-creationism views was education, showing that people with some college or just high school education are two to three times more likely to reject evolution in favor of creationism. This suggests that encouraging education of any sort, especially four-year bachelor's programs, may be more important to furthering acceptance of evolution than any method of instruction. Of course there are other correlations as well, such as a strong correlation between rejection of evolution and fundamentalist religious beliefs (Miller & Okamoto, 2006). One study of college students' understanding and acceptance of evolution before and after a course found no consistent change in understanding or acceptance. However, a consistent shift toward acceptance of evolution did not occur. Those initially in the middle shifted in both directions. A significant number of students originally accepting evolution changed their minds over the duration of the course. A significant number of students opposed to evolution on religious grounds became less religious as well as more accepting of evolution. There were some consistent changes in views. Students accepted nature of science views more accurately as well as evolution views not about humans (Lovely & Kondrick, 2008).

Regardless of the cause of acceptance of ID and creationism, and rejection of evolution, there is a definite need for scientists and educators to promote understanding of evolution in the United States (Coalition of Scientific Societies, 2008). Different methods produce different results in terms of understanding and acceptance of evolution (Hedegaard, 1996). Chinsam and Plaganyi (2007) discovered that participation of first-year university students in the Cape Town instructional program produced no statistically significant change in student acceptance of evolution. Short (1994) found similar results in Monash University in Australia. However, the data from Chinsam and Plaganyi suggest that although students absorbed many facts about evolution, they still held to their prior beliefs. Facts were understood on a low level of Bloom's taxonomy; deeper concepts showed less change after completion of the course.

Thorough teaching of evolution that incorporates the Nature of Science (NOS) needs to begin prior to high school. The nature of science has many definitions. Sandoval and Morrison (2003) state it is dependent on experimentation, questioning, and decisions made in peer-reviewed public media. Cavallo and McCall (2008) believe students do not thoroughly understand the definition of theory, an essential part of the NOS, and summarize the NOS as a system of knowledge and the way that information is increased and modified. As students begin to understand how facts, observations, and experiments develop into modifiable theory, they can better understand how evolution was introduced and why it is accepted today. Students entering university had little knowledge of evolutionary processes, supporting the need for better education in middle and high school (Chinsam & Plaganyi, 2007). Hedegaard (1996) showed that evolution can even be effectively taught in elementary school. Chinsam and Plaganyi (2007) suggest that teachers focus on obvious facts, such as experimental evolutionary studies. Therefore they also recommend teaching a strong base in the nature of science inquiry. Furthermore, since creationism is not science teaching the methods of science inquiry should be effective in supporting evolution (Alters & Alters, 2001). Lovely and Kondrick (2008) also support methods that focus on the nature of science.

Students often have misconceptions about the NOS. They sometimes think that the goal of experimentation is to prove a hypothesis, but not only is that not the goal, but such proof is non-existent in the tentative nature of science (Sandoval & Morrison, 2003). Students believed that given enough proof, a theory becomes a law, indicating a misconception about the definition of theory (an explanation supported by a wealth of knowledge yet open to change) and a law (Eick, 2000.) Laws were seen as absolute knowledge while theories were closer to guesses.

Cavallo and McCall's findings combine student beliefs about the nature of science (NOS) and evolution with their conceptual knowledge of evolution. Their data suggest that students rarely change their beliefs based solely upon facts and explanations offered in classes on evolution. In general beliefs do not change, but Cavallo and McCall conjecture that origin beliefs, due to their high profile in the news, may be even more difficult to change regardless of the evidence presented. One of the key elements they unveiled is a correlation between students' understanding of the tentative nature of science and acceptance of evolution (Cavallo & McCall, 2008).

A curriculum based on utilizing the NOS to create an academic environment for learning about evolution may be effective. Sandoval and Morrison (2003) found significant improvement in evolution understanding and acceptance when using inquiry methods. Many methods tested utilized both inquiry approaches and other methods as well, such as those of Scharman and Harris (1992). In a three-week teacher institute they hesitated to generalize the results but found definite improvement in evolutionary understanding. Scharman and Harris also found interesting results about teacher views of evolution. Teachers often avoid directly teaching about evolution, preferring to teach it indirectly as a part of ecology, genetics, and animal behavior without using the word evolution (the "E-word") or not teaching it at all. Among the teachers, gains in understanding were made through two methods: inquiry approaches and peer discussions. Scharman and Harris found the inquiry approaches improved knowledge of inquiry while the peer discussions increased acceptance. It was also determined that misconceptions about evolution need to be directly confronted in order to elicit change. Finally, Scharman and Harris noted that teachers tend to take sides in a debate about the reality of evolution, but did better when given a middle ground that allowed their religious views alongside evolution. One might be able to apply these results to student populations as well. Robbins and Roy (2007) cited Scharman and used similar methods in a high school. At the end of the unit, they found that 92% of the students accepted evolution. Before the unit, 53% accepted it. However, the percentage increase in understanding was far less, which they attributed to students accepting the ideas of experts rather than reaching their own conclusions, hardly the goal of NOS instruction. Robbins and Roy used three methods in their unit. First, they identified prior misconceptions about the NOS and evolution. Next they conducted laboratory exercises and presented lectures designed to counter the misconceptions. Finally they interpreted the results in discussions with the students. The exercises included reading quotes from well-known religious and scientific people in an effort to create the safe middle ground described by Scharman as well as experiences with homologous, analogous, and vestigial parts of animals directly and via computer modeling.

One misconception is the difference between individuals versus populations undergoing evolution. High school students often thought that individuals changed themselves and passed on the traits in a Lamarkian way. Some students even thought that the individual understood the environmental changes around it and chose to evolve. The suggestion is to develop a pattern of thought based on genetics and applied to populations (Baumgarten & Duncan, 2009).

Some recommend using inquiry methods, critical thinking, and interactive engagement (Desantis, 2009; Nelson, 2008.) Both authors only presented methods, not results indicating the effectiveness of their methods. However, they used methods utilizing the suggestions from researchers like Scharman (1992), Robbins and Roy (2007), and Hedegaard (1996). Desantis (2009) gave the students fossils and data about them such as stratigraphic information and radioactive dating data and had them determine the age of the fossil. Nelson agreed regarding the importance of teaching about fossils, stratigraphy, and basic geology. Desantis also included several lessons on classification followed by cladograms, finishing with games that modeled insect evolution. Only then was the word evolution used. From that day forward, the word evolution was used regularly. Nelson (2008) did not avoid the word evolution but did seek to bridge the commonly held belief that religion and evolution were mutually exclusive. Emphasis was also placed on evaluating hypotheses using fair tests and logic. Within evolution Nelson advocated showing how organisms contrived their parts into effective but imperfect adaptations. The religious view of perfect organisms designed by God does not fit the observations.

Pew Research (2005) shows that evolution is accepted by about half the population of the United States, despite acceptance by the scientific community. This correlates with a low education level (Lac & Himelfarb, 2010) and fundamentalist religious beliefs (Miller & Okamoto, 2006). Researchers found that beliefs in origins are strong, but somewhat malleable (Chinsam & Plaganyi, 2007). The most successful curricula in increasing understanding and acceptance of evolution was focused on inquiry and the NOS (Sandoval & Morrison, 2003) and removing misconceptions through activities (Robbins & Roy, 2007). Desantis (2009) and Nelson (2008) outlined more detailed and additional methods based on previous research of others.

METHODOLOGY

Starting in mid-August students in grades seven and eight participated daily in a three-week unit focused on the nature of science (NOS) and inquiry. The nature of science was incorporated into all units for the next ten weeks. Next the students participated in a two-week introduction

to the study of evolution that used games as models of the process of natural selection but without using the word *evolution*. The students then participated in a three-week long traditional evolution unit. Finally, the seventh grade students completed a three-week unit, Life Through Time, which simulated the evolution of life on Earth. The

Research Questions	Data Source				
	1	2	3	4	5
Understanding evolution	Pre-test	Post-test	Formal Interview	Zingy Assessment	Evolution Classroom Test
Understanding NOS	Pre-test	Post-test	Formal Interview	NOS Classroom Test	
Acceptance of evolution	Pre-test	Post-test	Formal Interview		

project addressed student understanding of evolution, their understanding of the nature of science (NOS), and their acceptance of evolution using multiple data collection strategies (Table 1).

Table 1
Triangulation Matrix

The initial data gathering occurred during the first week of school when the students in grades seven and eight took The Evolution/NOS Pre-test (Pre-test) that measured their understanding of inquiry, experimentation, and the general nature of science (Appendix A). Since evolution can be a divisive and emotional topic, the Pre-test was administered two months before the evolution unit so as not to prejudice the participants. One of the major intents of the treatment was to gradually have the students learn about evolution without knowing that it was the topic, so the Pre-test was given long before the unit began.

The goal of the first part of the treatment was to teach experimentation and the nature of science. This nature of science unit began with lessons about controlled experiments. The students learned about independent and dependent variables, control groups, and variables held constant. They examined experiments and identified each of these parts, evaluated methods used in experiments, and designed their own experiments. For example, they were given imaginary experiments where Homer Simpson used coconut juice to attempt to remove shower slime and had to identify the variables and evaluate his scientific methods. Later they had to determine the cause of the rate of movement of a pendulum, isolating variables like length of string and mass.

The students also learned through lecture and examples they had previously studied (for example genetics, plate tectonics, atoms) that accepted theories are the core of science, offering the only explanations for our observations. Students learned that a theory is based on many facts, observations, and often experiments. Theories are considered true yet technically cannot be proven, because science is tentative and open to change based on new observations. In this unit students developed simple hypotheses as well as theories. The Nature of Science Classroom Assessment followed the NOS unit (Appendix B).

The NOS unit led into cells and genetics, which continued to utilize NOS methods.

A unit followed the genetics unit that would typically be called natural selection was renamed “Genetics in the Environment.” Without using words like *evolution*, *Darwin*, and *natural selection* that could upset the students who oppose evolution, the unit incorporated games that showed the basics of natural selection. The students knew from genetics that the individuals from the same population have different traits that they inherit from their parents and pass on to their offspring. Next they saw how these differing traits led to differing survival rates in the face of a changing environment. For example with a population of two different colored insects of the same species, a change in the environment could favor one over an another due to visibility to predators. The students modeled this with colored candy “insects” and two different colored backgrounds. They also played a game called Clipbird Island where two populations of birds with varying beaks were isolated from each other by a volcanic eruption. The eruption led to different mini-climates and therefore different food species for the birds. After several generations the most common beak phenotype of each population had changed in response to the best beak for the available food.

After these models were completed the class was exposed to the basic concepts of natural selection, one at a time. Even then the concepts were not labeled with any kind of evolutionary term. The students were asked after each concept if the idea made sense, if they could accept it. Once all key principles of natural selection were accepted, the list was titled, “Natural Selection, a Part of Evolution.” In the past students have been known to burst into tears at this point as they felt their faith and scientific logic met head-on. A discussion was conducted based on the handout about what evolution *is* and what it *is not*. After this day students learned the vocabulary and methods of evolution in more traditional ways for the next three weeks. Lessons were conducted about homologous parts, contrivances, vestigial parts, and adaptations. As a review during the last two days the students used Zingylearning.com, an online tool for science instruction and assessment. The Zingy Learning Assessment included four brief multiple-choice tests that assessed understanding of the process of natural selection (Appendix C). The Zingy Learning assessments could be taken many times, so the final percentage score also showed the number of times the test was taken. At the end of the main evolution unit the students took an Evolution Classroom Test that has been given for many years as a summative assessment (Appendix D).

After the NOS unit and both evolution units were complete, The Evolution/NOS Post-test, identical to the Pre-tests, was given. The NOS/Evolution Pre-test & Post-test used simple objective questions that indicate the child’s religious views, their family’s education level, and their acceptance of evolution. All questions were on a semantic differential with a -2 to +2 scale to gain quantitative analysis (strongly disagree = -2, disagree = -1, neutral = 0, agree = 1, and disagree = 2).

Formal interviews conducted with select individuals examined student acceptance of evolution, though it also offered data on conceptual understanding. Individuals were selected who understood the NOS and evolution reasonably well based on assessment scores. From that group five students were chosen who did not accept evolution initially and five who did. All formal interviews were recorded and notes were taken (Appendix E).

The final treatment, given to grade seven, was a Great Explorations in Math and Science (GEMS) unit called Life Through Time. The three week unit presented five time periods in Earth's history, each with a terrarium, aquarium, animal and plant samples similar to organisms from that time period, drawings of fossils, and drawings of sets of organisms from that time period. The unit did not teach the processes of evolution, instead it gave students a chance to apply their knowledge. The students completed five to eight pages of work, with three of them requiring the use of the words *homologous, contrivance, adaptation*, or *vestigial* in comparing various similar organisms drawn on the page. After this final treatment, The Evolution/NOS Post-test was given again.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

DATA AND ANALYSIS

Several themes emerged. First, student understanding of evolution and the Nature of Science (NOS) increased. Second, student understanding of the tentative NOS did not affect acceptance of evolution, though it did correlate with understanding evolution. In the area of acceptance of evolution, two themes exist. First, the data indicated the treatment caused less certainty in terms of accepting evolution. Second, after the Life Through Time unit students had greater acceptance of evolution.

The results of The Evolution/NOS Pre-test and Post-test comparison indicated that 74% of the students either improved their scores or retained good scores in NOS after treatment (N=38). Twenty-six percent had low scores (under 72%) and showed no gains (Figure 1). In the area of understanding evolution, 66% showed gains in their overall score and 26% had no change (Figure 2). Pre-treatment interviews showed that students had ideas such as, “The nature of science is looking into things and finding facts” that changed after treatment to, “Scientists make observations, develop a hypothesis, test it, and attempt to disprove the hypothesis.” Regarding evolution, students said after the treatment, “Over many years the populations with the better traits survive and those without them go extinct.”

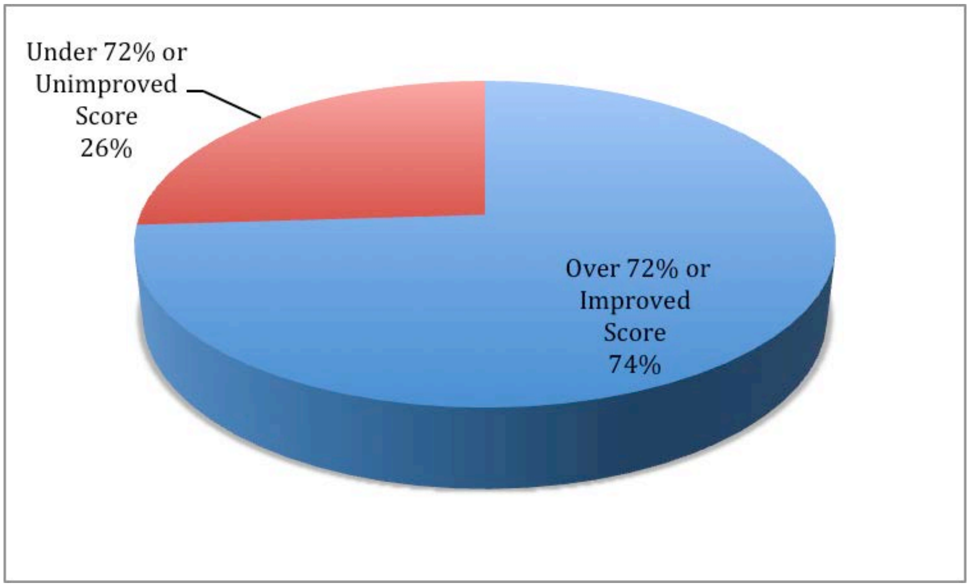

Figure 1. Post-test vs. Pre-test NOS Understanding Improvement, (*N*=38).

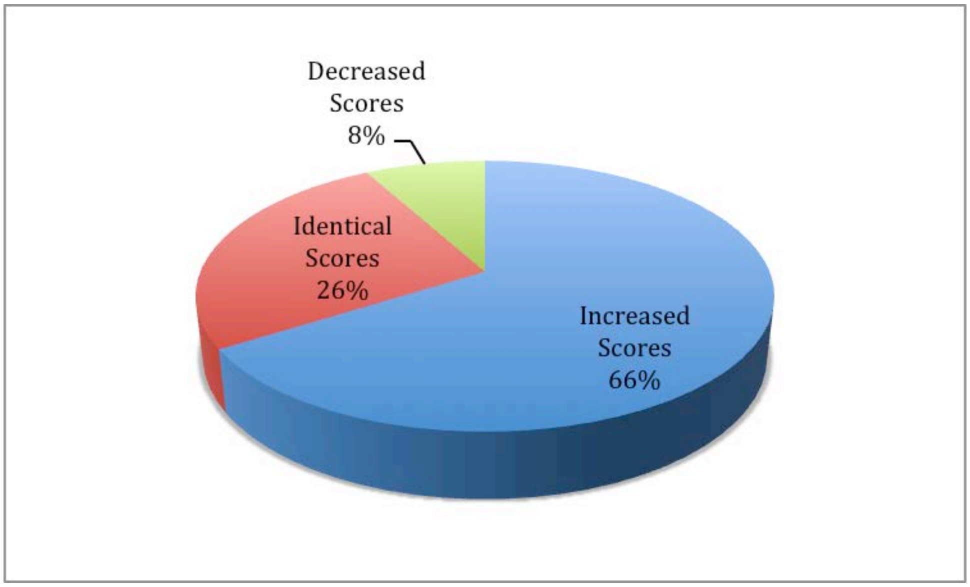

Figure 2. Post-test vs. Pre-test Evolution Understanding Improvement, (*N*=38).

Classroom summative test scores also showed gains on the evolution and NOS tests of 14% and 15% respectively when compared to classes from 2006-2010 (Figure 3). The Zingylearning.com assessment showed an average score of 88% in understanding of evolution.

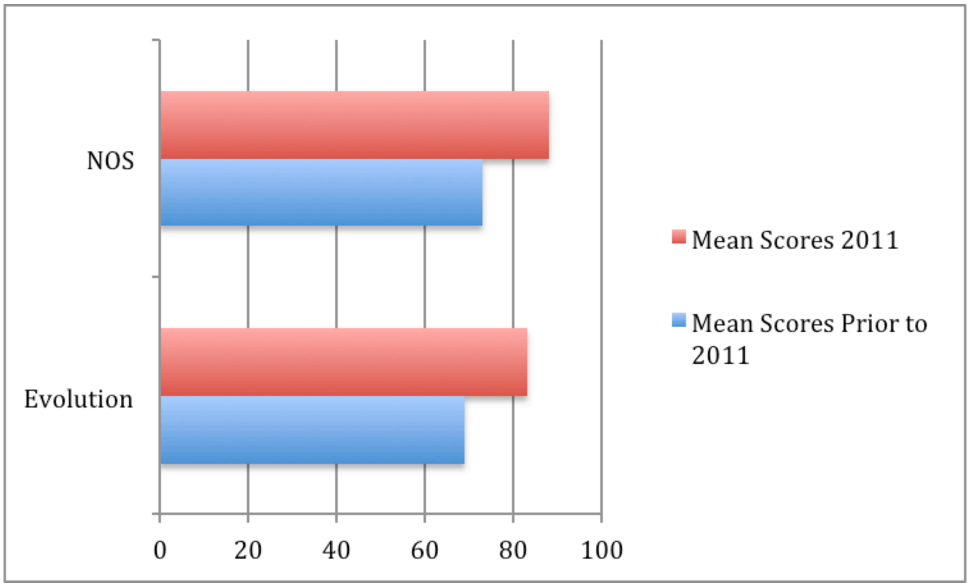

Figure 3. Classroom Test Scores, (*N*=38).

Regarding acceptance of evolution, prior to treatment 36% of the students accepted it and 29% rejected it, while the others were undecided. After treatment 31% accepted it and 20% rejected it. Unsure students went from 35% in August to 49% in November. This included students changing their views from *acceptance* to *unsure* as well as from *rejection* to *unsure* (Figures 4 and 5). Students originally stated, "Evolution could be true if the facts support it, but it is probably different for people and animals." One student made almost the exact same statement after treatment. One student began by saying, "I am unsure about evolution because I am of Christian faith and I believe that God created humans as they are, not as monkeys that evolved into people. But I do think that a lot of creatures changed, so maybe we didn't evolve? It's difficult." After treatment this student said he completely accepted evolution but "filled in any gaps in his understanding with beliefs." When asked why he changed his mind he stated it was the evidence.

Many students who did not make gains in knowledge rejected evolution prior to treatment. Of the students who did not increase their scores in understanding of the tentative NOS, 40% did not accept evolution on the Pre-test. In the area of understanding evolution, 60% of the students who did not make gains rejected evolution on the Pre-test.

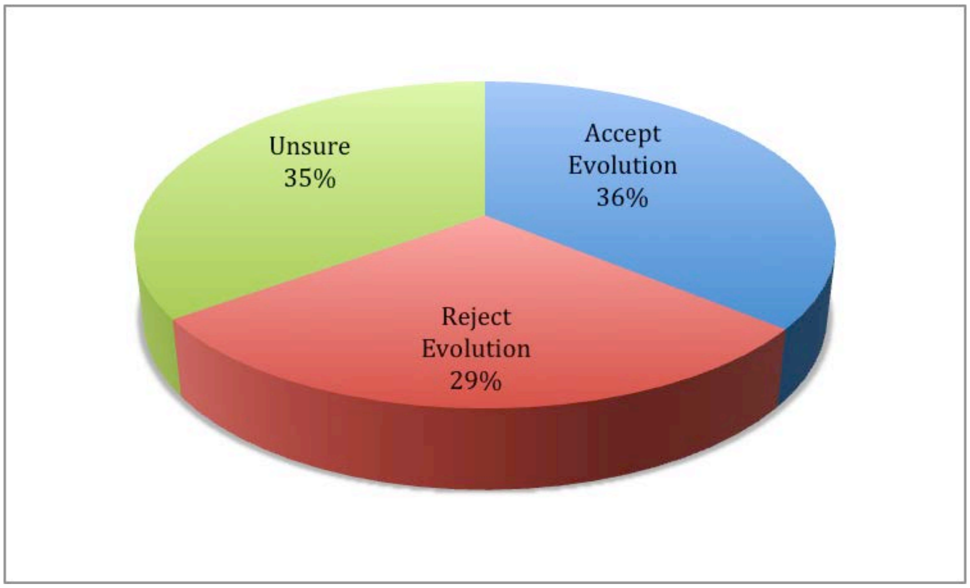

Figure 4. Pre-test Evolution Acceptance, (*N*=38).

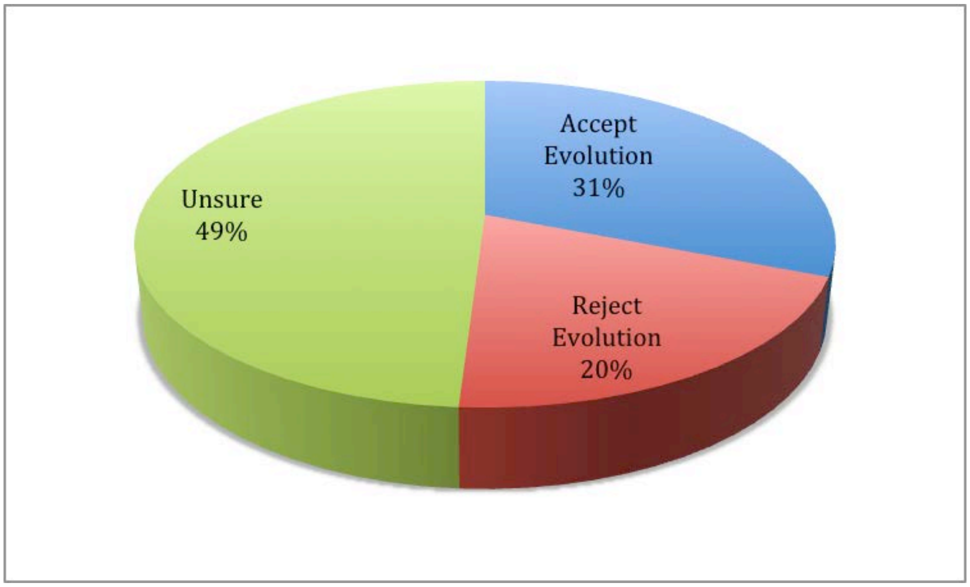

Figure 5. Post-test Evolution Acceptance, (*N*=38).

In comparing student understanding of the NOS with acceptance of evolution the scores for students with 100% on the The NOS/Evolution Post-test were within 2% of the scores of all students. Fourteen students who scored 100% on the *tentative NOS section* of their Post-tests were compared. Twenty-nine percent accepted evolution as factual and 21% did not. In the entire tested population, 31% accepted evolution and 20% rejected it and 49% were unsure (Figure 6).

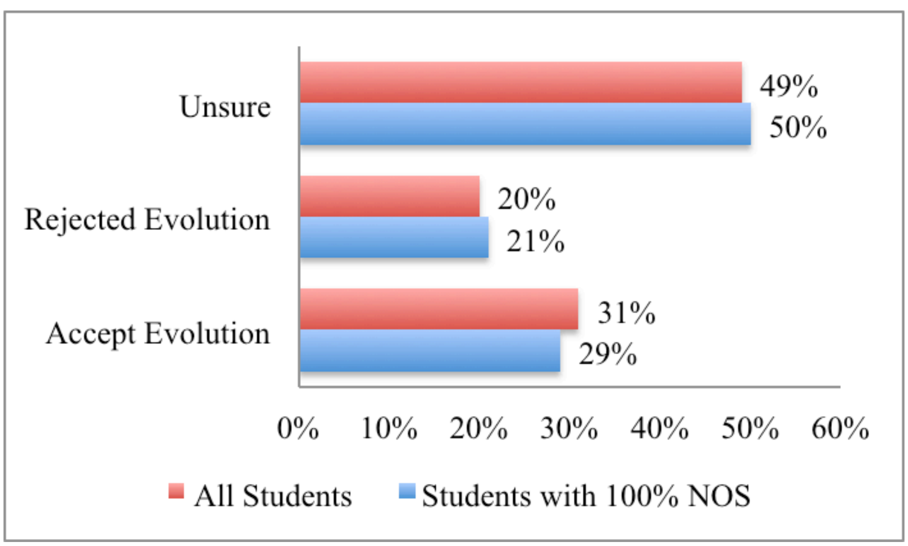

Figure 6. Post-test vs. Pre-test Evolution Acceptance Based on NOS, (*N*=38).

Similar comparisons were made using classroom tests and Zingy Learning scores for evolution. The ratio of students accepting, rejecting, and unsure of evolution was similar regardless of test score. The only exception was the Zingy Learning highest test score students, who showed the greatest acceptance of evolution (Figures 7 and 8).

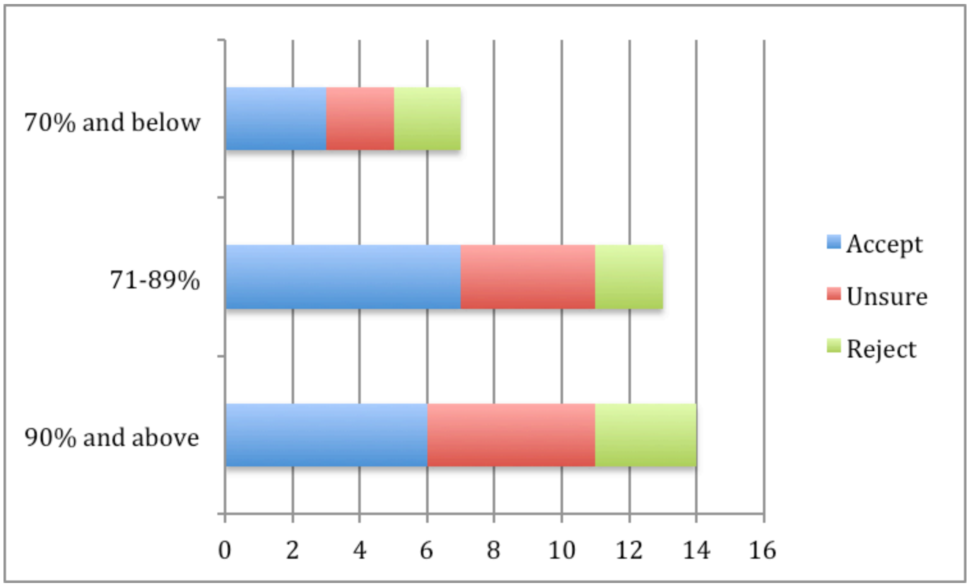

Figure 7. Acceptance of Evolution vs. Classroom Test Scores, (*N*=38).

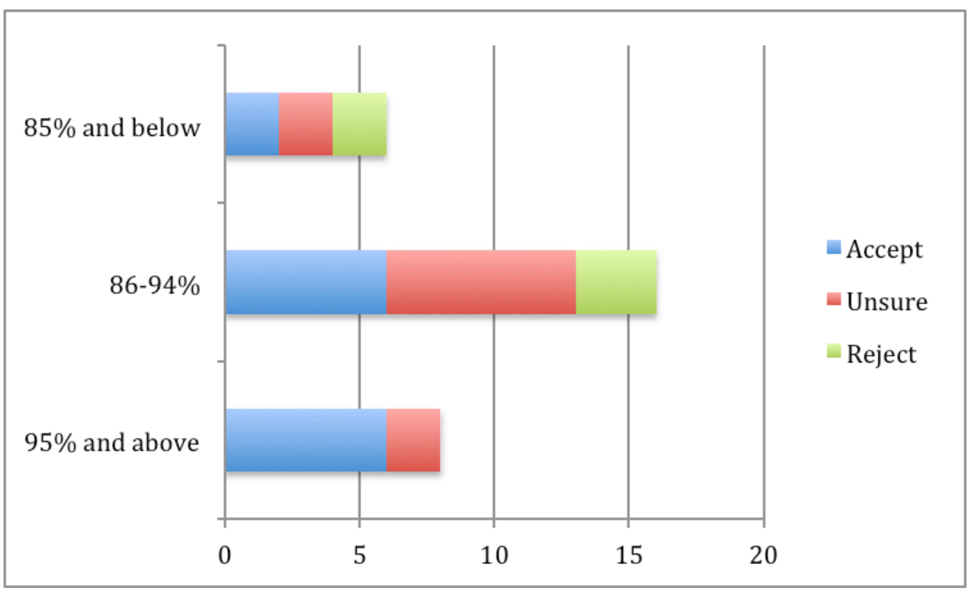

Figure 8. Acceptance of Evolution vs. Zingy Learning Scores, (*N*=38).

The students who participated in the final Life Through Time (LTT) unit increased their acceptance of evolution from an initial 31% to 60%, a greater change than the core evolution unit produced. One student started the year saying, “I really don't believe in evolution, lots of reasons. How could everything be so perfect? The Moon be perfect in size to affect the waves? The Sun be perfect in type of star and size? We be in the perfect spot in our Milky Way Galaxy?” After the core evolution unit, he still did not accept evolution, but after LTT he said, “I accept evolution for animals and plants. As the environment changes, so do the species. I struggle with accepting it for humans because…everything must match my faith, too.” It was common for students to report that “faith is needed for science just as much as for religion” or even “it takes more faith to believe that evolution happened than a super being.”

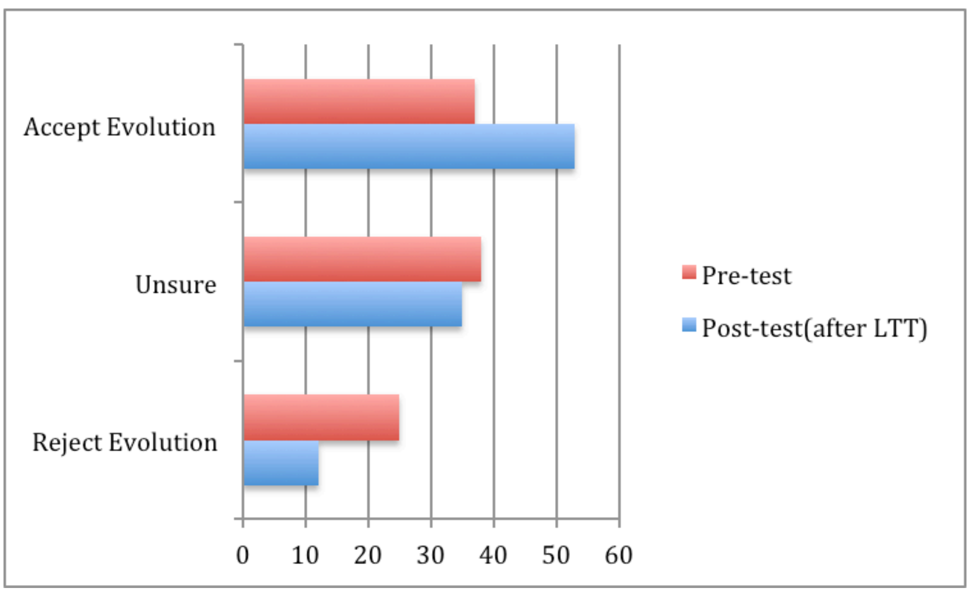

Figure 9. Acceptance of Evolution after LTT (final treatment), (*N*=17).

INTERPRETATION AND CONCLUSION

The project used two simultaneous approaches to teaching evolution, using strong nature of science instruction and initially teaching the concepts of evolution without the use of words like *evolution* and *natural selection*. The focus question and sub-questions asked for the effect on understanding and acceptance of evolution. The data and analysis show that students had greater understanding of evolution and the NOS and a high rate of acceptance.

The students showed understanding of evolution and the NOS that exceeded previous scores as measured by The Evolution/NOS Pre-test and Post-test (Appendix A), classroom tests, the Zingy Learning Assessment, and Formal Interview Questions. The analysis showed that students learned about variables, evaluated experiments done by others, and conducted experiments of their own. This process taught them the most basic tools of scientific experimentation. However, 26% of students either did not improve or remained at a low score of under 72%.

They also learned through direct instruction and lab experiences about the tentative nature of science and defined *theory* as an explanation of the natural world based on many observations and facts. The misconception that theories can be proved remains strong, however, and agrees with Eick (2000). Some students learned to understand how an explanation can be both accepted and tentative at the same time, preparing them to understand and evaluate the theory of evolution, in agreement with other studies (Sandoval and Morrison, 2003; Cavallo and McCall, 2008).

On a rational cognitive level, students appeared to gain understanding by gradually understanding the process of evolution without exposure to buzz words like *evolution* that have caused students to ignore instruction in the past. They learned how the genetic balance of a population would change due to environmental changes. A simple game that used candy as models for a population of insects with a 3:1 ratio of colors made it clear to the students that if the soil or leaf color changed that only those with background-matching colors would avoid predation. Other activities taught the students about the effect of isolating a population and how random events like mutations can result in non-random ways when directed by even a single rule. When the elements of natural selection were presented after this instruction, students indicated understanding and acceptance.

The analysis of acceptance of evolution showed a slight increase after the treatment described above. One might expect that after accepting all the ideas of the unnamed theory of evolution that students would accept it once named, but this was not the case. Studies have indicated that any education increased acceptance, but my results did not match that claim, at least not at this point (Lac and Himelfarb, 2010). The analysis better supports Lovely & Kondrick (2008), who found that college courses in evolution produced no significant change in beliefs. No clear relationship was found between understanding the NOS – including its tentative nature - and acceptance of evolution. The Classroom Test showed the same level of acceptance for students with low, medium, and high knowledge while the Zingy Learning Assessment showed that students with greater knowledge had greater acceptance. It's possible that this is because the Zingy Learning Assessment tests on a lower level with a multiple-choice format. The Classroom Test requires higher-level thinking and paragraph answers. A student that has been taught at home to reject evolution may have more trouble explaining how it works in a paragraph, but might get the correct answer on a multiple choice exam. Understanding and acceptance may be intricately linked so that discovering the antecedent is challenging. The main pattern that emerged was one of confusion; analysis showed an increase in students who were unsure if they accepted evolution. So while the students understood both science and evolution better, they did not change their acceptance level. Some of those who rejected it before were now unsure, but about as many who had accepted it previously were now also unsure.

The last phase of treatment was not expected to change understanding or acceptance, but it actually had a tremendous effect on acceptance. After the students completed the Life Through Time simulation of changes in Earth from early life to today, student acceptance increased. The analysis did not bring forth a reason for this, but it may have been the repeated exposure to the process of change over time. The students discussed the changes, examined drawings of fossils, and used the language of evolution daily. They saw dioramas change with time, adding a visual component to their past experiences. Perhaps they had time to see that it made sense. They may have moved from understanding the concept to seeing it in action in Earth's history, or it may have more to do with the many conversations they had as they moved from station to station, examining evidence. It is also possible the change is due to my not attacking their beliefs, instead allowing religious views to exist alongside evolution (Scharman and Harris, 1992). In the end, students in our conservative area accepted evolution at a higher rate than the national average (Pew Research, 2005).

VALUE

The experience of developing and conducting the project has led to three new approaches to teaching. The first is a more reflective approach to teaching in general. Since beginning this project I have started regularly using assessments to guide my practice in more formal ways. I created three surveys designed to draw out student opinions and knowledge in several areas and shared them with middle school staff to offer a chance for reflection and change. My role is Middle School Coordinator as well as teacher, but in the past I offered just my own judgment and reasoning. Now I am sharing objective data that we can analyze together.

All of my surveys and many of my summative assessments are conducted online through Google Docs (for surveys) and Clasmarker.com (for classroom assessments) because this allows for easy line-item analysis, transfer into Excel for simple statistical analysis, and digital storage for future comparisons. I see this as a natural extension of the cumulative assessments I have used for many years. I am measuring student learning in many ways and integrating that learning into my long-term lessons as well as my immediate teaching.

I also discovered that my NOS instruction is relatively strong in terms of understanding variables but weak in terms of understanding the basic fabric of the NOS, especially its tentative yet solid nature. Although understanding the tentative NOS did emerge as an important factor, I want to investigate this further. Overall it does not appear that very many students understood this aspect of the NOS. I am field testing a unit called Science Surprises created by the Evolution and the Nature of Science Institutes **(**ENSI) team that developed many effective lessons I currently use for the NOS.

It combines hands-on lessons I have used before with new textual material. Science Surprises has the potential to address the tentative NOS. I will continue to seek methods and lessons in this area and to assess their usefulness in measurable ways. It is clear to me that in some units I do not integrate the NOS well and I will comb through each unit to ensure it continues to use experiments with variables, justification for theories, and indications that although the explanations are well-accepted. They are still subject to change with new information and tools.

Since students learned effectively about evolution, I will continue to use the inductive method, avoiding the use of terms that may be off-putting to some students. Regardless of the measurable effect on acceptance, this seems to be a logical, inquiry-based approach.

Finally I know that the Life Through Time unit in addition to my main evolution unit increases acceptance of evolution. I have pondered a question I have received from many people: Is it wise or even ethical to attempt to change a learner's beliefs? If a learner believes the Earth is the center of the universe, do I try to change that belief? If the learner believes that life arises from rotting meat or that Earth's plates are static, do I accept that as their belief? Some beliefs are misconceptions about natural processes subject to scientific investigation, and students need to recognize that. There is value in students accepting that life has changed over time due to the process of natural selection. Teaching the Life Through Time unit reduces many misconceptions about evolution, so I plan to use it every year. Since it is possible that the reason for the increased acceptance is due to increased time the students are exposed to evolution, I am also open to new and better units that teach the way Earth's living things have changed over time.

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APPENDICES

APPENDIX A

PRE-TEST/POST-TEST

1. What is your first name? *
2. What is your last name? *
3. What grade are you in? *
Choose one answer
7th
8th

4. What variable is the one the scientist chooses so it can be tested and understood better? *
Choose only one answer.
Dependent
Independent
Control
Analysis

5. Which variable is measured at the end of the experiment? *
Choose only one answer
Dependent
Independent
Control
Analysis

6. Why is a control used in a good experiment? *
Choose one answer
For graphing purposes only
So the experiment can be contained in a logical system
For comparison with the effects of the independent variable
To keep the experiment from becoming too crazy

7. A student wants to find out if Bleach X or Bleach Y is better at removing stains. She plans to use two white shirts, stain each with mustard, and then wash each of them using bleach. She can change the size of the stain and the amount of bleach added. Which two tests should the student set up? *
Only choose one answer. Each answer already has two tests in it.
Large stain on one shirt with one cup of Bleach X. Small stain on the other shirt with one cup of Bleach Y.
Large stain on one shirt with two cups of Bleach X. Small stain on the other shirt with Bleach Y.
Small stain on one shirt with two cups of Bleach X. Small stain on the other shirt with two cups of Bleach Y.
Small stain on one shirt with one cup of Bleach X. Small stain on the other shirt with one cup of Bleach Y.

8. A swim team thinks that the type of swimsuit worn affects the speed of the

swimmer. They decide to test different suits. They split the team into two equal groups. The two groups wear different kinds of suits, but the same kind of swim cap. Why is it important that they wear the same kind of cap? *

Choose one answer.

By wearing the same kind of caps they can learn about the effect of the suits AND the caps.

By wearing the same kind of caps they can determine the effect of the caps.

If they do not wear the same kind of caps they cannot learn about the effect of the suits.

It is NOT important to wear the same kind of caps because they are not testing caps.

9. Which of the following best describes a theory? *

Choose one answer

An educated guess

A hypothesis about processes in the natural world

An idea that cannot be proven and is sometimes not true

An explanation about nature that is well supported but open to change.

10. Which statement best describes science? *

Choose only one answer

Science produces absolute truth that never changes

Science is a bunch of facts

Science discovers truth, but it can still change

Science is complicated, so it cannot be relied on for truth

11. According to science, what kinds of things evolve? *

Choose ALL correct answers

Non-living things

Plants

Animals

Humans

12. According to science, do individual animals evolve or do populations? *

Choose one answer

Individuals

Populations

Both

Neither

13. Could individuals of a species look different today than individuals of the same species did long ago? Why or why not? *

Yes. All individuals change randomly and pass those changes on to their offspring.

Yes. A few individuals can change a little and pass those changes on to their offspring.

Yes. Some individuals are more likely to survive and pass their traits on to their offspring.

No. Species do not change even after many generations, so individuals of the same species would not look different.

14. According to the theory of natural selection, what is likely to happen to a population when a change occurs in its environment (for example, the amount of rainfall decreases or the temperature increases)? *

Choose one answer

All of the individuals would try to develop new traits so that they could survive.

The individuals that have traits better suited to the changed environment would be more likely to survive and reproduce than those with less suitable traits.

Most of the individuals would live, but a few would die

Because all individuals of the same species have the same traits, they would either all survive or all die.

15. According to the theory of natural selection, what would happen to a species of lizards when a new predator is introduced into the environment where the lizards live? *

The lizards with good traits would survive and reproduce while the lizards with weaker traits might not.

All of the lizards would try to develop new physical traits to avoid the new predator.

All the lizards would die due to the advantages of the new predator.

Since all the lizards have the same traits, either all would die or all would survive.

16. In your opinion, is evolution true? *

Choose one answer

Yes

No

Unsure

17. In your opinion, is there a God? *

Choose one answer

Yes

No

Unsure

18. Is it possible to accept religion and evolution? *

Choose one answer

Yes

No

Unsure

19. What is the highest level of education of either of your parents? In other words, use the parent with the most education. *
Choose one answer

Did not complete HS
Completed HS, but did not go to college
Some college, but not enough for a 4 year degree
Earned four-year college degree (Bachelors)
Earned an advanced degree (masters or PhD)
Not sure

20. How long have you attended North Woods Discovery School? *

Less than one year
1 year
2 years
3 years
4 years
5 years
6 years
7 years
8 years

21. Is there anything you would like to add?

APPENDIX B

NATURE OF SCIENCE CLASSROOM ASSESSEMENT

Use this paragraph for the next questions:

Squidward loves playing his clarinet and believes it attracts more jellyfish than any other instrument he has played. In order to test his hypothesis, Squidward played a song on his clarinet for a total of 5 minutes and counted the number of jellyfish he saw in his front yard. He played the song a total of 3 times on his clarinet and repeated the experiment using a flute and a guitar. He also recorded the number of jellyfish he observed when he was not playing an instrument.

1. What is the independent variable?

2. What is the dependent variable?

3. What variables might be good to keep the same for all the instrument experiments?

Use this problem statement for the next questions:

Smithers thinks that a special juice will increase the productivity of workers. He creates two groups of 50 workers each and assigns each group the same task (in this case, they're supposed to staple a set of papers). Group A is given the special juice to drink while they work. Group B is not given the special juice. After an hour, Smithers counts how many stacks of papers each group has made. Group A made 1,587 stacks, Group B made 2,113 stacks.

4. What is the independent variable?

5. What is the dependent variable?

6. What would your conclusion be?

Label each of the following statements about <u>theories</u> with TRUE or FALSE.

7. ___________Theories are educated guesses
8. ___________Theories explain something in the natural world
9. ___________Theories are based on many facts and observations
10. ___________Theories are often not true
11. ___________Theories cannot be proven
12. ___________It's important not to measure the dependent variable

13. ___________We compare the results to the control
14. ___________A really good experiment has 2 or 3 excellent independent variables
15. ___________ A hypothesis is a prediction based on background research.

Use this question for the following two questions

"Does the temperature a cup of water affect how fast sugar dissolves in it?"

16. What will be the independent variable?
17. What will be the dependent variable?

Use this problem statement for the next three questions:

To determine the effect of time of day on the time it takes a hamster to negotiate a maze, Greg gets 100 hamsters and divides them into 4 groups. He makes 4 mazes, one for each group, each a different type of maze.

Group	***Maze***	***Time of Day***	***Ave. Speed***
A	*spiral*	*10 am*	*45 seconds*
B	*T-shaped*	*Noon*	*50 seconds*
C	*Zig-zag*	*4 pm*	*80 seconds*
D	*Straight line*	*Midnight*	*30 seconds*

18. What is wrong with the independent variable?
19. What is the dependent variable?
20. What would your conclusion be?

APPENDIX C

ZINGY ASSESSMENT QUESTIONS

Q7.1
Evolution (changing species)

1) Two organisms are able to produce fertile children. This is proof that they:

- A) have identical appearance
- B) belong to the same sex
- C) contain identical DNA
- D) belong to the same species

2) Which of the following is correct?

- A) All species evolved from a common ancestor
- B) All species contain identical DNA
- C) The first living organisms contained a nucleus
- D) The first multi-cellular organisms evolved on land

3) Of all the species that have ever existed on earth, most:

- A) could fly
- B) turned into fossils
- C) are now alive
- D) are extinct

Q7.2
Natural selection

1) Charles Darwin concluded that the different species of finches on the Galápagos Islands:

- A) ate the same food
- B) were identical to finch species in mainland South America
- C) had identical DNA
- D) evolved from one ancestral South American species

2) According to the theory of evolution:

- A) the best adapted individuals survive but do not have children
- B) the best adapted individuals survive and have children
- C) the strongest individuals survive but do not have children
- D) the strongest individuals survive and have children

3) What causes species to evolve?

- A) Ability to have children
- B) A changing environment
- C) An increasing number of children
- D) Inability to have children

4) A new species may emerge due to:

- A) a slow change in traits over many generations
- B) a change in traits over the lifetime of an organism
- C) a rapid change in traits during the first years of life of an organism
- D) a rapid change in traits during the last years of life of an organism

5) The diversity of species on earth is the result of:

- A) billions of years of natural selection
- B) increased reproduction of organisms
- C) decreased reproduction of organisms
- D) several days of natural selection

6) When a species evolves into several different species, the original species:

- A) will quickly become extinct
- B) may continue to exist
- C) will become extinct immediately
- D) will slowly become extinct

7) Which of the following is correct?

- A) Closely related species did not evolve from a common ancestor
- B) Evolution is generally a rapid process
- C) The living world stays stagnant
- D) Natural selection is a mechanism of evolution

Q7.3
Extinction

1) Of all the species that ever existed:

- A) 1% are now extinct
- B) half are now extinct
- C) 10% are now extinct
- D) 99% are now extinct

2) Species with _____ are of a particularly high risk of extinction

- A) high genetic variability
- B) low fertility rates
- C) high fertility rates
- D) little genetic variability

3) Species that _____ are of a particularly high risk of extinction

- A) are large
- B) can adapt to their environments
- C) cannot adapt to their environment
- D) are small

4) During the industrial revolution, the English peppered moth did not become extinct because:

- A) it evolved black wings
- B) it evolved into a weaker species
- C) it evolved into a stronger species
- D) it evolved white wings

5) The island fox of the Channel islands of California is in danger of extinction due to:

- A) loss of habitat
- B) a new predator
- C) little genetic variability
- D) increased competition

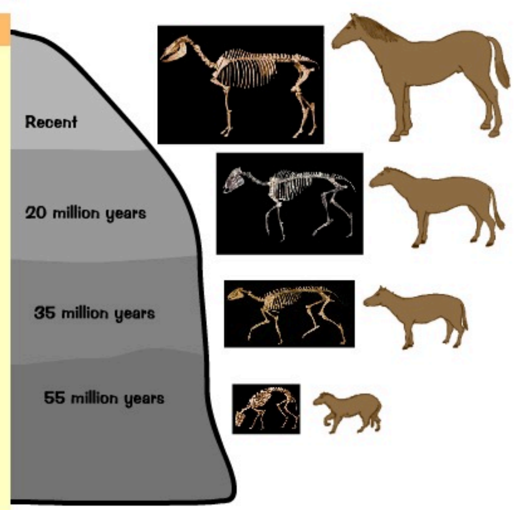
6) The Tasmanian Devil of Australia is in danger of extinction due to:

- A) a new predator
- B) increased competition
- C) loss of habitat
- D) disease

Q7.4
Evidence for evolution

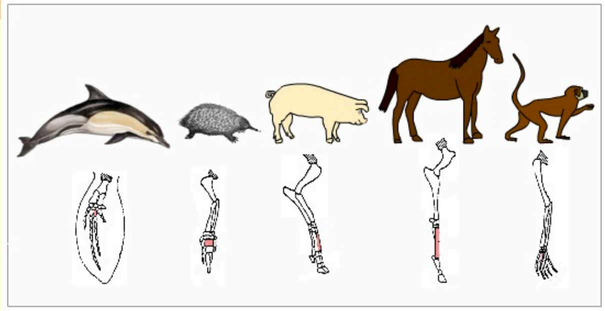
1) What type of evidence of evolution is depicted in the image?

- A) Molecular
- B) Comparative anatomy
- C) Geographical distribution
- D) Fossils



2) What type of evidence of evolution is depicted in the image?

- A) Fossils
- B) Comparative anatomy
- C) Molecular
- D) Geographical distribution



APPENDIX D

EVOLUTION CLASSROOM TEST

Fill in the blanks for the five main points in evolution (5 points per question)

1. Every population shows ________________variation ("Not all the individuals are alike")
2. There is differential reproduction (Some will __________ and ________________, and some will die and _______ _________________)
3. Certain ______________ ______________ caused the individuals to survive.
4. These traits are passed on to _________ ________________
5. These new traits become part of the ________________ and can make a new ______________

Match the definition and examples with the words. Answers may be used more than once or not at all. (5 points per question)

ANSWERS
a. Homologous
b. Contrivance
c. Vestigial
d. Adaptation

6. _____A structure that is useless in the current living thing, but once had a use. It is often quite small.
7. _____The tiny hip bones in whales
8. _____A structure that is used for an odd purpose. It works, but not very well.
9. _____A panda's thumb, the human larynx (voice box), and the gliding flaps of a flying squirrel.
10. _____The thumb of a monkey, the eyes of a squid, and the tail of a whale.
11. _____A structure that used to be a contrivance, but has evolved to work quite well.
12. _____The wing ("flipper") of a penguin that allows it to swim, but not as well as a fish.
13. _____The foot of a horse and the foot of a raccoon.

Multiple Choice (5 points per question)

14. ___________ According to science, what kinds of things do NOT evolve?
    a) Non-living things b) Plants Animals c) Humans d) Rocks
15. ___________According to science, do individual animals evolve or do populations?
    A) Individuals B) Populations C) Both D) Neither

Short Answer (5 points per question)

16. How do the fossils of whales provide evidence that whales have evolved over millions of years? Support your explanation with several evolving structures in the whale.

17. Imagine a population of birds living on an island. They are adapted to eat hard dry seeds. According to the theory of natural selection, how does the population evolve if the climate changed so there were very few dry seeds and lots of tiny

insects instead?

18. According to the theory of natural selection, how might a species of species of frogs evolve when a new predator is introduced into the environment where the frogs live?

APPENDIX E

FORMAL INTERVIEW QUESTIONS

1. Discuss the nature of science. Include ways scientists discover new things and how they determine if a theory can be accepted.
2. According to science, how does evolution work? Explain the causes of evolution and the process of species changing over time. In other words, how does a population change from one species into another?
3. Discuss your opinion about evolution. Is it true? Why or why not? Please include your thoughts on all living things, not just humans.
4. Do you see any conflict between faith and evolution? Please explain. If you see a conflict, can it be resolved?
5. Is there anything else you want me to know?