DEVELOPING STUDENTS' UNDERSTANDING OF EVOLUTION IN AN INQUIRY-BASED VERSUS A TRADITIONAL SCIENCE CLASSROOM

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Research studies over the past 30 years have found that individuals have a limited understanding of the theory of evolution and the mechanisms involved in species change. One possible avenue of improvement has been the use of alternative instructional methods, such as inquiry-based activities and teaching about nature of science. Using recommendations from research, this study integrated nature of science, evolution, and inquiry-based instruction to discern its impact on student understanding of evolution. An instructional unit was developed with a community college instructor and carried out in two introductory biology classes with a total of 38 participants. One class was taught using inquiry-based methods, with an integrated approach to nature of science and evolution, while the other was not. Data collection included student and instructor interviews, surveys, pre and post assessments, classroom observations, and student work products. The number of students holding accurate conceptions of the nature of science in the inquiry class was higher for all the reported categories on the posttest. Despite less direct exposure to evolution concepts in lecture, the inquiry class had higher means on two separate posttests for evolution. The traditional class performed better on the pretests yet the inquiry class had higher posttest scores on both measures. Students in the inquiry class held a positive view of the inquiry-based methods and they cited them as a reason for their understanding of evolution. Individuals indicated that the integration of nature of science and evolution allowed them to grasp the concepts of evolution better than if evolution was taught alone. A creationist student became more accepting of evolution and also improved her understanding of evolution. Another student interviewed four years after the intervention remembered only the inquiry-based unit and was able to still use examples from class to explain natural selection. The instructor had a positive view of many of the instructional interventions and integrated them into her course after the study. Four years after the study she has continued to use inquiry-based methods. A number of implications for evolution instruction and future research areas are explored.

BIOGRAPHICAL SKETCH

Robert Humphrey is a lifetime resident of New York State who attended the SUNY College of Environmental Science and Forestry where he earned his Bachelor's of Science degree in environmental and forest biology. During his time there he also participated in the concurrent degree program at Syracuse University and completed his New York State science teacher certification. While teaching at the Broome-Tioga BOCES Career and Technical High School he attended SUNY Cortland and finished his Master's degree in Secondary Science Education. After moving to the Syracuse area and teaching at Henninger High School he decided to pursue his Ph.D. in science education at Cornell University. At Cornell University he served as a graduate research assistant and a graduate teaching assistant. He participated in a research study of a preservice teacher's attempts at teaching evolution which helped him develop his dissertation research. While completing his graduate work he also served as an adjunct instructor at Cayuga Community College. He has presented research in student understanding of evolution at the Association for Science Teacher Education and the National Association for Research in Science Teaching national conferences. He is currently an Assistant Professor at Cayuga Community College where he teaches a range of courses in biology.

This is dedicated to my lovely wife, Joel, whose support and love allowed me to complete this.

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CHAPTER 1

INTRODUCTION

One of the most, if not *the* most, contentious issues in science classes across the world continues to be the topic of evolution. The science and science education communities both value an understanding of evolution, and have made sure to place it in numerous policy documents – including *Science for all Americans* (American Association for the Advancement of Science[AAAS], 1989), *Benchmarks for Science Literacy* (AAAS, 1993), and the *National Science Education Standards* (National Research Council, 1996). The National Academy of Sciences, the American Association for the Advancement of Science and the National Science Teachers Association (NSTA) all issued position statements that advocate instruction in evolution. Despite the overwhelming support for evolution in the science and science education communities, the American public has difficulty both believing in and understanding it.

Gallup polls over the past 30 years have consistently shown that only about 10% of the American population believes in a naturalistic form of human evolution, approximately 45% believe in theistic origins (humans were placed here no more than 10,000 years ago), and about 45% believe in theistic evolution (evolution proceeds with God guiding it) (Newport, 2007). A report by Miller, Scott, and Okamoto (2006) summarized public acceptance of evolution in 34 countries. Based on their results, the United States ranked 33rd, with only about 40% of individuals believing evolution is true and about 50% of respondents indicating that evolution is false. Although many Americans have opinions on the subject of evolution, individuals may not fully understand the topic. A survey conducted by the People for the American Way Foundation in 2000 demonstrated that many individuals were unclear about what the theory of evolution really is. Although almost all of those surveyed had heard of it (about 95%), only 50% said they were very familiar with it. In addition, about 30% of individuals provided an incorrect definition of evolution. Many Americans are also unclear about evolution's scientific status. Most are not sure that the theory, as they understand it, is fully accurate or proven (Moore, Froehle, Kiernan, & Greenwald, 2006; People for the American Way Foundation, 2000). The lack of acceptance, belief, and understanding appear to have multiple causes.

Changing the public's understanding of evolution requires that we start early in people's lives – especially in science courses. This is mainly due to the difficulty in changing the belief systems of adults (Pajares, 1992). We must consider the goals of science education as it pertains to evolution – is it acceptance, understanding, belief, knowledge, or some combination? Distinguishing between these constructs is vital to the approach that we take in the science education community. Unfortunately for many researchers, the terms acceptance and belief are often synonymous in evolution research studies and are reported as acceptance in one study and belief in another (McKeachie, Lin, & Strayer, 2002; Sinatra, Southerland, McConaughy, & Demastes, 2003).

For the purpose of this study we must identify and differentiate between the predominate terminology when discussing evolution. These major terms include: knowledge, beliefs, understanding, and acceptance.

KNOWLEDGE. A traditional definition of knowledge is "justified true belief," indicating the relatedness of belief and knowledge (Steup, 2006).

BELIEFS. The attitude whenever an individual takes something to be the case or regard it as true. To believe something need not involve actively reflecting on it (Schwitzgebel, 2010). Philosophers identify belief as a propositional attitude, a mental state of having some stance, or opinion about a proposition or about the potential state of affairs in which that proposition is true

(Schwitzgebel, 2010). Beliefs may be generated without empirical evidence and are less rigid in their criteria than knowledge and acceptance (Allmon, 2011).

While belief and knowledge are related, they are not synonymous. According to Pajares (1992) "belief is based on evaluation and judgment; knowledge is based on objective fact" (p. 313). Southerland, Sinatra, and Matthews (2001) have indicated that some educational psychologists view knowledge as a large category, of which beliefs are just one segment. Noting the difficulty with defining belief, Hofer and Pintrich (1997) state that belief "is a particulary slippery term in the psychological literature" (p. 112). Southerland et al. (2001) declared that "establishing a clear distinction between knowledge and beliefs is complicated" since they appear to "have related effects on measures of comprehension, understanding and learning" (p.335). Smith and Siegel (2004) presented a continuum of nine factors that were used to distinguish between beliefs and knowledge in various research studies. On this continuum, beliefs were described as subjective, irrational, and personal; while knowledge was more likely to be objective, rational, and public.

UNDERSTANDING. The act or state of comprehending how it is that a particular proposition or conception operates and the linkages and connections among its constituent elements or aspects (Smith & Siegel, 2004). Understanding can be viewed as a deeper component than acceptance or knowledge (Allmon, 2011).

Although understanding may result in belief, beliefs do not always follow understanding (Smith & Siegel, 2004). Students may be able to reproduce the information, but it does not mean that a new belief structure has been created. Students might know of something, but will not understand it. Students can demonstrate understanding of a concept or idea if they can "apply that understanding appropriately in both academic and non-academic settings (such as problem solving situations)" (Smith & Siegel, 2004, p. 562).

ACCEPTANCE. Allmon (2011) presented a definition of acceptance that is appropriate for this study, where acceptance may be considered a subset of beliefs that relies on empirical data for support, while beliefs do not. Smith (2010) points out that scientists use the term belief in a vastly different way from that of the everyday person "whenever a scientist uses the term belief in conversation, clearly he is referring to something that is well grounded in evidence (p. 592). Smith (2010) continues by introducing the concept of acceptance "when scientists or science educators say that they "believe in evolution," they mean to convey that they accept modern evolutionary theory on the basis of current evidence as the best explanation of life forms" (p.593).

One of the most significant challenges in reporting evolution education research study results is that acceptance and belief are often used interchangeably. On a personal note, as a science educator I have never been asked if I accept evolution by my students, but I have been asked every time I teach the topic if I believe in evolution. While some researchers support a movement away from the use of the terminology belief when discussing evolution, it is still used commonly by students (Smith, 2010). The issue is further confused by reporting of research studies that treat the terminology of acceptance and belief as synonymous. The use of acceptance implies that one is using empirical evidence to support a decision, not making a simple leap of faith, hence researchers support of acceptance as opposed to belief (Smith, 2010; Williams, 2009). Smith (2010) makes a very good point that distinguishing between acceptance and belief is vital to understanding nature of science.

Using the previous definitions as a guiding framework, the most desirable goals for evolution education are understanding and acceptance. Knowledge, as the construct is defined, does not appear to be sufficient as a goal. Change in beliefs would be a very desirable goal, however, beliefs are highly resistant to change (Pajares, 1992). When we discuss beliefs in America in the context of evolution, we are commonly discussing religious beliefs. A perceived choice between belief sets for individuals. Researchers commonly find a negative impact of religious beliefs on acceptance of evolution (Dagher & BouJaoude,1997).

Demastes, Good, and Peebles (1995a) found that conceptual change in evolution was not linked with a change in belief about evolution. Demastes et al. also indicated that it was not about the stated belief or disbelief in scientific concepts but rather the disturbance or conflict students felt. In Trani's (2004) survey of high school biology teachers he found that "teachers with extreme religious convictions scored nearly three standard-deviations below the mean on their acceptance of evolutionary theory, and more than two standard deviations below the mean on their understanding of evolution and the nature of science"(p. 424). Individuals with more conservative religious beliefs have been found to score lower on evolution assessments than students with more moderate or liberal religious beliefs (Moore, Brooks, & Cotner, 2011). However, not all studies have demonstrated a negative association between religious beliefs and acceptance or understanding of evolution. Research by Winslow, Staver, and Scharmann (2011) discovered that religious individuals can accept evolution through a reconciliation process between evolution and their religion. This reconciliation process was influenced by exposure to mentors and role models who expressed religious faith but also accepted the theory of evolution.

Regardless of the type of beliefs, they can be highly resistant, and are thus a more difficult goal for change. While beliefs play some role in knowledge, the majority of people view them as overlapping but not identical (Smith & Siegel, 2004, p. 561). For the science education community, the ultimate goal related to evolution is both belief and understanding of it. However, the variety of difficulties related to belief and evolution probably make belief an unlikely goal. In the case of evolutionary theory, students' belief constructs have been demonstrated to have a strong influence on understanding and acceptance of the theory (Bishop & Anderson, 1990, Settlage, 1994; Sinatra et al. 2003). Deniz, Donnelly, and Yilmaz (2008) found a significant positive correlation between knowledge of evolution and acceptance of evolution. Exposure to more science courses (which can increase both knowledge and understanding) appears in some cases to increase student's agreement with a naturalistic explanation of evolution (Ladine, 2009). Gregory and Ellis (2009) and Paz-y-Mino and Espinosa (2009) have both identified a positive correlation between acceptance of evolution and understanding of evolution.

While understanding of evolution should be a focus for science educators, numerous research studies over the past 30 years have demonstrated that students and teachers do not fully understand evolutionary theory, even following instruction (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Deadman & Kelly, 1978; Engel Clough & Wood Robinson, 1985; Hallden, 1988; Zuzovsky, 1994). At most, 50% of students appear to understand evolutionary processes (Brumby, 1984; Bishop & Anderson, 1990; Greene, 1990; Demastes, Good, & Peebles, 1995a; Ferrari & Chi, 1998). These results are telling, and indicate that problems exist in our instructional practice.

According to the National Science Education Standards (National Research Council[NRC], 1996,2000) classroom instruction should be carried out to engage students in learning about the nature of science and science concepts through inquiry (National Research

Council, 1996, 2000). Besides the recommendations from national science education groups, researchers have provided evidence to support the use of inquiry-based activities in classrooms. Minner, Levy, and Century's 2010 review of inquiry-based research from 1984 to 2002 found a majority of studies demonstrated positive effects of inquiry-based instruction on content learning and retention. Research studies involving large student populations have found inquiry-based teaching to be effective in increasing student understanding of scientific concepts (Geier, Blumenfeld, Marx, Krajick, Fishman, Soloway, & Clay-Chambers, 2008; Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier, & Tal, 2004; Pine, Ashbacher, Roth, Jones, Mcphee, Martin, Phelps, Kyle, & Foley, 2006; Shaw & Nagashima, 2009; Turpin & Cage, 2004; Von Secker & Lissitiz, 1999). Support for inquiry-based techniques has also been bolstered by results from numerous comparison studies of inquiry based-and traditional classes or courses. These comparison studies support inquiry-based instruction as an effective tool in teaching a variety of science concepts (Lee, Linn, Varma, & Liu, 2010; Lyons, 2006; Mao & Chang, 1998; McCrathy, 2005; Ruhf, 2006; Thacker, Kim, Trefz, & Lea, 1994; Tretter & Jones, 2003; Wilson, Taylor, Kowalski, & Carlson, 2010). Inquiry-based approaches may be more effective than other approaches in reducing the knowledge gap between different groups of students (Cuevas, Lee, Hart, & Deaktor, 2005; Lee, Buxton, Lewis, & LeRoy, 2006; Lynch, Kuipers, Pyke, & Szesze, 2005; McCrathy, 2005; Shaw & Nagashima, 2009). Evolution education studies demonstrate support for alternative teaching strategies. Studies by Demastes, Settlage, and Good (1995b), Jensen and Finley (1996), Passmore and Stewart (2002), Beardsley (2004), Crawford et al. (2005), Robbins and Roy (2007), Nehm and Reilly (2007), Heitz, Cheetham, Capes, and Jeanne (2010) indicate that inquiry-based and non-traditional instructional techniques are effective in helping students' to understand evolution.

Many researchers exploring the teaching of evolution have argued for the inclusion of nature of science with evolutionary concepts (Scharmann & Harris, 1992; Smith, 2010). In 1998, the National Academy of Sciences (NAS) published *Teaching about evolution and the nature of science*, which presented inquiry-based teaching approaches for evolution and nature of science. This document stressed an integrated approach of using nature of science to help bolster students' understanding of evolution. Instructing students in aspects of NOS is touted as a way to achieve greater understanding of evolutionary theory (NAS, 1998). Relationships appear to exist with an understanding of science; those individuals who have a better understanding of nature of science appear to accept evolution at a higher rate than those that do not (Johnson & Peeples, 1987; Scharmann & Harris, 1992; Akyol, Tekkaya, Sungur, & Traynor, 2012). Both teacher's and students' views of science may play a role in the acceptance and understanding of evolution. Aguillard (1999) identified a correlation between teacher belief related to the scientific validity of evolution and emphasis on evolution education. Downie and Barron (2000) found that students they classified as rejecters of evolution were more skeptical and uncertain in regards to science in general. A positive relationship understanding of nature of science and acceptance of evolution has been demonstrated by at least two separate studies (Rutledge & Warden, 2000; Rutledge & Mitchell, 2002; Akyol, Tekkaya, Sungur, & Traynor, 2012). Sinatra, Southerland, McConaughy, and Demastes (2003) found that epistemological beliefs were linked to students' acceptance of human evolution. Cavallo and McCall (2008) examined beliefs about evolution and NOS and found a positive relationship between the two. Individuals who viewed science as more tentative were more likely to have a belief in evolution; the more fixed it was the less likely they espoused a belief in evolution . Hokayem and BouJaoude (2008), in examining how eleven junior and senior college biology students' perceived evolutionary theory, discovered a link between acceptance of evolution and how students viewed evidence. In this study, a critical component of whether a student accepted or rejected the theory of evolution hinged on the argument about the nature of the evidence. Lombrozo, Thanukos, and Weisberg (2008) discovered a significant correlation between understanding of NOS and acceptance of evolution; students with more complex views of theories were more accepting of evolution. Cho, Lankford, and Westcott (2011) found that students were less likely to experience conceptual change if they believed in fixed knowledge and if knowledge comes from authority. Akyol, Tekkaya, Sungur, and Traynor (2012) offer strong support for the current study since they found a more sophisticated view of nature of science was "associated with higher levels of both understanding and acceptance of the theory" of evolution (p.949).

Believing that an integrative approach to teaching about evolution is more appropriate to achieve student understanding, Crawford, Humphrey and Vaccaro (2007) investigated the interplay between the nature of science, inquiry, and high school students' understandings of evolution. In this study involving a preservice teacher, the researchers collaboratively designed an instructional unit that focused on nature of science, what counts as evidence, and the justification of data in context of an evolution unit. The preservice teacher had students formulating explanations from evidence, and carried out whole group discussions that emphasized scientists use evidence in their work to construct explanations of how organisms changed over time. The findings of the study indicate that students' understanding of evolution and natural selection were affected by the instructional approach. On a pretest, only 21% of the students expressed scientifically informed views of evolution and natural selection. Following instruction, however, this increased to 69% of students and was significantly higher than other research studies dealing with students' understanding of evolution. Since the research study did not involve a control group, it is difficult to determine whether it was the instructional approach, or some other factor. This research study helped to place the focus on the current study on a comparison of traditional and inquiry-based pedagogy. By designing a comparative study, the researcher hoped to make the case for using inquiry-based activities when learning about evolution.

Although some research studies have examined the impact of inquiry-based activities on understanding of evolution (Demastes, Settlage, and Good (1995b), Jensen and Finley (1996), Passmore and Stewart (2002), Beardsley (2004), Crawford et al. (2005), Robbins and Roy (2007), Nehm and Reilly (2007), Heitz, Cheetham, Capes, and Jeanne (2010)), this research study is unique in its approach. This is the first study that couples the topics of nature of science with evolution through inquiry-based activities to achieve greater understanding of the topic of evolution for students. Using the prior study (Crawford, Humphrey, Vaccaro, 2007), recommendations from numerous research studies, as well as national policy recommendations, this research study will integrate instruction in nature of science and evolution through inquiry-based instructional practices. The purpose of the proposed research study is to explore the relationships between understanding nature of science and understanding evolution, as well as the impact of inquiry-based pedagogy on developing in-depth understandings of evolutionary theory. Based on current research findings I designed a course that integrated inquiry-based approaches with NOS to see how these approaches would impact student understanding of evolution. I carried out a quasi-experimental research study that employed mixed methods approaches to identify whether or not inquiry and NOS helped students understand evolution. Two intact introductory biology classes in a community college served as the site of the research study. This study was conducted in a college setting due to a number of reasons. As Pajares

(1992) has indicated, the beliefs of adults are difficult to change. By choosing an adult student population, one in which the beliefs are most entrenched, I hope to demonstrate that an alternative instructional approach may elicit some amount of change in these beliefs. For many of these students it may be the last opportunity for a science educator to influence their understanding, acceptance, or belief in evolution.

RESEARCH QUESTIONS

The over-arching research question for this study is:

> What is the effect of using inquiry-based instruction versus a traditional approach in teaching about evolutionary theory on student understanding of evolutionary concepts?

Within this larger question the following will also be addressed:

a. How was the inquiry carried out (what was the nature of the instruction)?
b. What is the influence on students' views of nature of science?
c. What is the influence on students' understandings of evolutionary concepts?

CHAPTER 2

LITERATURE REVIEW

Research studies selected for this review addressed student and teacher understandings of evolution in a variety of contexts. A thorough examination of references cited in articles on evolution education provided the researcher with an expansive list of relevant material. The author attempted to present as thorough a review of all articles on evolution education as possible, yet some articles were not included because they did not deal with understandings of evolution or natural selection. Dissertations on evolution education research were not included since they are not as influential in the research community and because a large number of articles existed on the topic already.

School age students' understanding of evolution

Research investigating student understanding of evolutionary theory significantly increased during the 1970's, stemming mainly from the curriculum projects of the 1960's that focused on evolution as a central and unifying theme in biology. One of the first studies related to school-age understanding of evolution was implemented after these curriculum projects were carried out by Deadman and Kelly (1978). The focus of this research was primarily concerned with students' prior understanding of evolutionary theory. Eight boys between the ages of 11 and 14 served as a pilot study with unstructured interviews. The main study involved two interviews (one a year after the initial study) with 52 boys from four grade levels in secondary education. The students involved in the study had not received “any formal teaching on heredity or evolution” but they had just finished the “Nuffield O-level biology course” (p.8). The findings demonstrated that the boys were uncertain about why evolution occurred, with explanations falling into naturalistic (needs, wants, internal forces) or environmentalist – “associating changes in the animals with specific physical changes in the environment” (p.9). Adaptation proved to be a key concept in explaining the process of evolution expressed by almost all of the boys. In the majority of cases, it was related to a naturalistic view of evolution (animals adapting due to need). Another key element of evolution and natural selection, variation, was not indicated as a focus and seldom mentioned. The authors identified two major issues related to teaching and learning about evolution: naturalistic and Lamarckian interpretations of concepts by a number of students, and their inadequate understanding of probability.

Unfortunately this study was weakened by a number of elements. The first deals with the study population, all boys, which makes it difficult to generalize the findings to other research settings. The researchers also do not indicate how students views changed throughout the duration of the study, and the interview questions about evolution are not described. Despite these limitations, the research does start to provide a foundation for understanding about how students understand evolution.

Building on the major finding of Deadman and Kelly (1978), Engel Clough and Wood-Robinson (1985) looked at student understanding of biological adaptation. Eighty-four students between the ages of 12 and 16 were the focus of the study. Students were asked to describe how traits developed given situations with caterpillars (different colored organism were found on different colored trees) and the artic fox (the fox has a thick coat of fur and lives well at low temperatures). The results suggest that students find the term and concept of adaptation difficult. Many students explained adaptation in "teleological and anthropomorphic terms" (p.125). Teleological explanations refer to some purpose or grand design, with anthropomorphic referring to an "animal's needs or wants" (p. 126). In looking at the responses to the two tasks, many students offered no explanation for the caterpillar coloration. Only about 10% of the students gave scientifically acceptable explanations of how traits would evolve for both the tasks. Alternative explanations provided by the students indicated that they felt adaptation was a "conscious and deliberate response to a need created by environmental change" (p.127). The researchers found an improvement in understanding of adaptation from years 14 to 16, but not between ages 12 and 14. Additionally, two thirds of students between the ages of 12 and 14, and one half of students of age 16 years gave teleological explanations. The researchers believed that student responses may be influenced by the context, since they saw differential responses in relation to the tasks. The researchers also acknowledged two important points that continue to plague teaching about evolution. The first is that we tend to talk about the process of evolution using teleological and anthropomorphic explanations. This serves as an element of further confusion for students. Another teaching issue related to adaptation is that, unlike other portions of biology, "none of us have experiental knowledge of such processes" (p.129). The research findings of this study are consistent with previous and current findings related to student conceptions of adaptation.

This study could have been improved by including information on how the reliability and validity of the questions were determined. In addition, the study lacked a sufficient description of the data analysis. For example, the researchers do not describe how the various categories were established, and they did not explain how the raters determined the categories of the responses or how rating agreement was achieved.

Students appear to have issues related to adaptation as a result of the everyday use of the term. Continued demonstration of this issue was observed in Hallden's (1988) study, which involved 27 students of about 17 years of age. The researcher was interested in understanding how students think about evolution and species development. Students wrote down explanations of how species developed before and after instruction in genetics and evolution. At the end of the unit, students were also asked to give oral descriptions of how traits and genetic predispositions are inherited. Essays submitted by 16 students prior to and after instruction were used in the data analysis. One of the major changes in students identified by the study was that seven students initially were unable to "give any kind of description of the development of the species in the first essay" with only two failing to do so the second time (p. 546). Students maintained that species would have to adapt to survive, with those species that do not adapt succumbing to extinction. In a number of cases students saw adaptation as intentional, with nature taking an active role in the process. The researchers found it difficult to differentiate between responses prior to and after instruction. Although more students gave Darwinian responses in their second explanation, they also had other explanations within it – indicating to the researcher that they had "simply added another explanation to the stock the answer that they already had" (p. 538). In 21 of 41 essays, students used a variety of meanings for adaptation, mostly corresponding to its everyday use. This confirms and reiterates the trouble that students have with understanding the term *adaptation*, as well as its concept. Students also appeared to have difficulty with differentiating between an individual and a species.

Several limitations exist for this study, the major one being the lack of description of the analysis of the qualitative data. The researcher does not describe the reliability or validity of the data. Finally a large number of students did not return their essays, thereby missing an important part of the data.

The prior studies demonstrate that students hold misconceptions related to evolutionary theory that typify teleological (driven by outside forces), anthropomorphic (needs and wants of the individual), and Lamarckian conceptions (acquired characteristics that are passed on to generations). Lawson and Thompson (1988) were particularly interested in identifying the factors that played a role in overthrowing these misconceptions. The researchers examined certain cognitive functions of students to see if there is a link between any of these and students' misconceptions. The focus of this study was 131 seventh grade students enrolled in a life science course. The researchers believed that for students to overcome their misconceptions: they must be aware of them; they must become aware of the evidence that bears on the validity of the alternative conceptions; and they must be able to generate and or follow a discussion of the logical relationships among alternative conceptions and the evidence. Students were pretested to determine a number of cognitive functions, including reasoning ability, mental capacity, verbal intelligence, and cognitive style, and then given instruction that followed a lecture/textbook approach for one month in genetics and evolution. Posttests were given that used open ended essay questions that "called for the prediction and explanation of biological phenomena involving principles of genetics and natural selection" (p.737). Student responses were then "evaluated and scored based upon the number of misconceptions" (p.737). Three questions involving skin color, an amputated finger, and dyed hair were used to explore these misconceptions.

Their responses indicated that a majority of students "seemed to hold a Lamarckian view of the inheritance of acquired characteristics" (p.739). A total of 128 student responses demonstrated biological misconceptions. Students categorized as being formal operational had less misconceptions per student (0.75) than those categorized as transitional (0.89) or concrete students (1.67). Based on this data, the researchers believe that formal reasoning ability is necessary to overcome misconceptions. Naïve students (in relation to the principles of natural selection and genetics) who are also considered concrete operational will fail to reject Lamarckian or teleological explanations even after instruction. This is because they lack the reasoning ability of formal operational students to consider the validity of alternative hypotheses. The researchers advocated allowing students to discuss prior conceptions in a classroom, and then carefully compare them with the newly introduced scientific conceptions in order to evaluate the logical and or empirical inconsistencies.

The researchers weakened their study by not reporting the inter-rater reliability for scoring the misconception questions. More troublesome was the lack of pretesting that took place to determine the students' knowledge and understanding of evolution before the research. Without doing this it is difficult to determine whether individuals who already had a better formal reasoning ability understood evolution better. Thus, the impact of instruction would not have been as strong in these students.

Confusion between scientifically accurate understandings of evolution (Darwin and Neo-Darwinian) and inaccurate understandings (Lamarckian) often plague students in biology courses. Jimenez (1992) was interested in testing "strategies intended to enhance a conceptual shift from Lamarckian to Darwinian views" (p. 51). Two intact classes, containing 34 (experimental group) and 35 (control group) 14 year-olds, were compared. Each class was taught by a different teacher, who had similar professional backgrounds and had been working together for ten years. The researcher examined a curriculum sequence, which had a constructivist approach, titled “How living creatures change” (p. 53). Both groups used the same instructional materials. The researcher was attempting to examine the confusion or lack of distinction by pupils between Darwinian and Lamarckian explanations/views. The major difference between the control and experimental groups had to do with small group and whole group discussions of student explanations and the “comparison between school science and their previous ideas, at the end of the sequence” (p. 54). The teaching process was as follows:

1. All students were given a pretest with the experimental group having small group discussions and then discussion with the teacher.
2. Both classes worked on solving counter example activities. These activities were intended to produce conflict. The experimental group focused their discussion on how their answers compared to their pre-test answers to the counter examples. The control group discussed Lamarckian explanations.
3. The experimental group compared their ideas at the end of the sequence to their original ideas – the control group did not do so.

The students were given the pretest before the sequence started, and then a posttest two weeks after the sequence end. The students were retested one year later. The researcher found that in the pretest, the largest group was Lamarckian in both the experimental and control. In the posttest, the experimental gave responses that were more Darwinian than the control group. One year later the experimental also performed better. Jimenez (1992) therefore asserted that it is not enough to have curriculum materials that present alternative ideas, but students also need to discuss their own ideas and compare them with school science. He argues that, unlike Lawson and Thompson (1988), it may not be cognitive reasoning ability that is a hurdle, but “cognitive development in a particular content area” (p.58).

Bizzo (1994) took a sociocultural perspective to examine student understanding of evolutionary theory. He believed that the "reconceptualization of evolution theory influences the current teaching of evolution in Brazilian schools" (p.538). The author believed that teaching style and student cognitive reasoning ability might not be the major factors contributing to student misconceptions. Three high schools in Brazil served as the setting for this research, with interviews of 11 students from each of the schools, coupled with 192 student surveys. The questionnaire used was based on Bishop and Anderson's (1990) instrument, with modifications. Interviews with students included questions asking them "what they learned about biology at school," and questions were asked "about the possibility of biological evolution" (p. 539). Interviews revealed that students viewed animals as being "conscious of the need of evolution, and therefore would be constantly trying to evolve" (p. 543). The environment was viewed as "the central source of variation" and adaptation was an "individual process of adjustment" (p. 543). This view of adaptation is particularly common in the research literature. Students also viewed evolution as a form of progress, with no clear distinction between biological and cultural evolution. Finally, students appeared to lack the ability to see a connection between molecular biology and evolution. When considering the survey results, students exhibited a very low understanding of evolutionary theory – 73% of students (based on verified answers) got zero questions out of five correct. None of the students got four out of five (80%) or five out of five (100%) of the answers correct. Ninety-four percent of students got either zero or one answer correct. A major limitation of this study was a lack of description of the scoring of the test questions as well as how the qualitative data was analyzed.

Wanting to determine if students' explanations shifted in a discernible pattern, Settlage (1994) examined students' understanding of evolutionary process after their involvement in the

Biological Sciences Curriculum Study project titled *Evolution and Life on Earth*. Seven field test teachers in five states agreed to give a pre and posttest based on Bishop and Anderson's 1986 study. The entire pretest came from the study, as did the second question on the posttest. Approximately two months passed between the pre and posttests. Students came from a range of biology classes in grades 9-12. A total of over 200 students took the test, with 50 randomly selected students used for the data in this study. The two essay items on each test served as the data for the study (p.450). Categories were created after student responses were read - responses were re-read and then assigned new categories, and then read again and categories were finalized. Two readers independently evaluated the responses, achieving a 90% agreement rate.

The results showed that the most common response category on the pretest was *need* followed by *use*, accounting for one half of all pretest responses. Teleological, anthropomorphic, and Lamarckian conceptions routinely account for the majority of the students' explanations regarding evolution. The posttest showed more promising results, with the most common response category variation followed by *adapt*, and then *need*. The increase in *variation* was 27 responses, and the greatest decrease was *need with loss* of 23 and *use* with 17. The most common change in category was *need* to *variation* followed by *use* to *variation*. The most common categories that showed no change were *need* followed by *variation*. Students in this study frequently attributed evolution to "the deliberate intentions of individual organisms" (p. 453). A significant result was the role that variation took in student posttest results. It was not clear to the researcher if the students had given up their misconceptions about evolution, but it appeared that their understanding increased.

Although a number of qualities about the research study were well reported (including the validation of instruments and how categories were assigned and confirmed), it is difficult to discern if the researcher tracked the pretest and posttest responses of students. Based on our own research (Crawford, Humphrey, and Vaccaro, 2007) it is important to track student responses to determine if any of the participating student's understanding decreased (such as moving from *variation* to *need*). The author also does not describe the inquiry activities and the extent to which students participated in them. Finally, due to the various activities students participated in, it would have been more appropriate to include other data sources for analysis besides the responses to essay questions.

Demastes, Good, and Peebles (1995a) considered the process of conceptual change in evolution. A university laboratory school served as the site for the research study, with a teacher who used evolution "as a unifying theme of her biology classes" and described her students as "very capable of applying the theory of evolution in structured tasks" (p. 639). Four participants were selected from 22 students in the class to represent the range of student views and knowledge. A set of 17 interviews was conducted, with very structured interviews related to explanations for exam responses and open ended questions related to religious beliefs and personal implications of acceptance of evolutionary theory. Interview questions were related to science and religion, how species become extinct, and if the reasons for extinction applied to people. Based on their responses, the students were classified as *Biologist as Scientific Theorist*, *Biologist as Multidisciplinary Realist*, *Biologist as Authority Seeker*, or *Biologist as Pragmatist*. The influences for conceptual change that the researchers identified included prior conceptions, scientific orientation, scientific epistemology (view of nature of scientific knowledge), view of the biological world, religious orientation, and acceptance of evolutionary theory. Of particular importance to research that is related to acceptance and understanding of evolution was the finding that conceptual change occurred in the "absence of a corresponding change in belief" (p.

659). Students can therefore reject the truthfulness of evolution, but still experience a change "toward a scientific conceptual framework for this topic" (p 659). On the opposite spectrum, students may accept the theory without having a scientific conception of it. According to the researchers, the most influential factor inhibiting scientific conceptual change is not a "stated belief or disbelief, but the learners' feelings of disturbance and conflict as learning occurs" (p.659). Demastes et al. (1995a) concluded that a learner's approach to "understanding natural phenomenon can play an important role in aiding or hindering the construction of a scientific conceptual framework" (p. 660). Finally, for some learners, their epistemological approach to science may be the strongest controlling factor, while for others it might their personal emotions or view of the biological world (p.661).

While this study provided an in depth analysis of multiple data sets, it was weakened by the very selective population and limited sample size – four students at the university laboratory school. As such, it is very difficult to generalize these findings to other research settings.

Demastes, Settlage, and Good. (1995b) replicated Bishop and Anderson's 1990 study with college and high school students. For the first study, Study A, the college students were enrolled in a nonmajors' introductory biology course. A total of 192 college students in four sections were involved in the study. These students were taught by two separate instructors, who each taught one experimental section. A teaching module from Bishop and Anderson was employed in the experimental sections for the duration of one week. The module included a range of materials, including laboratory activities and student problem sets about variation and adaptive traits. Students took a pretest at the start of the module and at the end of the course.

Study A's findings indicated that few students understood the scientific concepts of evolution, with no more than 25% of the students using a scientific conception in any of the questions. The researchers found no differences between the pretest and posttest scores for each group and there was no significant difference between the scores in the two classes. No relationship was found between student learning and the amount of prior coursework. Additionally, the study did not have a large impact on a student's beliefs in evolution. There was a 22% increase in the experimental groups' reported belief in evolution on the posttest. Beliefs were not found to be linked to a students' ability to use scientific concepts.

For Study B, high school students from schools in Colorado, Wisconsin, and Tennessee were involved in the research study. Teachers from these schools each taught at least two sections of a high school biology course. A control group and an experimental group were used in each situation, with teachers in the experimental group using an inquiry-based teaching approach for at least five to six weeks. The materials were developed by *Biological Sciences Curriculum Study* (BSCS) and included hands-on activities. The materials focused on implementing process and thinking skills that including "forming, testing, and evaluating hypotheses" and "predicting, observing, and synthesizing new information and knowledge" (p. 543).

Students were given a shortened version of the Bishop and Anderson (1990) instrument for the pretest and posttest. The posttest was modified to include different organisms and situations. Students were categorized as either *poor*, *fair*, or *good*. The majority of students initially exhibited a poor understanding of the majority of the scientific concepts being tested, with none of the students designated in the *good* category. On the posttest, both groups increased in the number of students at the *fair* and *good* levels of understanding. The experimental group had statistically significant higher levels of understanding for two of the three issues on the instrument.

Although this study supports the use of inquiry-based approaches when teaching about evolution, there are some drawbacks. For instance, the duration of the instruction at the college was extremely short and it is not clear when exactly the pretest was administered. The researchers do not clearly identify how many students participated in Study B, or how many elected to withdraw from it. While different schools were used in Study B, the courses that the high school teachers taught were not all consistent. Instead of using the whole Bishop and Anderson instrument, a partial instrument was utilized, thus decreasing the ability to compare results of the study.

Work by Beardsley (2004) addressed middle school students' understanding of evolution. The subjects, 86 students, were enrolled in multiple sections of general eighth grade science class taught by the same instructor. Students had previously received instruction in genetics prior to their unit on evolution. Bishop and Anderson's (1990) essay questions and three multiple choice questions were used as the pre and post instrument. Based on the success of previous studies (Jensen and Finley, 1995; Demastes et al., 1995a), the researcher used an approach to teaching evolution "using both historical arguments as a part of a conceptual change strategy and inquiry-based activities" (p. 606). Students worked on the historical argument in small groups by examining a problem involving whale development – in that students were asked to "devise a mechanistic explanation for the observation that whales lost their legs" (p. 607). For inquiry-based activities, students counted seeds to show exponential growth, measured leaves on plants to examine variation, made future predictions of offspring based on environmental conditions, and participated in a hole-punch activity that simulated predator/prey interactions involving camouflage. The results of the pretest demonstrated that most students (78.7%) had a poor understanding of evolution and 21.3% had a fair level of knowledge in each of three categories.

The posttest results showed that students understanding of evolution increased, with a mean of 58% in the two columns for all three categories. For the *origin of traits and natural selection* category, most students moved from poor to fair. The greatest improvement in the *role of variation* category was the move from poor to good (many of the initial poor responses showed no role of variation). It is important to note however, that many students (52.7%) did not improve in their understanding (this number was a mean over three categories).

Although this study does a good job of detailing the instructional strategies used, it could have been improved in several aspects. The researcher does not describe the multiple choice questions used, only making reference to other studies that have employed similar questions. It is not evident if another scorer was involved and the inter-rater reliability was not provided. It is also not clear when the pre and posttests were administered since a testing effect could have been at play.

Moore, Froehle, Kiernan, and Greenwald (2006) examined how students in Minnesota view evolution. Surveys were administered to 246 high school students at a public school and a private school affiliated with the Catholic Church. University of Minnesota students in an introductory biology class between the fall of 2002 and the spring of 2004 also participated in the study. The survey questions were based on other studies related to students' views of evolution and creationism. The high school students exhibited a number of misconceptions about evolution. Most of the high school students believed that "the evidence for evolution is full of conflicts and contradictions, that there are many good scientific theories to explain the diversity of life, and that a scientific theory is a hunch or guess" (p. 38). University students had similar thoughts – believing there were many valid scientific theories for the diversity of life. Some college students (20%) also claimed that creationism was taught in their high school biology classroom. This is consistent with other surveys related to teaching of evolution in high schools.

Based on the aforementioned studies, it is evident that middle school and high school students lack adequate understandings of evolutionary processes. The level of understanding at the college level also raises concerns about the current instructional methods employed to teach evolution.

College students' understanding of evolution

Secondary students are not the only individuals to be plagued by misconceptions or have difficulty understanding the process of evolution. Dudycha (1934) conducted one of the first studies involving college students and their beliefs concerning evolution. A total of 1054 college students were surveyed - freshmen at six Midwestern colleges and seniors at six Midwestern colleges in 1930. Freshmen were surveyed at the start of their college career and seniors were surveyed close to the end of their college courses. Students were asked to react to 25 statements concerning evolution and were asked to rate them on a belief scale that ranged from implicitly belief to absolutely do not believe. There were five different belief options to choose from but students were asked to respond using only one belief choice for each statement.

The researcher found that a large percentage of freshmen were noncommittal, with at least 10% of responses for each question marked as noncommittal. Thirty five percent of students believed in evolution, while 36 percent did not believe in evolution. A large percentage of students (71%) believed that evolution was a description of nature's process of development and a majority (65%) believed that evolution accounts for the development of organisms from simple to complex forms. Only 21% of students believed that there isn't any doubt about the fact of evolution, while 47% did not believe. Students also had an inaccurate view of humans evolving from monkeys, with about equal percentages believing (46%) and not believing (44%) this statement. More students (42%) also believed that evolution should be taught in every college while 26% did not believe in this. Thirty six percent of students also believed that evolution is "diametrically opposed to all religious teachings" while 38% did not believe in this statement.

More seniors believed in the concepts of evolution, that it is a description of nature's process of development (86%) and evolution accounts for the development of life (84%). Three fourths of seniors believed in evolution, which was much higher than the freshmen. Fifty percent of students believed there wasn't any doubt about the fact of evolution, while 32% did not believe in this statement. Unlike the freshmen, seniors were less likely to believe (80%) that evolution was diametrically opposed to all religious teachings. They also did not believe (76%) that man came from monkeys, which was much higher in freshmen. Based on these results, the author indicated that seniors were more likely to "harmonize" their faith and views on evolution. The researcher also found that the responses of the seniors indicated that they were more open-minded as well as more informed and inclined to believe in evolution.

This study dealt with a large population of students and looked at different colleges as well as educational levels. However, Dudycha did not report how the instrument was developed, how the instrument was pilot-tested. In addition, he did not report on the instrument's reliability and validity. The study was restricted to the Midwest, which means the population may not be generalized to other areas. It would have been helpful to indicate where the students came from to show if it was more representative of the country. Interviews with students may also have helped elucidate how well the survey matched their viewpoints on evolution.

Grose and Simpson (1982) surveyed introductory college biology students to investigate their attitudes toward evolution. The researchers used an instrument titled *The Attitude Toward Evolution* that was originally published in 1931 by Thurstone and tested by Likert, Roslow, and Murphy (1934) and Lorge (1939). A total of 120 students in six laboratory sections at a large Southeastern state university served as the study population. The study was conducted in 1976 and students were asked to complete both a background survey as well as the attitude scale.

Students completed 15 questions on demographic aspects as well as 20 items on evolution. Approximately one fourth (24%) of students expressed a belief against evolution. An almost equal percent (22%) were neutral or doubtful toward evolution. The majority of students (54%) believed or strongly believed in evolution. The researchers found that individuals who though their church influenced their thinking had lower mean scores than those who felt that their church did not influence it. Religious preference was not correlated to belief in evolution, which suggests it was faith in religion that influenced attitudes toward evolution. It is noteworthy that biology majors did not score significantly higher than nonbiology majors and there was not a significant difference in beliefs. There was a significant difference between male and female students, with females scoring higher than their male counterparts. The researchers found a strong influence of the high school biology teacher on female students in regards to their belief in evolution, but not with other students. They also found that female biology majors scored significantly higher on *The Attitudes Toward Evolution* scale than male biology majors as well as the nonmajors. One rationale for this may have been the perceived influence of the high school biology teacher on the students' beliefs. Other factors (such as the number of high school science courses, educational level of parents, occupation of parents, and influence of parents) did not correlate with beliefs in evolution.

The researchers acknowledge one problem with the study, the age of the instrument, which was 44 years old at the time of the study. Although the information may be relevant for comparison purposes, there have been a number of changes in the focus of science education from the time the instrument was developed to when it was administered in this study. The researchers also relied solely on quantitative data, and did not conduct interviews to help explore the views of students (and to make sure the survey is identifying what it should).

Brumby (1984) is often cited in the literature related to student conceptions of evolutionary theory at the college/university level. He was interested in exploring the "conceptual frameworks and reasoning patterns used for unfamiliar biological problems which are based on real world instances" (p.494). In this case, the study participants were 150 first-year Australian medical students, of which about 40% had completed high school biology. Qualitative problems based on evolutionary principles were developed and given to students in three different formats. A set of written problems with open responses were given in the second week of the class, individual structured interviews involving 32 students occurred in the following four weeks, and one question on the end-of-year examination involved applying the concept of natural selection. The data analysis depended on "identification of key concepts and phrases used" (p.495). The researcher developed categories based on student responses, which were then used to tabulate their concepts. The two written problems – one involving insecticide and the other bacteria - showed that students had some difficulty in identifying the involvement of natural selection in organism change. Although two thirds of students recognized that the insecticide problem involved natural selection, only 21 of 150 (14%) were able to do so with the bacteria problem. A strong relationship was found with the 21 students and previous biology courses – 19 of them (90%) had previously studied biology in high school. In the interviews, only one third of students indicated that their responses were based on evolution or natural selection. Over the study period, only 10% of students interviewed were consistently able to recognize and correctly apply the concept of natural selection and were categorized as having sound understanding. Ten students were able to explain one or two problems and were categorized as having *poor* understanding. All students categorized as having *sound* or *partial* understanding had previously studied biology. The majority of those categorized as *poor* had not previously studied biology. On the final exam question, only one third of the students correctly "explained the effect of natural selection on the frequency of genetic disease" (p. 497).

To the investigator, the study results indicate that students "leave school believing that evolutionary change occurs as a result of need, i.e. a Lamarckian view" (p.499). Previous instruction in biology did not appear to have an effect on student understanding, as the majority of students (15/18) who had taken a biology course had a *poor* or *partial* understanding of natural selection. Students have intuitive ideas that result in the belief that organisms respond to environmental pressures by developing new traits, and then pass those traits on to their offspring. Brumby points out that the way in which science is presented, in lecture form, may convey a view of science as absolute knowledge. The way in which students learn about evolution currently in high schools - the passive learning of lectures - may be "insufficient in themselves to create sufficient conflict in students' minds to alter their existing understanding" (p.501)

Although this research study provides a number of important findings, it was limited in some regards. For instance the population of study is fairly selective and the results may not be generalized to other settings easily. The researcher does not adequately describe the qualitative analysis, and no information is provided regarding how the questions were developed. Additionally, the reliability and validity of the questions was not reported for the study.

One of the most cited, and replicated, studies related to student understanding of evolutionary processes comes from Bishop and Anderson (1990). A college non-major's biology course served as the site for analyzing students' conceptions of natural selection prior to and following instruction in evolution. One hundred and ten college students completed diagnostic tests at the beginning and end of the course that asked students questions concerning natural selection and whether they "believed the theory of evolution to be true" (p.417). Many students believed that the environment causes traits to change over time. In line with our understanding of the difficulties in teaching students about the process of natural selection, the researchers found that "the amount of previous biology instruction had little or no effect on student conceptions" and student understanding was not "significantly associated with previous biology coursework" (p.424). Less than 25% of the students were initially able to explain evolutionary change using scientific conceptions, this increased to over 50% in the posttest. Although an increase occurred, the numbers indicated that change is difficult for students even when using "revised teaching methods and materials" (p. 425). The researchers also indicated that students have difficulty with terminology – especially the terms *adapt/adaptation* and *fitness*. Although a term is used in an evolutionary setting, students may instead regard the term in its colloquial usage (for example, adaptation - considering change at the individual rather than population level).

In regards to beliefs about evolution, the researchers asked the questions "do you believe the theory of evolution to be truthful?" (p. 425). Surprisingly, Bishop and Anderson (1990) found that "a slightly higher percentage of nonbelievers understood the scientific conceptions," although it was not statistically significant (p.425). Although religious beliefs are viewed as a serious impediment to understanding the theory of evolution, this is not entirely the case. Despite understanding the process of natural selection, students "did not generally change their convictions about the truthfulness of the theory" (p.426). Demastes et al. (1995) later confirmed that acceptance and belief do not have to go together. Other studies have looked at the relationship between beliefs and understanding different aspects of evolution.

Although this study provides a number of important findings, it does have limitations. The study population was composed of juniors and seniors and thus had participants with higher education level than other student populations. The authors do not adequately discuss the instructional process for conceptual change – one of the main components of the study. The intervention lasted a very short duration (one week), although that is not uncommon in college settings. Finally, a control group is not included to compare the results to, which is particularly important when discussing instructional strategies and their impacts.

Disconnect between understanding and acceptance is a recurrent theme in the literature related to evolutionary theory. In regards to the impact of pedagogical techniques, the researchers believe that current methods of instruction were ineffective for inducing change and understanding in the student population studied. In an important statement related to classroom instruction, Bishop and Anderson conclude that "many students can change their naïve conceptions on the subject if instructors are aware of them and are prepared to confront them" (p. 425). The problem for most instructors, however, is the comfort in which they feel in doing this.

Greene (1990) studied whether student misunderstanding of evolution and natural selection occurred due to explanations based on incorrect assumptions about organisms and the environment. Three hundred and twenty two students in an introductory one-semester biology course for education majors were given evolution problems as part of the normal testing procedure in the class. Data was generated from over 11 classes over eight years (1977-1984). An evolution problem was given unannounced at the beginning of the third lecture after natural selection had been introduced (the first lecture covered special creation and Lamarck, and the second introduced Darwin's idea of natural selection). The results showed that only 3% had a true understanding of selection, with 46% having a "functional understanding" (p.884). Most of the student responses were within a typological framework, where need would direct change in organisms. The researcher suggested that evolution problems are a "very good way for students to become aware of their misconceptions and to begin to rethink their assumptions" (p.884). A number of other research studies have indicated that students need to be made aware of their misconceptions so that they might rethink and address them. The author also indicated that students must be *shown* that Lamarckian explanations do not work, rather than being *told* by their instructor.

This research study had a number of weaknesses, despite some strengths (such as population size and study length). The development of the evolution assignment problems was not discussed, although the validity and reliability was (in regards to inter-rater reliability). The evolution questions were given after the lectures on natural selection, it would have been more appropriate to employ a pre and a posttest measure to assess understanding of the concepts used. The study population was 90% white females who were education majors, therefore the findings may not be easily generalized to other study populations.

Non-traditional teaching strategies have been explored by researchers as a means to change students' conceptions of evolution. Jensen and Finley (1995) used a teaching strategy that employed historical arguments in the context of a biology class in the spring of 1990. The data was generated from 42 of the 85 students. A control group was not used in the study. A treatment was applied that happened during one 2-hour lab period. This treatment included:

1. Introducing students to the general nature of evolution,
2. Teaching of Lamarckian principles,
3. Evidence that opposed Lamarck's principles,
4. Teaching of Darwin's theory of evolution by natural selection, and
5. Solving evolutionary problems from both Lamarckian and Darwinian perspectives.

An assessment instrument was given one week before and one week after the treatment. Students displayed limited understanding of Darwinian principles – answering fewer than 25% of all pretest questions in a manner consistent with this model. After the treatment this jumped to 45% of answers. Students initially averaged about 23% (8.02 out of 34) on the pretest and 46% (15.76 out of 34) on the posttest. While these results were significant, students' performance was still "less than optimal" (p.159). The researchers also conducted a trace analysis that showed 41% of students with the worst understanding did not change – other groups (best understanding and complete/incorrect) were also largely not affected by intervention. Individuals moving into the "Best Understanding" category increased by 98%, and 33% of the worst responses moved to the best response. The researchers were encouraged that only 11% of the responses were worse than the initial responses. Two major points identified by the researchers were that fewer than 50% of students were still answering correctly and that some key evolutionary concepts "remained difficult to understand" (p.164).

The lack of a control group for comparison purposes is a serious limitation of this study. The treatment applied was of an incredibly short duration and would appear unlikely to cause conceptual change. The short time from the pretest and the posttest and the closeness to the intervention is cause for concern. The same test was used for the pretest and the posttest so there is the possibility of a testing effect from familiarity and exposure to the question. Finally, less than 50% of the students completed the posttest; therefore the data is restricted to a certain student population who is more likely to be motivated.

Jensen and Finley's (1996) research study was an extension of their earlier study in 1995. In this case, the researchers were looking specifically at the effects of curricular changes on student understanding of evolutionary theories. The same introductory biology class (not the same students) was the focus of the study in 1992. The student population in the class was considered to be under-prepared, and included a variety of ethnic and socioeconomic backgrounds. A traditional curriculum was compared to what the researchers described as a "historically rich curriculum" (p. 882). The traditional curriculum used a standard textbook approach, while the historically rich curriculum was intended to address student preconceptions by discussing the history of evolutionary thought. Four classes were involved in the study, with six days of instruction devoted to evolution and natural selection. Two classes used the traditional approach, and two used the historically rich curriculum. One class of the traditional approach curriculum classes also used paired problem solving, as did one of the historically rich curriculum classes. In the pretest, three out of four sections had a 50% Darwinian and 50% alternative conception rate, with one section – the historically rich problem solving section having 37% Darwinian to 62% alternative conception. The majority of alternative responses on the pretest were teleological and Lamarckian, with teleological the majority. After the treatment, Darwinian responses increased to a range of 73% and 86%; the use of alternative conception responses decreased from 5% to 20%. Students in the historically rich curriculum reduced their use of alternative conceptions more than the students who studied the traditional curriculum.

The largest difference appeared between the students in the historically rich curriculum that used problem solving and the traditional curriculum that used traditional instructional methods. As a result of the treatment, students increased their understanding of Darwinian principles and reduced their use of alternative conceptions – although they dropped less in the Lamarckian views. Similar to other researchers, this study points out the importance of explicitly identifying and addressing student preconceptions about evolutionary theory.

The researchers did improve their earlier study by creating a controlled experimental design, but did retain a number of issues from the earlier study. A testing effect could be an issue due to using the same pretest and posttest, and duration of the intervention being only one week. The authors also do not describe how students were recruited or the amount of attrition in the study (which was a problem in their first study).

Students routinely provide teleological explanations for evolutionary processes; therefore it is important to consider the relationship between religious beliefs and evolution. Dagher and BouJaoude (1997) considered the relationship between scientific views and religious beliefs as they related to biological evolution. In their study, 62 out of 76 undergraduate biology majors enrolled in a senior seminar responded to a questionnaire administered during the class. Three essay questions asked students:

1. to list the major principles of the theory of evolution
2. if they believed that the theory of evolution presented a conflict between science and religion
3. if they believed the theory of evolution clashed with their own beliefs about the physical and biological world

Fifteen students were selected for semi-structured interviews, based on diverse religious backgrounds and on students who "held representative views pertaining to personal perceptions of conflicts" (p. 433). These students were analyzed in a 2004 study by the same authors. In response to the questionnaire, the most common principle identified was natural selection – with some misconceptions, such as apes evolving into man, and some beliefs involved (such as God laying down the basic principles of natural selection). Many students, in later questions, cited "that evolution is only a theory and not a law" (p.437). None of the Christian students rejected evolution but 47% of the Muslim students rejected evolution. A student's religious orientation may be related to their acceptance of evolution and views of science. They found that students tended to generalize and misapply aspects of scientific epistemology to different scientific theories. The researchers believed that teachers should provide opportunities for students to "discuss their values and beliefs in relation to scientific knowledge" (p. 429). The authors point out, like other researchers have, that a change in students' acceptance requires actively engaging "factors that underlie their resistance to the ideas about evolution" (p. 441).

This study could have been improved by identifying the factors that lead to such a low survey completion rate. In addition, the researchers do not report their inter-rater reliability for placing students into categories. It is also not clear how the interviews were combined with the other data to establish the findings.

The nature of naïve explanations of 40 college students with no prior college courses in biology or evolution was the focus of a research study by Ferrari and Chi (1998). The students were asked to solve five prediction-explanation problems. These problems were designed to assess Darwinian explanatory patterns – each student was given 7 minutes "to predict and explain the outcome of a hypothetical situation" (p.1238). Sixty-three percent of student answers were classified as non-Darwinian with the most common being Lamarckian (52%). Consistent with other studies, a much smaller percentage (37%) were classified as Darwinian. Although 37% were classified as Darwinian, the overall framework of the response was still not correct. Students, for the most part, appeared to classify evolution as an *event* rather than as an equilibration *process*, which is not an accurate understanding (p.1246). The authors stressed the importance of not teaching cold facts, but rather conveying scientific conceptions so that students can move away from this view of a bounded event that is Lamarckian in nature.

Identifying the nature of naïve explanations is important, especially considering the fact that prior knowledge and attitudes can influence these explanations. Downie and Barron (2000) examined the evolutionary theory attitudes of Scottish biology and medical students. They administered a survey to biology students during the years of 1987 to 1995 and then in 1998 and 1999. Between 500 and 900 students took the course each time it was offered and most of the students had previous coursework in biology. The majority of students had intentions of a degree in biological sciences. About four to six lectures concerning evolution were given each year. First-year medical students were surveyed in 1999, and did not cover evolution in the course. Between 3% and 11% of biology students over the years, and 10% of the medical students, rejected the notion that a long period of biological evolution has occurred. The most common reasons for rejection were literal interpretations of the Bible and contradictions of evidence for evolution. A majority of students accepted natural selection at the species level - 88% of biology students and 83% of medical students. The main objection of individuals over evolution was the production of new species. A number of students across the years indicated that acceptance of evolution was based on a lack of good alternatives. Based on the results of the survey, individuals who were classified as *rejecters* may be somewhat more skeptical and uncertain in regards to science in general. These results support the idea of strengthening student understanding of the nature of science for both individuals who accept *and* reject evolutionary theory.

This study, while having a number of good qualities, including its long duration and the size of the participant pool, is limited in some respects. Although there was a large sample size, the exact size of the sample was not reported and the authors do not indicate when the survey was given. If the survey was given before, *versus after* the study, the results can be interpreted differently. The authors did not discuss the development of the instrument or the process by which it was validated.

The impact of creationist and evolutionary beliefs on learning biology were investigated by McKeachie, Lin, and Strayer (2002). Their study took place at a Midwest community college in an introductory biology class of 75 students. Sixty students completed a pretest questionnaire on evolution and 28 completed posttest questionnaires. The evolution questionnaire involved four items to assess a student's beliefs and attitudes about creation and evolution. Additionally, students completed the *Motivated Strategies for Learning Questionnaire* (MSLQ) at the start of the semester to assess students' motivation and learning strategies.

At the beginning of the course, a small group of students (10) did not accept evolution, 22 did not know enough, 17 accepted evolution but believed in the teaching of the Bible, and 11 stated evolution was a fact. At the end of the course, students were more likely to shift toward a belief in evolution, although students who did not accept evolution were more likely to drop the course or failed to complete the posttest. When examining grades, students who believed in evolution did better than those who believed in creation, although both passed the course. The grades increased for the students in the categories in the following order, creationists, don't know, religious evolutionists, and finally evolutionists (who demonstrated the highest increase). Students in the creationist group differed in a number of aspects from that of evolutionists. Creationists differed on all scales on the MSLQ from the other students. They had a higher motivation for grades, lower interest, were more anxious; lower intrinsic motivation, lower self-efficacy, and lower task value. They also had low scores on learning strategy and thinking scales. The researchers argued that the creationist students encountered cognitive dissonance and resolved this by dropping the course or not completing the questionnaire.

The small population study as well as the lack of discussion concerning the evolution questionnaire is troublesome for the research findings. The large attrition rate for the posttests (dropping from 60 to 28 students) further complicates the results of the study. The researchers effectively did not capture more than 50% of the initial study population. The findings of the study could have been strengthened if interviews with students were conducted to confirm their views.

Attitudes towards evolutionary theory are influenced by a host of factors. Some of these factors may be perceived to be in conflict with evolutionary theory (such as religious belief). The social consequences of acceptance of evolutionary theory were also examined by Brem and Griffith (2004) in their study dealing with college-educated adults. The researchers explored the relationships amongst "participants' beliefs, their perceptions regarding the social and personal impact of evolutionary theory, their prior exposure to and knowledge of evolutionary theory, and their opinions regarding the teaching of evolution" (p.181) . One hundred thirty five men and women from ages 18 to 38 were asked to complete evaluations of evolutionary knowledge, questionnaires addressing aspects of evolutionary theory, and open ended questions related to the origin of life on earth and the teaching of evolution and creation in schools. The participants were then placed in belief groups ranging from *strong creationists* to *strong evolutionists* based on their responses. A number of important findings from this research relate to our understanding of how individuals come to accept and understand evolutionary theory. The participants reserved "spheres of influence for both evolution and divine intervention," with varying degrees of conviction placed on each sphere (p. 198). Students may have multiple belief constructs depending on the context in which they are acting. Demastes et al. (1995) demonstrated that individuals have multiple ways of considering issues. The researchers asserted that belief systems, epistemological beliefs, and knowledge are all intertwined constructs that may or may not depend completely on one another. Another finding that emerged from their research concerned those participants that identified a relationship between evolutionary theory and aspects of their personal/public lives. All participants in the study who identified a relationship between evolutionary theory and their lives held negative views of accepting evolutionary principles including "increased selfishness and racism, decreased spirituality, and a decreased sense of purpose and self-determination remove period" (p. 181). The historical implications of acceptance of evolutionary theory (in particular the eugenics movement), may provide a block for students.

Continued examination of the influence of beliefs on students' understanding of evolution and natural selection is vital. Sinatra, Southerland, McConaughy, and Demastes's (2003) study of 93 undergraduate students enrolled in a non-major biology class attempted to determine the link between intentions and beliefs, and understanding and acceptance, of biological evolution. Students completed measures that dealt with content knowledge, acceptance of theories, and epistemological beliefs and cognitive dispositions. The researchers found no evidence of "a relationship between understanding evolution and its acceptance" but they did find that epistemological beliefs were linked to students' acceptance of human evolution (p.521, Sinatra et al., 2003). Epistemological beliefs did not appear to have an impact on acceptance of animal evolution or photosynthesis and respiration. In addition, knowledge of evolution showed no relation to students' acceptance of human or animal evolution. Related research (Bishop & Anderson, 1990) supports the fact that prior biological knowledge does not have an impact on students' acceptance of evolution. Students can accept evolution without having any understanding of the principles involved (Demastes et al., 1995a). This particular study illustrated that students may "have an understanding of evolutionary theory without accepting its validity" and that the reverse also held true - that students may not understand evolutionary theory but would accept is validity (p.521). Students who were more open-minded were more likely to accept human evolution, as was the case with students who had more sophisticated epistemological views. This open-mindedness might be useful for teachers to consider when they are teaching about evolution - instead of being dogmatic about evolution they might create a climate of open discussion. At the very least, teachers need to consider the prior knowledge, preconceptions, and misconceptions that students are entering the classroom with. This is in accordance with the importance of understanding the nature of science, in that students can more easily negotiate their beliefs about religion and science if they have a better grasp of both fields.

This study could have been improved by including qualitative data to bolster the quantitative measures. This is especially important when considering the difficult-to-measure scales that they were dealing with. Interviews would have been helpful in more accurately establishing the connection of open-mindedness and acceptance of evolutionary theory.

Misconceptions continue to be held by college-level students. Westcott and Cunningham (2005) explored student misconceptions dealing with the nature of science and evolutionary processes in an undergraduate introductory anthropology course. The authors were looking to identify commonalities and discrepancies between their own students and the existing literature. Participants in the study were 547 undergraduates, of which there were 243 males and 304 females. Questionnaires were given on the first day of class. One half of the students held a misconception that traits gradually change over time. Sixty one percent of students reflected support for the use/disuse idea in answering a question on webbed feet in ducks. Students had issues with origin and survival of traits, as well as biological terms such as *fitness* and *theory*. Forty percent of students did not differentiate between the common use and scientific use of the term *theory* (although when it was rephrased 78% answered correctly). Consistent with other studies, students had issues with the validity of evolution - 22% thought there was a lot of evidence against evolution and 27% agreed that it can't be demonstrated scientifically. In addition, 37% of students believed in a teleological explanation of species development, which may relate to their thoughts about need driving change. Encouragingly, 83% of the students did indicate that variation was important to evolution, although they do not appear to understand its role.

This study did not include a posttest to determine what impact the class had on student misconceptions. Interviews with students could have helped further clarify the misconceptions that students had. The authors did not describe how they developed the questionnaire, whether it was pilot-tested, or the validity and reliability of the instrument used.

Ingram and Nelson (2006) attempted to determine the relationship between achievement and acceptance of evolution in an upper-level college evolution course. Over the course of three semesters, the researchers asked students to participate in pre and post surveys related to evolution, and examined three main areas: students' acceptance of evolution; the influence of instruction of evolution; and the relationship between achievement and acceptance of evolution. The findings indicated that students had a high degree of acceptance of evolution before the course, that instruction in evolution slightly affected acceptance of evolution, and achievement had little to do with acceptance of evolution. These results are consistent with other research that has indicated that understanding a concept does not necessitate acceptance of it (Bishop and Anderson, 1990; Sinatra et al., 2003). Another important theme that emerged from the results was the researchers' beliefs that some students viewed acceptance of evolution as negatively impacting religious beliefs. This is a difficult and hard to treat issue that must be addressed if students are to come to an accurate understanding of evolution.

Moore (2007) examined the perceptions of biology teachers and students regarding the emphasis of evolution in their classes. One hundred and seven randomly selected Minnesota science teachers who attended science conferences in 2003 served as the teacher population. The study population consisted of 685 first-year college students enrolled in a large introductory biology course for non-majors at the University of Minnesota. All of the students had taken high school science courses in Minnesota and they were surveyed on the first day of the course.

Approximately 10% of the teachers voluntarily identified themselves as creationists. Sixty six percent of the teachers reported their classes included evolution but not creationism, 20% included evolution and creationism, 12% included neither topic, and 2% reported including creationism but not evolution. In both cases (teachers and students), the numbers closely mirrored each other concerning what the biology courses included in regards to evolution. The emphasis values were not as aligned. For instance, 52% of the teachers in the study said they emphasized evolution in their classes, yet only 36% of students reported that their biology class emphasized evolution. In another discrepancy, 21% of students reported that their biology course emphasized creationism, yet only 2% of teachers indicated as such. Students were also asked to comment on whether their courses should include more, less, or the same amount of creationism/evolution. In both instances (creationism and evolution) approximately equal percentages of students were split between including/emphasizing more or the same amount of each topic in their course. Small percentages (13% for evolution and 17% for creationism) indicated they wanted less of the topic included or emphasized.

The conclusions of this study are limited. The researcher did not describe how the study instrument was created or pilot-tested. The study could have been improved by inclusion of a focus group of students and teachers, and/or interviews with teachers and students to further explore their perceptions of their courses.

Nehm and Reilly (2007) placed their focus on biology majors' knowledge and misconceptions about natural selection. They also separated themselves from other studies by examining two classes that each employed different instructional strategies. One class used active learning and the other was taught in a traditional manner. The study took place in an urban college in the Northeastern United States and involved two classes of second-semester biology majors. A total of 182 students participated in the study, with 82 students in the active learning group (82% completed the survey) and 100 students in the traditional class (99% completed the survey).

The two classes had the same textbook, lab experience, reading assignments, and instructional time, but different instructors. The active learning class participated in discussions on the nature of science, paired problem solving, small group discussions, and group response questions. A new instrument was developed (based on prior research) to assess understanding of natural selection. The instrument was scored using a scoring rubric for key concepts and a scoring rubric for misconceptions. Finally, a natural selection performance quotient (NSPQ) was calculated for each student.

Although a majority of active learning students (83.8%) had been taught the idea of natural selection in high school, only 3.2% of students in the active learning group used four or more key concepts (on a scale of seven) in their precourse definitions. In their definitions of natural selection, 87.4% of students used two or less key concepts. In the post course assessment, 58% of the traditional learning students used four or more concepts; this is compared to 69.5% in the active learning students. The mean NSPQ score for active learning students had a significant increase from pretest to posttest (62 to 79) but there was a significant difference between the posttest scores in the two groups (79 versus 74). A larger percentage of students in the active learning group (85%) had a NSPQ over 65, compared to 74% in the traditional group. Fewer students in the traditional group had no misconceptions in their post course responses (14%) than the active learning group (30%).

A major limitation or weakness of this study is the unequal student populations in both groups, as well as the fact that only 82% of the students from the active learning section completed the survey, versus 99% in the traditional class. The researchers do not discuss why one class had a higher response rate than the other. A number of questions on the instruments were not completed by the students, which would impact result reporting. The classes were taught by two separate instructors, which could have certainly impacted the outcomes. Additionally, the description of the active learning was limited. Finally, the two classes were taught in a different fashion – the traditional group had a discrete unit on evolution while the treatment group was taught in an integrated fashion.

Robbins and Roy (2007) employed an inquiry-based approach with college students to alleviate non-science preconceptions about evolution. One hundred forty one students in a nonmajors' biology lab served as the population of study. The researchers first identified preconceptions by giving students a two-question pre-quiz in lab on the theory of evolution and their belief in it. A guided discussion was then developed based on the responses provided by the students. These guided discussions involved questions that required students to work in peer groups to explore the ideas. Students also examined fossils, traveled to a zoo, and were routinely asked about the evidence and data to support evolution (the inquiry component). Students were assessed through a variety of worksheets, quizzes, and their final exam.

Fifty nine percent of the students initially indicated evolution was the best explanation we had based on the evidence, which increased to 92% on the posttest. Very few students initially understood evolution, even if they accepted it. This study could have been improved if a comparison group had been used. A pretest and posttest of evolutionary knowledge would have strengthened the results as well. Another weakness of the study deals with the fact that the researchers did not discuss if they had previously tested their questions before administering them to students.

Hokayem and BouJaoude (2008) examined how eleven junior and senior college biology students perceived evolutionary theory in regard to their beliefs about science, religion and science, and nature and causality. The instructor's point of view on evolutionary theory was also compared to categories identified among students. The study population included 11 students enrolled in a course on evolution at a university in Beirut, Lebanon. Students were identified as either Christian or Muslim. The instructor taught by lecturing for 25 minutes, pausing for questions, and then lecturing again for 25 minutes. The course covered a number of elements of evolution, from the historical development to human evolution. The professor did not discuss the controversy between religion and evolution except during a historical part, and only discussed science as it pertained to Darwin's deductive approach.

Data was collected using two questionnaires and semi-structured interviews. Two questionnaires were used, the *Measure of Acceptance of the Theory of Evolution* (MATE) and the *Test of Preferred Explanations* (TOPE). The MATE measures the acceptance of the theory of evolution while the TOPE determines students' presuppositions about causality. Student interviews took place after they finished the course, and the interviews included questions regarding changes, if any, in views about the theory of evolution and their views about religion and science.

Students ranged from two extremes, with some agreeing with evolution and others rejecting the theory of evolution. All of the students recognized the validity of scientific explanations. A critical element of whether a student accepted or rejected the theory of evolution hinged on the argument about the nature of the evidence. Students who were "uncertain about the theory, or those who rejected it held a strong position against the scientific nature of evidence supporting the theory" (p. 410). Students placed the evidence for evolution on par with that of creationists, and did not see that their "evidence" could not actually be classified as evidence. The researchers found that the nature of the evidence supporting the theory of evolution was important to whether students dismissed the theory or not; individuals often were speculative of the evidence. Students in the course did not change their views on the theory of evolution but they used the new knowledge to fit within their current views.

Nehm and Schonfeld (2008) compared the CINS (*Conceptual Inventory of Natural Selection*), ORI (*Open-Response Instrument*), and an oral interview to see which was better at assessing conceptual understanding of natural selection amongst minority undergraduate biology majors. The study involved two samples of biology majors in the second semester of an introductory biology course at a large urban university in the Northeastern United States. The population included a diverse student group – 32.5% were Hispanic, 30.12% were African-American, 25.5% were Asian, 11.75% were non-Hispanic white, and 0.09% were Native American. The two sample were designated with letters, sample G, which took the CINS and ORI, and sample N which took the ORI. In addition, 18 participants from sample G participated in a voluntary interview that involved four questions taken from the other instruments.

The *Open Response Instrument* was developed using two questions from Bishop and Anderson's (1990) study as well as three questions from Nehm and Reilly's (2007) study. This instrument was designed to measure an individual's knowledge about natural selection at different complexity levels. The questions were organized from concrete knowledge to abstract problem solving questions. The oral interviews were comprised of four questions – two from Bishop and Anderson's study, one from the CINS, and one from the ORI.

The ORI was coded in two ways based on whether or not they exhibited key concepts in natural selection and whether they included alternative conceptions. Student responses were separately coded using two different rubrics for key concepts and alternative conceptions. The seven key concepts for natural selection came from Mayr (1982); students could thus receive up to seven points for their responses. The responses were initially coded, then blindly recoded using the same rubric. The student scores for the alternative conceptions resulted from a rubric developed to identify these alternative conceptions. The rubric was based on the commonly cited *Alternative Conceptions in the Research Literature*.

Using the ORI, the diversity of key concepts was measured as 4.33 for sample N and 3.78 for sample G. Seventy percent of sample N students employed four or more key concepts while 58% of sample G students employed more than four key concepts. Students in both groups had a particularly high use of misconceptions: 1.9 for sample G and 2.4 for sample N. Very small percentages of students used no alternative conceptions (14% in sample G and 30% in sample N). The researchers reported high difficulty values in the five open response questions. Only sample G students took the CINS due to instructor time restraints. Sample G had an average score of 62.9% and students commonly chose alternative conceptions when they were offered. Interviews from sample G had a "broad distribution of knowledge and alternative conception scores on the ORI and CINS" (p. 1149). For the oral interviews, all of the key concepts of natural selection from the ORI and CINS were identified. The ten most identified misconceptions in those instruments were also the ten most identified misconceptions in the interview.

In general, the researchers found that the oral interview was the best and most thorough analysis of student knowledge. The researchers found that the ORI and CINS produced comparable measures of key concept diversity and key concept frequency. However, they differed on alternative concept diversion and frequency, with the ORI providing a more diverse description of the alternatives used. They indicated that the CINS and ORI provided an effective alternative to the use of the oral interviews. They believed that both instruments should be used until a better measure is developed.

Ladine (2009) surveyed 311 students in a private liberal arts university affiliated with the Baptist General Convention of Texas. The researcher administered the survey to selected general education classes during the spring semester of 2008. The survey included 15 questions to determine how students would prefer to learn about evolution in a biology classroom. Students responded to a Likert scale for five questions on their understanding of science and evolution.

The students were split between their preferences about how they would like evolution presented – half had a preference for "including the science supporting evolution and showing how evolution affected them" or "including creationism and intelligent design but showing how the two are not science" (p. 388). A large percentage (34%) felt that the professor should "accept creationism and intelligent design as legitimate theories and teach them in that manner" (p. 388). A large percentage of students (64.4%) agreed that God should be included when defining science, but most students did appear to also understand that science provides only a naturalistic explanation. The researcher found a relationship between agreement with a naturalistic explanation and two demographic components: the number of sciences courses a student had taken and their classification (freshmen – senior). Students taking three years of science were more likely to agree with a naturalistic explanation, and freshmen were more likely to disagree with the naturalistic explanation of evolution. The information regarding the definition of evolution was disheartening, as only 37.6% of students provided a correct explanation, and 37.3% indicated no knowledge of the definition. There was a correlation between the preferred evolution teaching approach and the definition of evolution and the definition of science.

While this study investigated an underrepresented part of the evolution education research, it does have some weaknesses. For instance, no discussion is made concerning pilot testing, content validity, and reliability of the assessments used. The researcher also did not report whether any students opted out of the taking the survey, nor was the total number of students in the class reported.

Moore and Cotner (2009) examined the impact of the inclusion of creationism in high school biology courses. The researchers attempted to answer a number of questions which included: are students who believe in creationism more likely than nonbelievers to have had a high school biology course that included creationism?; are acceptors more likely to have had a high school biology course that included evolution?; are students whose biology courses did not include either creationism or evolution more likely to accept evolution or creationism?; and does an introductory college biology that emphasizes evolution change students' views of evolution?

The research study took place at the University of Minnesota in an introductory nonmajor's biology course. A total of 728 undergraduate students were surveyed via email prior to the first week of classes. Students were asked questions pertaining to the teaching of evolution and creationism in their high school biology classes as well as eight statements from the MATE (*Measure of Acceptance of the Theory of Evolution*). Sixty nine students were also voluntarily surveyed at the end of the semester and per item comparison of the means was carried out using a t-test for significant differences

Based on the total responses (N=728), 64% of the courses included only evolution, 21% included both evolution and creationism, 13% included neither, and 2% included only creationism. The researchers reported a pattern in student responses on the MATE. Students with a high school course that only included evolution were significantly more likely (72%

versus 58%) to accept the validity of evolutionary theory, science-based claims about the age of the earth, the mutability of species, and humans being a product of evolution. Students whose course included creationism were more likely to believe in a young earth, the immutability of species, question the validity of evolutionary theory, and were more likely to use a Biblical response to evolutionary theory. Students whose biology course included neither of the topics fell between the two groups – their responses were more included with accurate conceptions of evolution than the creationism group, but less than the evolution group. The pre and posttest MATE surveys of the 69 students did not reveal a significant difference between the pre course and post course responses.

One the major limitations of the study, acknowledged by the researchers, is the dependency of the data on the self-report information from students concerning their high school science classes. Another limitation, not addressed by the researchers, was the use of the partial MATE as opposed to the whole MATE, thereby limiting the strength of the instrument.

Cunningham and Westcott (2009) tried to identify the misconceptions held by undergraduate students and explain the rationale behind those misconceptions. The researchers carried out their study at the University of Missouri-Columbia in an introductory biological anthropology course. A total of 547 undergraduate students (243 males and 304 females) participated in the study. The researcher developed an anonymous questionnaire to assess students' misconceptions and opinions about the nature of science and evolution and administered the questionnaire on the first day of the class. The instrument involved a section on demographic data concerning students' background, including prior biology classes and the topics covered. The second section explored whether students agreed, disagreed, or had no opinion on 24 statements.

Fifty one percent of the students had been taught evolution in high school while 23% were never exposed to evolution. Twenty two percent of students agreed with the statement that there was a lot of evidence against evolution. Seventy eight percent of students indicated they had a clear understanding of the meaning of *scientific study*. Fifty five percent of students agreed that the theory of evolution correctly explains the development of life. Thirty seven percent of students accepted the idea of theistic evolution. The authors indicated an overall positive disposition to evolutionary ideas.

In regards to misconceptions, the researchers found that a majority of students (66%) thought organisms developed new traits dependent on need. About half of the students indicated they understood the phrase “survival of the fittest” but 64% of them accepted the common misconception that survival of the fittest means only the strong survive. When, according to the researchers, natural selection was phrased correctly, 89% of the students agreed with the statement. In general, the researchers found that when statements included common misconceptions students were likely to agree with them. The researchers found that many students think environmental factors determine what traits appear in the population. Overall, students demonstrated limited understanding of evolutionary processes. Interestingly, students who accepted the validity of the theory of evolution did not understand the various mechanisms at work. The researchers also found that confidence in science was not related to competency in science.

Like other studies in this research area, the authors did not discuss how they developed their instrument, the pilot testing involved in the instrument, or the validity and reliability of the instrument. The researchers point out another issue, that of the phrasing of some of their questions, which could have been avoided if pilot testing had been done.

Gregory and Ellis (2009) focused their research on an infrequently studied population in evolution education, science graduate students. Science graduate students from the University of Guelph in Ontario Canada served as participants in the research study. A total of 186 graduate students (both Master's and Ph.D.) participated in the voluntary and anonymous online survey. The online questionnaire was designed by the researchers to identify the education level of students, their level of acceptance of evolution, their understanding of the mechanisms of evolutionary change, and their understanding of the history of life. It consisted of 32 questions divided into four parts; a number of indices were calculated based on the question that students answered correctly.

A large majority of students (70%) indicated evolution was an established scientific fact and less than 4% of students felt that evolution was unsupported by evidence. The level of acceptance was related to the "self-assed level of understanding, Darwin index score, and theory index score" (p. 794). Interestingly there was not a relationship between acceptance and the time since an individual had taken an evolution course. There was a positive correlation between acceptance of evolution and understanding of evolution (represented by the Darwin index score). When asked to rate their views of understanding of evolution, most students (60%) gave themselves and their peers a rating of *good*. Students who had taken a course in evolution were much more likely to rate their understanding as *high* than students who had not taken a course in evolution. Very few of the individuals (8%) rated the public's understanding as *good* and the majority (65%) felt it was *poor* or *very poor*. Students also appeared to have issues with some of the aspects of science. The mean calculated Darwin index score was about 74 on a scale of 100. This indicated the students accepted Darwinian explanations rather than other alternatives, with a low adherence to non-Darwinian explanations.

Almost three fourths of the students agreed or strongly agreed that a theory in science means something different than in everyday usage. A number of students (40%) did not disagree with the statement that theories are promoted to facts when they are supported by evidence. However, 70% agreed or strongly agree that theories do not become facts but instead explain facts. At least one fourth of the students appeared to have an issue with the concept of a *theory in science* (misunderstood, neutral, or unsure). This was less of a problem amongst students who were had a background in basic sciences. The researcher found a positive correlation between the understanding of scientific theories, acceptance of evolution, and the Darwin index.

This study served to investigate a valuable niche in the evolution education research, that of graduate students. However, a weakness of this study again hinged on the instrument used. The survey was created based on other available instruments and new questions were also created. Instrument pilot testing, construct validity, or reliability were not reported for the survey. Additionally, the scoring process (including any inter-rater reliability) was not reported for the two open response questions.

With the theme of religion and its impact on evolution, Ladine (2009) examined the attitudes of students at a private Christian university towards the teaching of evolution. The researcher asked students to complete a 15-question anonymous survey to determine the most comfortable learning environment when learning about evolution. The survey was administered to selected education courses that were being taught by the researcher in 2008 and a total of three hundred and eleven students took part in the survey. The survey also included five questions that examined a student's understanding of science and evolution.

The results showed a number of interesting elements. For instance, slightly more than 37% of the students indicated no knowledge pertaining to the definition of evolution. The researcher indicated that this "appears to contrast to the findings of other surveys that belief and acceptance of evolution are negatively correlated" (p. 391). Older students (seniors) and students with a greater science background (three or more classes) were more likely to provide the correct definition of evolution. Biology majors were also more likely to answer correctly than nonmajors. When asked about their learning preference, approximately equal numbers of students had a preference for including the science supporting evolution and showing how evolution affected them, or including creationism and intelligent design but showing how the two are not science. About one third of students indicated that the professor should accept creationism and intelligent design as scientific theories and should teach them in that manner. Students appeared to be open to the teaching of evolution as long as it was taught in the proper context. A limit of this study, which appears to be consistent with others of this nature, was the lack of a discussion of the research instrument.

O'Brien, Wilson, and Hawley (2009) discussed the development of an evolution course and its impact on students. The "Evolution for Everyone" course was assessed at Binghamton University in the fall semester of 2009. The course was taught in a modular format that included topics on economics, mating and dating, personality and strategies, and cultural psychology. When they could, the course included "experiments" (games and surveys) to help with the topics covered. The course was also designed around scientific methodologies, following a scientific paper format. The instructors spent time in the first week of class delineating between a *fact* and *the theory of evolution* as well as going over methodological approaches. The researchers tried to ascertain the impact of the course by administering an *Evolutionary Attitudes and Literacy Survey* at the beginning and the end of the semester.

The assessment used six scales to assess belief systems, attitudes toward evolutionary theory, and knowledge about scientific topics. The survey also included background information on politics, religion, major, class level, and experience with courses teaching evolution during high school. According to the findings, the average individual was receptive to evolution and did not support creationism or intelligent design. At the start of the course, an individual's high school experience with evolution was positively associated with factual understanding and evolution relevance. Students studying physical sciences reported lower scores on the Relevance scale than other individuals. Christians, Jews, and individuals scoring high on the liberalism scale reported fewer social objections to evolution, although liberalism in Christians was found to associate with more social objections. Factual understanding and Relevance increased after the course and the initial factors influencing views on evolution were not present at the end. Higher levels of political activity were associated with higher scores in knowledge and attitudes. Generally, students of all backgrounds benefited from the course, but liberalism in Christians was associated with less growth in knowledge. Biology majors had a greater change in their factual understanding than others, which may have been due to taking other biology courses. Beliefs typically negatively associated with evolutionary theory were low to start with in the course and did not change over the semester. This study could have been improved by including interviews with students to determine if the survey actually matched their views on evolution and religion.

A comparison between a secular college and a religious college was carried out with the goal of determining the relationship between academic level and acceptance of evolution by Paz-y-Mino and Espinosa (2009). Four hundred and seventy six students at Roger Williams University served as the research population for the secular institution, while three hundred and fifty five students at Catholic Providence College was the population at the religious institution. Students completed a six-question survey that was administered approximately four weeks into the semester at each school. The six questions asked about students' views on evolution in science classes, their understanding of intelligent design, their reaction to evolution, their position on teaching human evolution, the inclusion of evolution in science exams, and their willingness to discuss evolution.

Their findings included more biology majors at both colleges (64%) versus non majors at the secular (42%) and religious (62%) supported teaching evolution exclusively in class. When asked about intelligent design, secular biology majors (24%) were less likely to see it as an alternative to evolution than other groups. A large percentage (76%) at both colleges accepted an evolutionary explanation about the origin of life. The majority of students at both colleges (86% for biology majors; 79% for non-majors) preferred to have science classes that discussed human evolution. A much larger percentage of biology majors (66%) accepted evolution openly and/or privately than nonmajors (46%). The acceptance of evolution amongst biology majors increased at both institutions as students moved from freshman to senior year. The authors thought a possible explanation might be the increased exposure of evolutionary content in biology classes.

This study was limited by the lack of discussion surrounding the study instrument. The researchers did not describe how it was developed or whether it was pilot-tested. They also did not describe how individuals were selected for administration of the survey – no information was provided about the site selection process, the courses in which it was administered, or the modality in which the students were given the survey.

Different curricular approaches in the instruction of evolution were the focus of Heitz, Cheetham, Capes, and Jeanne's (2010) research. The researchers developed a number of online modules to help improve the students' understanding of challenging concepts in biology. Two of the modules were designed to cover evolutionary concepts, *Natural Selection and Species* and *Speciation*. In the Natural Selection module, students go on a virtual trip with Darwin around the world, play a game called "Fitness Fever" and examine a simulation of peppered moths. Students in the Species and Speciation module look at the meaning of the term *species*, examine the impact of geology of speciation, and explore two case studies.

The researchers examined the effectiveness of the online modules, as compared to lectures, in the first semester of their two-semester introductory biology course. All students (N=283) were given a bioinventory test one week before, and one week after, three lectures on speciation. After the posttest, students were divided randomly into three groups – the first group completed the online module, the second group received the material from the online module in PDF form, and the third group was given a multipart homework question as well as one case study in PDF form. After completing the assignments, the two modules were opened and students could voluntarily complete them. The researchers replicated the study in the second year with 186 students. Unlike the first year, however, students were not required to complete the modules and grades were not assigned. The researchers used self-report data to determine the students who completed the assignments.

In the first year of the study, all of the student groups had significant improvement from pretest to post test. In all cases the scores were low on both tests, and the students with grades in the class of 80% or higher accounted most of the improvement. Students in the interactive module group with class grades less than 80% did better on the evolution questions and the third exam of the semester. A large percentage of these students (73%) voluntarily completed the second module while only 11% of groups two and three completed the second online module. The researchers found that the interactive nature of the online modules was better for students than simply reading the information in PDF form. These students increased their exam scores by approximately 10.5 points. In year two, the individuals who participated in the modules with grades lower than 80% had an increase of about 4 points on the exam. The other groups experienced decreases on their third exam. When comparing the data from year one and year two, the researchers found that the voluntary nature of the assignments (as well of the lack of grades) did not promote thorough and complete participation in the modules. The researchers acknowledge that the lack of value attributed to the modules may not have been helpful for the students.

There are a number of issues with this research study. One of the major issues revolves around how the researchers looked at the learning gains of students on the third exam. Students answered different (but similar) questions on the pretest and posttest, but these questions were not reported in the study. The researchers compared a known assessment exam to questions that had not been examined for content validity or reliability. Additionally, the researchers depended on self-reported data concerning the use of the interactive modules. It is therefore difficult to fully ascertain the impact of the online modules since we do not know how many students actually used them or the time-frame in which they used them.

Jakobi (2010) also examined the lack of understanding of evolution with college freshmen in an introductory biology course. He asked the students to answer three questions: to define evolution; whether they agreed with the concept; and why they agreed or disagreed with their definition. Over the course of five years the researcher collected 306 surveys from students. The student responses were divided into six categories – *organisms adapt themselves to their surroundings*, *organisms go from simple to complex or advanced*, *changes occurred over a long time*, *apes to humans, other*, and less correct answers. About 42% of the students provided a teleological response (organisms adapt themselves to their surroundings), 13% identified organisms going from simple to complex forms, 15% said changes occurred over time, 7% said apes went to humans, 17.6% provided responses that were difficult to categorize or lumped a number of items together, and only 5% of the students provided relatively correct responses. Students who disagreed with their statements concerning evolution often stated religious reasons, even though the professor had not asked for explanations. The researcher identified terminology, in particular the different meanings in different areas, as one possible issue with understanding evolution.

Although Jakobi collected data over a number of years with a large population of students, there were issues with the study. He clearly points out the limitation of the research study – that he is not using a scientifically validated instrument. He does not adequately report if any individuals were missing from the sample, or the grading framework. Inter-rater reliability was not established or utilized in this case.

Misconceptions concerning evolution have not been limited to American students, as Pazza, Penteado, and Kavalco (2010) discuss. The researchers interviewed 231 freshmen who were attending classes in biological sciences, exact sciences, and human sciences. A ten-question questionnaire about major issues in the field of evolution was used for the interviews. The total average for the students was 48.8%, with highest average belonging to the biological sciences group (58.7%). An ANOVA analysis showed a significant difference between biological sciences and the other areas. On the ten-question assessment, students had a number of difficulties with questions on natural selection and the source of variation. Students did not appear to know about “the role of random effects, variation, and natural selection in evolutionary processes” (p.112).

This study was limited in that the assessment tool was not thoroughly discussed in terms of its validity and reliability. Jakobi did not indicate if the instrument had been pilot-tested prior to the research study. A pretest/posttest model would have been appropriate to see if there were changes as students progressed in their courses.

Paz-y-Mino and Espinosa (2010), building on their earlier research, compared the views about evolution, creationism, intelligent design, and religiosity of New England Faculty and college students. Thirty five academic institutions in the New England area served as a sample, with each state (Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont) providing two public secular colleges, two private secular colleges, and two religious colleges. The researchers contacted 992 faculty members by email in two distinct groups – biology or biology-related faculty, and non-biology faculty. Two hundred and forty four faculty members and six hundred and forty four students responded to an eleven question anonymous and voluntary survey.

The survey included seven questions regarding participant views about evolution, creationism, and intelligent design, two questions on how evolutionary processes work, and two questions about their personal convictions about human evolution and their religiosity. The researchers found a number of differences between the student and faculty responses. The vast majority of faculty (96%) supported the exclusive teaching of evolution while 72% of students supported the exclusive teaching of evolution. A very small percentage of faculty (4%) supported equal time for both topics, while 28% of students favored equal time. Almost all faculty members (92%) versus 52% of students held the view that intelligent design was not scientific or relied on false claims or a religious doctrine such as creationism. Most of the faculty and students (96%) preferred science classes that included evolutionary processes and human evolution. Very few faculty members (3%) compared to 23% of students thought that evolution and creationism were in harmony. Eighty two percent of faculty and 58% of students thought that evolution is definitely true. Although most (92%) of the faculty and students thought that evolution relies on common ancestry, 25% of the faculty and 33% of students did not know that humans are apes. A surprisingly large number of students (72%) and faculty (30%) ascribed to a Lamarckian belief of the inheritance of acquired traits.

Epistemological beliefs, the nature of science, and conceptual change were recently the focus of a study by Cho, Lankford, and Westcott (2011). The researchers conducted their study on a biological anthropology course between 2006 and 2007 at a Midwestern University. The study involved a total of 133 students; 57 and 76 students in each semester. Students took three assessments: the *Epistemological Beliefs Inventory* (Schraw, et al., 1995), a *Nature of Science* (NOS) assessment created by pooling questions from two other surveys, and an *Understanding Evolutionary Theory* survey that the researchers developed using previous surveys on conceptual change. The *Episemological Beliefs Inventory* and the *NOS* survey were given at the start of the semester, the *Understanding Evolutionary Theory* survey was given at beginning and the end of the semester.

In regards to epistemological beliefs and NOS, the researchers found that simple knowledge beliefs were negatively correlated with the tentative aspects of the nature of science. Additionally, they discovered a negative correlation between omniscient authority and both tentative aspects of NOS and the sociocultural nature of scientific knowledge. The researchers also found that students were less likely to experience conceptual change if they believed in fixed ability and that knowledge comes from authority. The researchers did not find a relationship between NOS and conceptual change in evolution. The authors made the blanket conclusion that immature epistemological beliefs are negatively correlated with tentativeness of scientific knowledge. Students who also see knowledge as certain and coming from authorities are not likely to identify the influence of social and cultural contexts in science.

Unfortunately, this research study is plagued by a number of issues. These issues particularly apply to the assessments used in the research study. The two assessments dealing with NOS and evolutionary theory were constructed from existing surveys, and as such, any prior validity or reliability for those measurements is not applicable. In addition, the researchers did not report any of these values for the newly constructed measures. The instruments also were not reported to have been pretested or examined previously in any fashion. The researchers also did not report what questions were used from each of the surveys. They also failed to describe the teaching methodologies and processes employed.

Moore, Brooks, and Cotner (2011) explored how college students' knowledge of evolution was related to their religious beliefs and their high school biology courses. The researchers surveyed 179 students in introductory biology courses before the start of classes at the University of Minnesota. Students were asked about the evolution content of their high school biology courses, and answered ten questions on evolution-related items and their religious beliefs. Students were asked to report their religious beliefs as *conservative*, *liberal, middle of the road*, or *nonexistent*. The questions on evolution were from the *Knowledge of Evolution Exam* (KEE), which had previously been tested over several years.

The results demonstrated a number of interesting findings. For instance, 13% of students said they were not taught either creationism or evolution in their high school classes, while 22% said their high school biology courses included both topics. The majority of students (62%) indicated that only evolution was taught, although a small minority (2.6%) reported being taught only creationism. The researchers also found limited evolution knowledge amongst the college students, with the mean score on the KEE being 53% and the highest subset 57%. Religious views were highly variable amongst this population, 35% were liberal or progressive, 28% were moderate, 28% were atheistic/agnostic/not religious, and about 10% were conservative. Students only taught evolution in their high school biology courses scored on average 1.5 points higher on the KEE than students who were taught neither topic. Students' evolution knowledge appeared to be strongly correlated to their religious views and evolution content of their high school biology courses. Conservative or moderate-belief students scored one point less on the KEE than liberals/progressives or atheists/agnostics/nonreligious students.

This study was limited in a number of ways, one of which was identified by the researchers. The researchers acknowledged the possible inaccuracy of the students' reports on the content of their high school biology courses. This may have been strengthened (although making it more cumbersome and possibly impossible due to time restrains) by following up with their high schools concerning the content of the biology courses. A limitation ignored by the researchers was that no explanation was given for the decision to split the religious beliefs into the four categories, as opposed to having the students report their religious affiliation and religiosity.

Winslow, Staver, and Scharmann (2011) attempted to determine how Christian university biology-related majors perceived the conflict between evolution and their religious beliefs. The research study took place at a Christian liberal arts university and involved current and recent graduates of the college who were biology-related majors. Each of the individuals had completed an evolution course title *Origins*. Fifteen students participated in the study by completing semi-structured interviews, an *Evolution Attitudes Survey*, and by writing scholarly papers. Two interviews were conducted – one that examined faith, and the other examined the perceived conflicts between evolution and personal religious beliefs. Interviews took place about one week apart. The second interview also included the *Evolution Attitudes Survey*. Additionally, a scholarly paper was completed to assess students' views on evolution. A total of 41 codes were developed from the first two interviews.

Interview results showed that students fell into three main categories – *young earth creationism*, *progressive creationism*, and *theistic evolution*. The majority of participants (13 of 15) students were grouped into the *theistic evolution* category at the time of the study. Only one of the fifteen students did not accept evolution. Most of the participants had been raised to believe in young earth creationism. Upon entering college most of the participants had antievolution views, but they came to accept evolution as God's mechanism for creation. Most of the anxiety related to accepting evolution stemmed from the influence of their parents. Eight of the participants had indicated that their parents had expressed a strong belief in creationism and that they were expected to share those beliefs. Many of the students were pressured by their parents to reject evolution, and the antievolution rhetoric from their childhood continued while at the university. At least five of the participants described heated arguments with their parents, and many of the participants reported emotional stress.

When considering the participants' views on science and religion, the researchers found that the participants valued science as a way of knowing but they also trusted and were committed to their religious beliefs. These participants wanted a positive relationship between these two items and expressed a desire for coexistence in a compatible fashion. Most of them viewed science as separate, but interacting, domains, some viewed them as integrated, and none of them viewed them as separated and isolated. Most of the participants accepted evolution as a valid theory and accepted human evolution. They did so through a reconciliation process between evolution and religion. The majority of participants "discussed an affective response to learning about evolution in the context of their university studies" (p. 1040). The bulk of the participants accepted evolution through a long process that took several years. They identified apprehension coming from the awareness of changes in their beliefs as well as how they would defend their acceptance of evolution to their parents.

Four major factors helped individuals accept evolution, including: evidence for evolution; a non-literal interpretation of the Bible; the belief that acceptance would not jeopardize their salvation; and the Christian professor who served as a role model. This was a very small population, with a particular focus on a certain university and student type. As a result it is very difficult to generalize the findings from the study to the larger population.

Teacher understanding of evolution

As the source of knowledge in the classroom, the understanding that teachers exhibit related to evolutionary theory can present both a hindrance and boon to students' understanding of this scientific theory. Teacher understanding will be examined here in relation to the study types – the initial studies are not survey dependent.

Scharmann and Harris (1992) investigated how well secondary science teachers understood the nature of science and accept the theory of evolution in the context of a 3 week

NSF-funded institute. Nineteen teachers, 6 exclusively biology, 2 earth science, and 11 who taught both, served as research participants. During the first two weeks of the session, teachers were "required to actively engage, both formally and informally in discussions related to direct content information presented on both biological and geological themes" (p.378). Teachers were also asked to discuss the instructional activities that were "designed, taught, and modeled" (p.378). The activities included field trips, lectures, question and answer sessions, small group discussions, and inquiry activities. Data on the teachers was collected on the first and last day of the institute. The *Nature of Science Scale* was used to address the question of "how well do secondary science teachers understand the nature of science and accept the theory of evolution?" (p. 377).

The results indicated a significant increase in applied understanding of the nature of science, but not philosophical understanding of the nature of science. Additionally there appeared to be a significant increase in understanding and acceptance of evolution. A follow-up workshop 8 months later included 9 of the original nineteen teachers, and found a slight decline in most of the measures that were used in the original data collection. However, none of the declines was statistically significant. The researchers found that the institute may also decrease anxiety related teaching about evolution. Therefore, institutes that provide teachers with training in instructional methods for the nature of science, inquiry, and evolution may prove effective at modifying teacher understanding of evolution – thus impacting their students.

Zuzovsky (1994) examined a course that was aimed at getting "student teachers to learn about the development of evolutionary thinking by analyzing their own explanations to several phenomena involving evolutionary processes and comparing them to historical, scientific explanations and to children's explanations" (p.559). The study participants were third-year student teachers, many of whom had “specialized in biology in high school and studied the topic of evolution” (p.559). The student teachers had extensive teaching experience “some even taught a topic on human evolution to sixth graders as part of their field experiences” (p.560). The class was taught twice, with about 20 individuals each time. An introductory activity used questions from earlier studies, to which the student teachers answered in written form. Students compared their responses to biology textbooks, and then identified and discussed discrepancies. Interestingly “many of them who realized that they held Lamarckian conceptions regarding evolution either expressed embarrassment or were apologetic” (p. 560). This initial step of identifying the student teachers’ understanding was followed by historical discussions related to evolutionary theory. The third component of the course involved students assessing their initial reports using a category system developed by the instructor. Student teachers identified the type of argument they were aligned most closely with, followed by reflection on their responses, discussing similarities between their preconceptions and milestones in the development of the evolutionary concept. Students then read and prepared presentations based on studies related to children’s misconceptions. The student teachers conducted mini-research projects on misconceptions regarding evolution, and then the study was replicated with first-year student teachers.

The findings revealed that first-year and third-year students were predominantly unchanged in giving Lamarckian explanations, with third-year students showing only a small decrease in Lamarckian conceptions. Students assessed their own ideas and those holding “Lamarckian ideas, in spite of their education and their background – perceived themselves as captives of some intuitive, strongly appealing folk ideas that reflect their belief system and that are, as such, extremely resistant to change” (p.565). Although the author did not notice substantial change in students' explanations, she reported that she was positive about the experience of the course. She also felt that using a constructivist learning approach that had students considering their own beliefs, preconceptions, and views on science was an important tool. A number of students expressed interest in the subject from the beginning of the course, and found it valuable to identify their own ideas related to evolution and the scientific enterprise. One issue with this course would have been to use the initial questions as a follow-up survey to see if views had changed as students entered the full-time teaching arena.

Even if teachers have extensive science backgrounds, they may still have limited views of evolutionary processes. Crawford et al.'s (2005) study on 21 prospective teachers in a science inquiry environment found that participants in the study initially demonstrated "alternative understandings of evolutionary concepts" and "uninformed understandings of the nature of scientific inquiry" (p. 631). This occurred despite extensive science content backgrounds and experience in scientific research settings. Additionally, the researchers were alarmed at the prospect that these advanced college students held "naïve, alternative, or partial conceptions of evolution and less-than viable notions of the nature of scientific work" (p. 633, Crawford, et. al, 2005). Pre and posttest results (based on Bishop & Anderson, 1990) show that the understanding of students became more scientific – but only for one third of biology teachers and two thirds of non-biology teachers. One limitation of this data is the small sample size. These future teachers were involved with authentic learning contexts that involved elements of the nature of science and inquiry. Teachers used a software program to consider data, generate hypotheses, develop alternative explanations, and evaluate scientific arguments. This research study stressed an important theme in the evolution education literature – students need to be presented with opportunities that will allow them to identify and evaluate their prior conceptions.

Oliveria, Cook, and Buck (2011) conducted a research study dealing with how evolution was framed in the context of project-based curriculum. The research study focus was a ninth grade section of an integrated Biology Literature class at a large high school. Forty six students participated in the study as well as a first-year biology teacher; the class was on block scheduling. The evolution unit had been designed by the teacher and the goal was to have students research the evidence for and against evolution. Students started the class by participating in three whole class discussions that provided them with information about evolution and the evolution debate. Students then worked on their projects in small groups of three, these projects focused on examining different lines of evidence related to evolution, teaching about evolution in schools, and the age of the earth. Students also read the book *Inherit the Wind*.

The researchers found that the teacher focused on creating a positive social environment rather than on conceptual change. The teacher promoted a less authoritative social structure during the discussion. The teacher was less authoritative and less imposing when dealing with more controversial parts of the discussion. When the teacher discussed microevolution, he shifted to a more authoritative stance, while with macroevolution he shifted to a less authoritative stance. During these discussions he used more tentative language and appeared to remain neutral or distanced himself from ideas. When talking about the requirements for teaching evolution the teacher framed evolution as partially obligatory and partially voluntary in nature. The teacher also created a moderately humorous mood during discussions about evolution. The teacher had strong orientation to nature of science ideas while a weaker orientation to historical figures. The teacher was focused on politeness rather than standard concepts and for the most part maintained a non-authoritative social structure. This study was limited in the fact that it focused on a small number of students in a classroom that had a new teacher. As such, the findings might not be generalizable to other settings.

Survey-based research of teacher understanding of evolution

Teacher understanding of evolutionary theory has predominantly come from surveys administered to current teachers and preservice teachers. While the surveys over the years have supported some consistent themes, they still rely on self-report data and are limited in their use of open or short answer responses to flesh out the information gleaned from the surveys. Qualitative research methods coupled with quantitative surveys would have strengthened these results. These studies are presented here because they share the survey as the main method of data collection.

Van Koevering and Stiehl (1989) examined evolution and creation among Wisconsin biology teachers. The researchers used a stratified sample of teachers and sought to get 10% of teachers in each sample area. A total of 146 questionnaires were returned after contact by mail or at a national convention. The questionnaires asked questions about teachers' experiences with teaching evolution, their views on how evolution was covered in textbooks, how important the evolution debate was to them, and how they taught about the origin of life.

About one fifth of the teachers had been asked by individuals in their community to change how they taught evolution. The majority of teachers did not support the de-emphasizing of evolution in biology textbooks. Most teachers indicated that the coverage of evolution in a textbook would not impact how they taught evolution. A large percentage of the teachers also opposed a law giving equal treatment to evolution and creation. Only "30 percent of the teachers responding to this questionnaire actually committed themselves to promoting either evolution or creation as the only explanation that is supported by scientific evidence; only four percent favor creation." This study was limited by the population used (teachers in the Midwest) as well as a lack of discussion of pilot-testing of the survey. The validity and the reliability of the instrument were not reported.

South Dakota teachers served as the focus of Tatina's (1989) study in considering the teaching of evolution and creationism. The researcher surveyed high school school teachers to determine whether they believed in evolution, whether they were pressured to teach either creationism or evolution, whether they viewed religion and creationism as equal, whether religion was acceptable in public schools, and what amount of their course they devoted to teaching evolution/creationism. A 23-item questionnaire was mailed to teachers at each of the 200 high schools in South Dakota. Biology teachers were asked to fill out and return the item. A total of 99 teachers completed the surveys from 93 high schools.

The majority of courses (72.7%) included evolution, while some courses (16.3%) included creationism. When evolution was taught, teachers spent an average of 5.3 class periods on the topic; when creationism was taught teachers spent 3.0 class periods on the topic. The majority of teachers (80.6%) were satisfied with the coverage of evolution in their textbooks, while only 49.6% indicated satisfaction with creationism. A little more than 11% of the teachers indicated they had been pressured not to teach evolution and about 9% of the teachers had been pressured to teach creationism. About 40% of the teachers felt that introducing creationism brought religion into the classroom. When asked about their acceptance of the modern theory of evolution, 73% indicated a belief in evolution, while 86% felt most scientists accepted it. When considering the validity of theories, 75% of teachers thought that the theory of evolution was scientifically valid, while 34.3% of teachers thought creationism was scientifically valid. A large percentage of teachers (39%) thought creationism should be taught in public schools. Finally, a large number of teachers did not appear to understand evolution, since 27% identified it as "purposeful striving" (p.278). In a similar vein as the prior study, the research instrument was not adequately discussed. The development of the instrument (including pilot testing, content validity, and reliability) was not reported.

The role of pseudoscientific beliefs was explored with high school biology and life science teachers by Eve and Dunn (1990). The researchers used names from the *National Science Teachers Association* data to identify a random sample of 387 teachers. These teachers were sent a questionnaire that included demographic information and their opinions on a range of pseudoscientific beliefs. The items also tried to determine the likelihood that they presented the material in class and if they were pressured by any individuals concerning teaching topics. The final results included a sample of 149 teachers.

The researchers found that teachers have many pseudoscientific beliefs. One major finding was that many (30%) portrayed a view that was *labeled as Biblical literalism in* that their expressed views adhered to Biblical literature. Eleven of the items were collectively placed in this group due to the number of responses. Twenty seven percent of the teachers saw the Bible as the authoritative and reliable source on scientific issues, like the age of the earth and origin of life. A large group (19%) believed that humans and dinosaurs existed at the same time. Forty five percent of the teachers supported creationism, and 30% of the teachers would teach only creationism if they had to choose between that and evolution. A large percentage (39%) of teachers indicated there were problems with the theory of evolution which cast doubt on its validity. Other non-Biblical pseudoscientific beliefs included the view that individuals could communicate with the dead, people can predict the future with psychic powers, and that astrology predicts an individual's destiny. A duality with the samples was discovered - although there were high numbers of teachers with pseudoscientific beliefs, there were also many teachers who indicated strong disbelief in the items.

The researchers did not discuss how the instrument was developed, whether it was pilot-tested, or the extent to which it was assessed for content validity and reliability. The population size was also relatively small (149) when considering the type of instrument used (a survey).

Osif (1997) surveyed Pennsylvania high school teachers to examine the relationship between evolution and religious beliefs. An 84 question survey was used that included 24 questions from the *Christian Orthodoxy Scale*, and 14 statements were written from beliefs "held by the National Association for Evangelical" (p. 552). A random sample of 50 schools yielded 21 schools that agreed to participate. Eighty seven responses were gained from surveys sent to 132 teachers. The sample study population included English and science teachers. When asked if the theory of evolution is central to the study of biology, 66.7% of English teachers and 68.4% of science teachers agreed. On a discouraging note, 14% of English teachers disagreed with the statement, as did 22% of science teachers. In all, about one third of teachers indicated that evolution was not central to the study of biology. No significant difference was found when teachers were asked if creation science should be taught in the public school. Surprisingly, teacher views do not appear to change depending on the study of biology. The author suggested a need to include the study of the philosophy and methodology of science in teacher education. A number of issues related to this study included information regarding the sampling methodology used, the actual survey instrument was not included, and the survey instrument did not appear to be pilot-tested or measured for validity and reliability.

Aguillard (1999) also examined teacher attitudes related to evolution and creationism. In this survey, Louisiana biology teachers reported a slightly higher indication (84%), that the theory of evolution has a valid scientific foundation. Selected interviews with 18 teachers showed that 61% of responders believed that evolution had a valid scientific foundation. Forty three percent of teachers indicating that evolution was scientifically valid allocated more than five class periods to evolutionary theory. A correlation was found between teacher belief related to the scientific validity of evolution, emphasis on evolution instruction, and belief regarding evolution as appropriate. In relation to training, 62% of survey respondents agreed that academic training was adequate for teaching evolution, while 27% indicated that academic training was inadequate. However, only 22% of interview subjects reported adequate training, with 78% inadequate. Somewhat discouraging was that 52% of respondents agreed that all Louisiana students were capable of understanding the theory of evolution. Thirty five percent of teachers also reported some time devoted to creationism (between less than 30 minutes and more than 60 minutes). An important additional finding was the relationship between emphasis placed on evolution and college semester hours in biology and college courses dealing specifically with evolutionary theory. Teachers who have more experience with evolutionary theory are more comfortable teaching it and feel that it is more important to biology (unifying theme).

Understanding nature of science may have an influence of understanding evolution. Rutledge and Warden (2000) examined the relationships between teacher understanding of the nature of science and acceptance of evolutionary theory through survey instruments received from 552 Indiana public high school biology teachers. Some disheartening results were identified - teachers only had a moderate understanding of evolutionary theory, with teachers answering correctly on only 71% of items. Teachers also had a moderate level of understanding of the nature of science, with only 70% of teachers answering all eight items correctly. Significant relationships were found between teacher acceptance of evolutionary theory and both teacher understanding of evolutionary theory and teacher understanding of the nature of science. Teacher acceptance of evolutionary theory was directly related to teacher understanding of the nature of science (r=.76). At least one fifth of the teachers were undecided about or did not accept the scientific validity of evolutionary theory, that life in general, particularly humans, is the result of evolutionary processes, that evolution is supported by available evidence.

Rutledge and Mitchell (2002) extended the work of the earlier study by Rutledge and Warden (2000) by including concept maps with surveys of Indiana public high school biology teachers. It is not clear, nor is it indicated in the study, whether this data was collected at the same time as the earlier study – since the same number of teachers were reported to have participated in the survey. About half (235) of the teachers completed concept maps. Based on their concept map construction, the teachers were differentiated and categorized as *non-acceptance*, *undecided*, or *acceptance*. The non-acceptance group, supporting other research related to evolution education, depicted evolution "as an explanation of low scientific status" (p. 24). The undecided group had similar descriptions, while the acceptance group commonly noted evolution as a "well-supported scientific explanation" (p. 25). This is a relatively consistent theme throughout the literature. Survey data revealed that 80% of teachers who had a course in the nature of science accepted evolutionary theory, versus 60% accepting evolution that did not have a course in nature of science. Acceptance of evolution occurred in 80% of teachers who had taken a course in evolution and 61% those who had not taken a course in evolution. Despite the apparent importance of these courses to acceptance of evolution, only 31% of the respondents indicated that they had taken a specific course in evolution with only 33% taking a course in the nature/philosophy of science. While taking a course in evolution is not necessary to teach the theory and processes involved, it appears to definitely influence understanding and acceptance by teachers. Of great concern to science educators was the finding that 43% of the teachers "avoid or only briefly mention evolution in their biology classroom" (p.25). This aversion can be traced to a number of factors, a major one being religious beliefs.

Religious beliefs continue to be a stumbling block for instructors when they are teaching about evolution. In Trani's (2004) survey of high school biology teachers, he found that "teachers with extreme religious convictions scored nearly three standard-deviations below the mean on their acceptance of evolutionary theory, and more than two standard deviations below the mean on their understanding of evolution and the nature of science" (p. 424). It was also noted that 16% of Oregon biology teachers "do not present evolution, do not understand science, do not understand evolution, and have strong or extreme religious convictions" (p. 425). The researcher believed that while these teachers might reject evolution based on their religious convictions, they "may state that they reject evolution based upon their religious convictions, but their rejection of the evolutionary theory appears to be related to their lack of understanding the theory itself and their lack of understanding of the nature of science" (p.425). This supports my own research endeavor of teaching evolution using explicit instruction in the nature of science and inquiry-based methods.

Weld and McNew (2004) surveyed 224 life science teachers in Oklahoma to identify aspects of their backgrounds that might influence teaching evolution and their feelings on evolution, creationism, and standards. Seventy four percent of the respondents felt well prepared to teach evolution, yet only 57% viewed evolution as a unifying theme in biology (p.52). Sadly, about 25% of the teachers placed "moderate or strong emphasis on creationism" in their classrooms, and 48% “agree or strongly agree that there is much scientific evidence for creationism” (p.52). This emphasis on creationism is prevalent in science teacher studies, and remains an issue that needs to be addressed. As has already been discussed, teachers who better understand the nature of science are less likely to emphasize creationism.

Moore and Kraemer (2005) asked Minnesota biology teachers to answer a variety of questions about evolution education in public schools. Ninety-one teachers participated in the survey in 2003. Results of the survey were compared to findings gleaned from a similar survey in 1994. Confirming again the difficulty that some teachers have related to the nature of science, one-fourth of teachers believed that “creationism has a valid scientific foundation and 16% believe[d] that evolution is not a scientifically valid idea” (p. 463). The controversial nature of evolutionary theory was also exhibited, as teachers who reported pressure to avoid teaching evolution increased from 19% to 48% from 1995 to 2003. Most of this pressure was identified as coming from parents of students. Giving teachers the necessary set of skills and content background is extremely important to achieve student understanding of the theory of evolution - but training does not always guarantee this goal.

Deniz, Donnelly, and Yilmaz (2008) investigated the factors that impacted the acceptance of evolutionary theory among Turkish biology teachers. The researchers collected data from 132 Turkish preservice biology teachers from a university in western Turkey who were enrolled in a biology education program. Students’ understanding of evolutionary theory, acceptance of evolutionary theory, epistemological beliefs, and thinking dispositions were all measured. Understanding of evolutionary theory was measured using an instrument that was modified from Rutledge and Warden (2000). Acceptance of evolution was measured using the MATE, and epistemological beliefs were assessed using a 38-item questionnaire developed by Wood and

Kardash (2002). Finally, thinking dispositions were determined by using the *Actively-Open Minded Thinking* (AOT) scale (Stanovich and West, 1997).

The researchers found a significant positive correlation between knowledge of evolution and acceptance of evolution. Furthermore, a significant positive correlation was found between parents' education level and an individual's acceptance of evolution. However, only 10.5% of the variance in the acceptance of the theory of evolution was accounted for. They were able to find that understanding of evolution was related to acceptance of the theory. Students who were more open-minded were more likely to accept evolution, which was consistent with Sinatra et al. (2001). Also consistent with Sinatra et al. (2001), a relationship between epistemological belief and acceptance of evolution was not found.

A large percentage of students did appear to support evolution as a scientifically valid theory. On the MATE, the mean was a 50.95, which fell between a score of 20 (flat rejection) and 80 (highest degree of support). Although understanding of evolution increased with the number of years in the biology program, acceptance was not related with the number of years in the program. In terms of understanding, students answered less than half of the questions correctly with a mean of 9.29.

Ha, Haury, and Nehm (2012) recently explored the connection between knowledge and acceptance of evolution. In particular, the researchers examined what they called *feeling of certainty*, as well as the relationships between religion, education level, knowledge, feeling of certainty and level of acceptance of evolutionary theory. The research study involved 124 preservice biology teachers at two universities in South Korea.

Level of education was determined by the year in college in which they were in and students were asked to self-identify their religion. Evolution knowledge and acceptance were measured, as well as feeling of certainty. Evolution knowledge was measured using the *Conceptual Inventory of Natural Selection* as well as the *Open Response Instrument* that was modified from Bishop and Anderson's (1990) test. Three of the five questions were used. Students also took the MATE (Measure of Acceptance of Evolutionary Theory) to establish their acceptance of evolutionary theory. Finally, the researchers administered FOC (Feeling of Certainty) items that they drew of from prior medical research.

Scores from the CINS were comparable to other populations that have participated in this assessment as well as the ORI scores. The MATE scores for the pre-service biology teachers were slightly lower when compared to American biology teachers, although standard deviations of the participants were less than those populations of study. There was a significant difference in knowledge about evolution across education levels, but no difference in knowledge among religions. The researchers found that third-year teachers had higher MATE scores regardless of religion, while Protestant teachers had the lowest scores when compared to other religions.

The researchers used multiple regression analysis to determine the explanatory power of the variables included. With FOC there was a significant increase in the amount of explained variance in acceptance of evolutionary theory. FOC was also related to level of acceptance while knowledge level was not related to the level of acceptance.

One of the serious limitations of this research study was a general lack of discussion of FOC item assessment. The researchers did not describe who developed the assessment, how it was developed, the content validity and reliability, or the degree of pilot-testing prior to the research study. The researchers briefly indicated that their "FOC items were nearly identical to those used in this prior medical work" (p. 104). This is a serious issue with the findings of the study. Additionally, they used part of the *Open Response Instrument*, as opposed to the whole assessment.

Many of the studies concerning student and teacher understanding of evolution are discouraging due to the lack of understanding of evolution, as well as science in general. However, a connection between one's ability to comprehend how scientific knowledge is evaluated and generated and understanding of evolution appears to exist. Instruction that bolsters one's understanding of science may result in an increased understanding of evolution.

Nature of Science

What is the nature of science (NOS)?

Scientific endeavors are an integral part of most of the world's societies, thus an understanding of science is often stressed as an educational goal by scientific organizations and policy documents (American Association for the Advancement of Science [AAAS], 1989; National Research Council [NRC], 1996). A general understanding of science, or scientific literacy, is part of the National Science Education Standards (NSES) here in the United States (NRC, 1996). Before the development of the NSES, AAAS' Project 2061 made a strong case for scientific literacy in *Science For All Americans* (1989). Scientific literacy is the "knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (NRC, 1996, p.22).

One of the major components of the science education standards, as well as scientific literacy, is an understanding of the history and nature of science (Driver, 1996). Why should the nature of science be understood by the public? Driver (1996) indicated five arguments for the importance of learning about the nature of science - utilitarian, democratic, cultural, moral, and science learning (Lederman, 2006). Learning about, as well as understanding, the nature of science will allow individuals to: make sense of science and manage it as they encounter it; make sense of socioscientific issues and participate in decision making process; help individuals appreciate science as a major element of contemporary culture; develop an awareness of practices of the scientific community and the moral commitments; and successfully learn science content. The arguments in favor of an understanding of the nature of science beg the question - what is the nature of science?

According to Lederman (1992), the nature of science is used to refer to the epistemology of science, science as a *way of knowing*, or the values and beliefs inherent in the development of scientific knowledge. The nature of science, or NOS as it is often abbreviated in the literature, has been the subject of intense research in science education. This research embodies four major areas as described by Lederman (1992). These include: students' understandings of the nature of science; the analysis of methods used to improve students' conceptions of the nature of science; teachers' understandings of the nature of science; and the relationship between teachers' conceptions, classroom practice, and students' conceptions (Lederman, 1992).

The importance of the teacher to student learning cannot be overemphasized. If teachers lack an adequate understanding of the subject they teach, then our students will be negatively affected. Research involving teachers understandings of science has consistently indicated that most teachers have naïve, uninformed, or simplistic views of the process of science (e.g. Abd-El-Khalick, et al., 1998; Abd-El-Khalick, 2001; Abd-El-Khalick & BouJaoude, 1997; Akerson, Abd-el-khalick, & Lederman, 2000; Craven, 2002; Irez, 2006; Kang, 2007; Lederman, 1992; Lederman, 1999; Mellado, 1997; Murcia & Schibeci, 1999; Tsai, 2002; Waters-Adams, 2006).

A common characterization of science espoused by research participants is the discovery of truths or science as a body of facts. This is a naïve understanding, but one which may be explained from a personal epistemology standpoint. College students are often found at the initial levels of these developmental models that view knowledge in absolute terms. Authority figures (such as teachers, professors, and scientists) are the caretakers and conveyors of this knowledge. Progressing to more advanced epistemological standpoints may not have occurred in teachers (especially those not yet engaged in the teacher field), thus simplistic views of knowledge may exist.

Personal epistemology and NOS

Epistemology is most often defined as the study of "knowledge and justified true belief" (Steup, 2006). Each individual evaluates knowledge in a different manner and each has a personal epistemology. When we are considering the epistemologies of individuals, we may conceptualize personal epistemology in a number of ways. The largest body of research indicates a "patterned sequence of development" in one's "beliefs about knowledge and knowing" (Hofer, 2001, p. 355). These models of personal epistemology may be traced to Perry's (1970) work with college students. Using a *Checklist of Educational Values* he initially interviewed 313 first year students, with follow-up interviews conducted with 31 students. From these interviews, Perry identified a pattern of how students viewed their world. Longitudinal studies in the following two years were conducted to fully form the model. Perry's view of intellectual and ethical development involves nine positions that can be grouped into four main categories: dualism; multiplicity; relativism; and commitment with relativism (Hofer and

Pintrich, 1997). One critique of Perry's work is his lack of investigation into epistemological development and student learning.

An understanding of the developmental stages/schemes is critical for understanding how individuals view science and scientific knowledge generation. It may also be helpful in explaining the consistent themes that researchers see in students' and teachers' understandings of NOS. The initial (and later) stages of epistemological development of Perry (1970), Belenky, Clinchy, Goldberger, and Tarule (1986), Baxter-Magolda (1992), King and Kitchener (1994), and West (2004) share common patterns in how individuals view knowledge. At the beginning stages, most individuals are absolutist - things are right or wrong, truths are to be "discovered." Perry's dualism, Belenky et al.'s received knower, Baxter-Magolda's absolute knower, King and Kitchener's stage 1-2, and West's stage 1-absolute, are relatively similar in the views of knowledge. Based on these stages, it is little wonder that students and teachers often characterize science as a body of facts or truths, rather than as a tentative construct. Lower stages often view knowledge as dispensed by authorities – which further compounds the issues in understanding NOS.

The relationship between personal epistemology and NOS may be addressed from the standpoint of the way in which knowledge is viewed. There are a number of elements that the various personal epistemology models generally have in common. In regards to the nature of knowledge, individuals progress from a view of knowledge as "absolute to a relativistic view and then to a contextual, constructivist stance" (Hofer and Pintrich, 1997, p. 119). The certainty of knowledge appears to move from lower levels where absolute truth exists to higher levels where knowledge is tentative and evolving (Hofer and Pintrich, 1997). Furthermore, views of knowledge as facts, concrete, and discrete occur at the lower level and progress to views of knowledge as relative, contingent, and contextual. When considering the source of knowledge, lower levels consider knowledge as residing in an external authority that may transmit the information, while the higher levels begin to construct meanings. Finally, justification of knowledge and knowing also changes from lower levels to higher levels. Individuals move from dualistic beliefs, to acceptance of multiple views, to finally reasoned justified beliefs.

If we examine the various tenets of NOS we can see the direct relationship to these shared elements in personal epistemology. Lederman (1992) described seven key aspects of science which included:

1. The distinction between observation and inference.
2. The distinction between scientific laws and theories.
3. All scientific knowledge is, at least partially, based on and/or derived from observations of the natural world.
4. Although scientific knowledge is empirically based, it nevertheless involves human imagination and creativity.
5. Scientific knowledge is at least partially subjective.
6. It is socially and culturally embedded.
7. Scientific knowledge is subject to change.

In particular, the NOS tenet numbers three to seven seem to have the strongest interaction with personal epistemology. The certainty of knowledge changing at higher stages to a view of tentativeness is directly related to scientific knowledge being subject to change. A change of view of knowledge from concrete to relative, contingent, and contextual is reflected in a number of elements of NOS that involve creativity, subjectivity, and social/cultural elements. The tenets of NOS also portray knowledge as constructed rather than from an authority figure. Reasoned justified beliefs are not as thoroughly explored in the tenets, but the empirical basis of knowledge and focus on observations support this aspect of personal epistemology. Justification of knowledge continues to be more and more of a focus in frameworks related to science education. The focus on evidence for justifying scientific claims is an integral part of new policy documents in educational settings. Changing personal epistemology could have a direct impact on the epistemology of science and vice versa – as we explore how scientific knowledge is generated in science classes it could change an individual's views on science and knowledge in general. One's views about knowledge as they enter classes could also have an impact on how they learn about science.

As previously indicated, an understanding/view of NOS may be influenced by the personal epistemology of individuals. One of the epistemological concerns in understanding the nature of personal epistemology is whether it relates to a particular discipline and context. Early personal epistemology research has assumed that an individual's views of knowledge and knowing are general and stretch across various domains (Hofer, 2000). Most of the research studies of the last decade have focused on discipline-specific issues related to personal epistemology. Hofer (2000) explored the dimensionality and disciplinary differences in personal epistemology of first-year college students enrolled in a psychology course. Her findings indicated that there is evidence of "an underlying dimensionality to epistemological beliefs that cuts across disciplinary domains, but those students do hold differing epistemological beliefs about 'disciplines' such as science and psychology" (p.400). In comparing the fields of science and psychology, students saw knowledge as more certain and unchanging in science than in psychology, were more likely to regard personal knowledge and firsthand experience as a basis for justification of knowing in psychology rather than in science, viewed authority more in science than psychology, believed that truth is more attainable by experts in science than psychology (p.394). In addition, the students' academic disciplines showed that individuals in the natural sciences were more likely than those majoring in social sciences to view truth as attainable. This, however, should not be considered to be a result of one's major field of study - but rather may be a self-select aspect of individuals who enter these majors.

Individuals in the United States do not demonstrate an understanding of how scientific knowledge is generated. According to the *Science and Engineering Indicators* (National Science Board[NSB], 2012), “42% of Americans exhibit an understanding of scientific inquiry in 2010, up from 36%”. When asked directly about how scientists go about their work, only 18% of Americans understood what it means to study something scientifically in 2010 (NSB, 2012). Regardless of which of these two values you consider, the bulk of Americans do not appear to know how science is conducted. In addition, Americans do not understand scientific experiments and controlled variables. As reported in the *Science and Engineering Indicators*, only 12% of Americans correctly answered all questions on a topic on experiments, and almost 20% did not respond correctly to any of them (NSB, 2012). This particular view may be the result of the use of experiments and evidence in science classrooms. Although numerous policy documents continue to advocate an increased focus on evidence and justification in science classrooms, the unfortunate state is that students are not engaged in these activities.

The use of evidence to support findings is critical to the generation of scientific knowledge. Unfortunately, students do not get an accurate picture of science in the majority of their science classes. This stems from the reliance on verification labs - whereby students are not challenged to develop ideas based on evidence. Instead, students are often reporting an already known value or conclusion, hence the moniker *verification labs*. The new K-12 frameworks strengthen the focus on students engaging in scientific practices, thereby learning how scientific knowledge is constructed. Resier (2012) argues students need to engage in and reflect on scientific practices to learn how the scientific community develops knowledge. Students need to investigate their own questions and work with these practices to come to an understanding of how scientific knowledge is generated. By participating in investigations of questions they create, students can make sense of how scientists work as opposed to simply confirming something in a textbook or lab manual. If these situations are not created in science classrooms, then students will not be able to challenge their current epistemic frameworks concerning the development of science and scientific knowledge.

In *Taking Science to School*, Duschl (2007) investigates a variety of elements related to student understanding of science and how scientific knowledge is created at the K-8 levels. This document is appropriate to use since, again, one of our goals in science education is to help create a scientifically literate populace. The pursuit of scientific literacy obviously begins in elementary school and continues through high school and college. Duschl (2007) indicated a number of ways that students learn science by:

> *Actively engaging in the practices of science, including conducting investigations; sharing ideas with peers; specialized ways of talking and writing; mechanical, mathematical, and computer-based modeling; and development of representations of phenomena.*

These classroom practices have a direct impact on how students learn science and could affect an individual's personal epistemology.

Research on students' epistemologies and the classroom practices

Smith and Wenk (2006) investigated the relationships between three aspects of first-year college students' epistemologies of science. Thirty five college freshmen, half from a private liberal arts college, and half from a large university, were the participants in the study. The freshmen were interviewed during the beginning of the fall semester. The researchers' working hypothesis was that the freshmen would have a simple differentiation between "scientists' ideas and evidence, but would not have made a deeper differentiation between scientists' theories and hypotheses wherein theories are seen as explanatory frameworks guiding hypothesis testing" (p. 753).

Students' epistemologies of science were identified using three different assessments. A modified NOS interview examined aspects of a student's views on evidence, theories, and hypotheses. Another assessment provided provocative statements to students concerning the certainty of knowledge to determine a student's conception of scientific truth. The final assessment presented students with a controversy and asked them to reason about it.

The researchers found that very few college freshmen understood that theories serve as a larger framework that help in the formation of testable hypotheses. Only 23% of the students thought that theories could influence hypotheses that scientists were testing. The majority of students thought that theories and laws were equivalent, that hypotheses lead to theories (but not in the reverse direction), or they misunderstood the question. The researchers determined that students do not view theories as the frameworks that drive all components of scientific inquiry.

When asked about the certainty of knowledge, 34% of students thought that science has the right answers to all questions, 23% of students thought science has the right answers to some questions with other questions unanswerable, and 43% thought scientific knowledge is uncertain. The researchers also found that all three measures of epistemological understanding were intercorrelated. An individual's ability to differentiate between ideas and evidence was related to their view of uncertainty in science and their reasoning ability about specific controversies.

This research study was limited in the aspect of the small population size as well as the lack of detail about the students – such as their demographic information and majors (they allude to some being science majors and non-majors).

Havdala and Ashkenazi (2007) examined the effect of epistemological theories on students' laboratory practices. The authors wanted to demonstrate that students who view science differently will employ different approaches when they examine theories and empirical evidence from labs. A total of 25 undergraduate chemistry students served as the population of study. Students were selected after an analysis of their lab reports and their work in lab. Students were interviewed during the second semester of their freshman year. During the interviews, students were asked to describe their views of science, the relationship between educational experiments and real science, and their approach toward work in lab and writing of labs. Three students, who had very different views of the connection between theory and evidence, were identified for a deeper analysis. Lab reports were also examined to see how theory was coordinated with experimental results. Analysis of the lab reports took place separately from the interviews.

The researchers identified a number of differences between how the students viewed science. These categories included: the basic component of knowledge in science; the purpose of scientific work; accuracy in science; the role of mathematics in science; and the way science is reflected in the students' lab (p. 1141). Students were labeled based on a focus that emerged from their interview responses. Daphne, a student who focused on "real science" had an empiricist view of science. Ted, who was focused on the mathematical aspects of science, had a rationalist-oriented view of science. Robert, who focused on the subjective component of science, had a constructivist-oriented view. Daphne, with her focus on experiments as real science, approached the lab by considering the theory and experimental procedure as a list of facts with equal footing. Ted focused on laws and formulas that he had been taught in other courses. Robert regarded knowledge as uncertain and considered the context of the experiments in relationship with the theoretical components.

The researchers found a relationship between the students' epistemological theories and their laboratory experiences. The constructivist student was able to coordinate between the theory and experimentation components of the lab, but the other two students could not do so. Their overconfidence in one area led them to an oversimplification of scientific knowledge. They ended up distrusting the uncertain components, instead of trying to coordinate the two areas. The way that the students approached the lab and how they worked on the lab were both influenced by the students' epistemological theory.

The main limitation of this study was the population of students used for research. The researchers chose students who "appeared to put effort into their work" (p. 1139). The selected population may not be representative of other students. Additionally, only three students actually served as part of the full analysis, as opposed to the 25 who initially started.

Trautwein and Ludtke (2007) attempted to discern the role of academic environment on predicting global and topic-specific beliefs. The researchers identified topic-specific beliefs as those epistemological beliefs that might vary across theories. They focused on the certainty of knowledge and that students who believed in certain knowledge would believe that scientific theories are certain or true. The attempt was made to discern if different views of knowledge existed in different fields of study.

They utilized standard *Epistemological Belief Questionnaire* items that they tailored to the topic level. The researchers modified epistemological belief items to relate to specific scientific theories. They also used a "decontextualized measure of certainty beliefs" to address the certainty issue (p. 914). Two studies took place, one with secondary students and one with college students (which was a replication of the first study).

A total of 662 secondary students in a German school participated in the first study. The questionnaire was administered in their regular school classes and was part of a larger study about students' future study plans. The students completed the *Epistemological Beliefs Questionnaire* and a topic-specific *Epistemological Beliefs Questionnaire* on the certainty of knowledge. Two hundred and eleven college students participated in the second study. The only variation in the study instrument involved providing students with ten theories on the topic-specific certainty items.

For the first study, the researchers found that there was a moderate overlap in certainty beliefs concerning the different theories. However, this was a lower association than that usually found in other research studies. They found higher certainty beliefs in students at an economics gymnasium than at a traditional gymnasium. There was a negative relationship between certainty beliefs and school achievement. They also discovered a significant association between the different belief types (global and topic-specific). Finally, students who reported being more familiar with a theory had a stronger belief in the certainty of that theory.

For the second study, there also was a moderate correlation between the topic-specific certainty beliefs. A student's major was a strong predictor of global certainty beliefs, with those individuals in fields like engineering, mathematics, and natural sciences reporting higher certainty beliefs. Major was a lower predictor for topic-specific certainty beliefs. There was a significant negative relationship between academic achievement and topic specific beliefs. Similar to study one, the researchers found a positive relationship between global and topic-specific certainty beliefs. As with study one, students who were more familiar with a theory had a stronger belief in the theory.

This study could have been strengthened in a number of ways. The study does not clearly indicate when the research instruments were administered for both groups. Interviews with small groups of students could have taken place to further confirm the views held by the student groups (only questionnaires were administered).

The interplay between scientific reasoning ability and epistemological commitments of students was investigated by Zeineddin and Abd-El-Khalick (2010). They found that both prior knowledge and epistemological commitments were positively related to the quality of scientific reasoning. When they controlled for prior knowledge, the researchers discovered a positive relationship between epistemological commitment (appreciation for the role of evidence in relation to theories) and the quality of reasoning. By focusing on the evaluation of evidence and its relationship to scientific theories in science classrooms, we may be able to improve an individual's reasoning ability.

While participating in an investigation-rich classroom, third-grade students described science as an "active endeavor involving testing or investigation" (Kittleson, 2011). When asked about how science knowledge is generated, students actually drew upon investigations for those explanations. However, students focused on tests for particular purposes thus demonstrating a narrow understanding of testing in science. Kittleson also connected research on epistemological beliefs and Duschl's (2007) description of student proficiency in science. Again, certain interactions in science classrooms may allow students to develop new views on the nature of scientific knowledge and knowledge in general. Science education that involves students in science practices may allow them to develop their reasoning abilities.

A recent study by Liu, Lin and Tsai (2011) identified a relationship between beliefs about scientific knowledge and the socioscientific decision-making process. Although other researchers have critiqued the tentative aspects of NOS, the researchers demonstrated a link between a students' beliefs about the tentativeness of scientific knowledge and the decision-making process. College students were asked to explore a controversial issue of environmental management and then completed two instruments – a 25-item *Scientific Epistemological Views* survey and a decision-making instrument. The researchers found that individuals who had tentative beliefs were more likely to consider the multiple aspects of the issue and to question authorities on the knowledge.

Teachers' epistemology and understandings of NOS

The personal epistemology of teachers may have a direct impact on how they teach and the topics that they teach. If NOS is a part of science education policy documents and teachers do not recognize or understand how scientific knowledge is developed, there no doubt will be issues in student learning.

Tsai (2002) investigated the relationships between teachers' beliefs about teaching science, learning science, and the nature of science. A total of 37 secondary school physics and chemistry teachers in Tawain were participants in the study. The researcher interviewed the teachers about their beliefs of teaching science, their beliefs of learning science, and their views about the nature of science. The interviews were analyzed and a framework was created to represent the teachers' beliefs about the various constructs. The framework consisted of three main categories: traditional; process; and constructivist.

The findings showed that more than half the teachers fell into the traditional category, with very few teachings in the constructivist category. Fifteen of the teachers held consistent traditional beliefs across the three categories, four held consistent process beliefs, and two held constructivist beliefs. While some teachers varied across the categories, only two individuals had divergent beliefs. Twenty one of the teachers had congruent beliefs across the three categories and fourteen teachers had congruent beliefs across two of the categories. The researcher referred to these consistent belief systems as nested epistemologies that included their beliefs about teaching and learning as well as about science.

The majority of teachers had a traditional view of science whereby they are a presenter of factual knowledge that is to be transferred to students. This may be a result of the teachers' school science experiences that have reinforced these views of science. Learning, for these teachers, was the reproduction of knowledge.

This study could have been strengthened by increasing the size of the study population. The researcher dealt with a highly selective population, which included physics and chemistry teachers. These teachers may not be representative of all science teachers, as their disciplines are different.

Akerson, Morrision, and McDuffie (2006) investigated the retention of NOS among preservice elementary teachers. A cohort of 17 graduate-level preservice elementary students served as the data source for the study. The students were all taking an elementary science methods course which served as the context of the study. The methods course included various NOS activities and reflective practices to encourage the preservice teachers to reflect on aspects of NOS.

Data collection included version B of the *Views on the Nature of Science Survey* (VNOS-B), which was given at the start and end of the course, as well as 5 months later. In addition, students were interviewed at the beginning and at the end of the course, as well as 5 months later. The researchers used the results to categorize the students into different Perry positions and examined what impact these positions had on their views of NOS.

As a result of the instructional intervention, all of the students initially improved their understanding of NOS. Five months after instruction, the researchers found that individuals at higher Perry positions (which they identified as 5 or 6) tended to retain most of their understandings, while those at lower levels did not. Those below level 5 reverted to original ideas more often than those at positions 5 or 6. Some level 3 and 4 students did retain improved views of NOS, which might be explained by their ability to make room for uncertainty. The views of NOS appeared to be contradictory to those individuals at the lower levels. Only the students at the higher levels retained the view that science changes with new evidence. The initial understandings of the students at the lower levels could have been a result of searching for the answer that an authority wanted, thus their views did not actually change because they had not committed to these new views.

While informative because of its integration of Perry's positions and NOS, the impact of this study is limited by its highly selective study population - graduate students in an elementary science education methods course. As a result, the ability to generalize these findings to other settings is severely limited.

Tsai (2007) examined the relationship between teachers' scientific epistemological view and science instruction. Four Tawainese science teachers were participants in the study and were selected based on their performance on a *Science Epistemological View* instrument. Teachers who had very different responses on the instrument were chosen as subjects. All of the teachers chosen for inclusion in the study taught physical science and their classes were surveyed about their epistemological views perceptions of their science classrooms. Teachers were interviewed by the researchers about their views on science, teaching, and learning. Classroom observations and student assessments were also used as data sources.

The interview results concerning teachers' views of science positioned one teacher as having a positivist orientation, and one teacher with a constructivist orientation. Teachers with a more positivist orientation focused on the acquisition of correct knowledge and better grades for science learning. These individuals viewed themselves as "information providers and often used lectures, tutorial problem practices, and examinations in classrooms" (p. 233). The constructivist-oriented teacher focused more "on the understanding of scientific concepts for science learning, and use inquiry activities or interactive discussion to challenge students' prior knowledge or alternative conceptions" (p.233). This individual also espoused constructivist views about teaching and learning. These views were also reflected in their teaching practice and the activities they employed in the classroom. Student epistemological views were slightly aligned with their teachers' views, as the teacher with a constructivist orientation had students express more constructivist oriented views. Students in this class tended to view their classroom experiences as "offering more opportunities for peer negotiations, exploring prior knowledge, autonomous learning, and student centered activities" (p. 238).

This study was limited in that it involved only four teachers who were specifically chosen from a largely sample based on their surveyed views. This may not be indicative of the results had the other teachers been included.

Akerson and Buzzelli (2007b) explored the relationships between early childhood teachers' cultural values, ethical and cognitive developmental levels, and views of nature of science. A total of 17 preservice teachers who were part of a cohort program leading to a BA degree participated in the study. Data collection involved completion of the VNOS-B, the *Learning Context Questionnaire* and the *Schwartz Values Inventory*. By analyzing the questionnaires, the researchers were able to determine relationships between the various elements.

The researchers found eight teachers at the dualism position, seven at the multiplicity position, and two at the relativism position. All of the students at the dualism and multiplicity levels thought that theories would eventually turn into laws and a law is scientific knowledge that is certain. The two teachers at the relativism position did not suggest laws were facts but laws were based on evidence and were subject to change. All but one of the individuals at the dualism level did not have an adequate view of the need for data collection to support scientific claims. The preservice teachers' views of the tentative aspect of NOS were consistent with their positions. Those at the dualism level did not believe that scientists change their minds, those at the multiplicity position indicated there were many views, and those at the relativism position indicated that information is unsure and changes. There was a consistent pattern between the types of response regarding NOS and the Perry position that the teachers existed in. Regardless of the position that individuals found themselves in, they all held misconceptions about NOS.

This study could have been strengthened by an indication of when the research instruments were administered, and the inclusion of pre and post testing. Interviews with all of the teachers, considering the small sample size, should have been included. The sample size is also problematic since it is small and included a specific group of students.

Akerson, Buzzelli, and Donnelly (2008) studied early childhood teachers to determine the influence of intellectual levels, cultural values, and explicit reflective thinking on their views of nature of science. Participants in this study came from an early childhood science methods course of which there were 14 individuals. The study took place during the spring of their junior year within the methods course and cultural foundations of education course, which they were all taking at the same time.

Data collection for the study included: VNOS-B to determine NOS understandings, the *Learning Context Questionnaire* to measure intellectual levels, and the *Schwartz Values Inventory* to measure cultural values. The class sessions for both classes were taped to confirm that the instructional strategies addressed the NOS and cultural values. Work from the preservice teachers was also collected to assess the effectiveness of their teaching strategies.

The researchers found that eight students advanced in their Perry positions, three remained in their original positions, and three moved back to a former position. There was a consistent pattern between a preservice teachers' description of the NOS aspects and their Perry positions. Individuals at the dualism position indicated they "held a view of scientific knowledge as developing ultimate truth, that scientific claims were factual and unchangeable" (p. 766). Multiplicity position teachers had a view of scientific knowledge where various perspectives are equally good. Those at the contextual relativism position thought our scientific knowledge was the best that we had now, but it was changeable with new evidence. The retreat of some teachers into prior positions might be explained by the existence of cognitive dissonance. The researchers discovered a relationship between some cultural values and the sociocultural/subjective NOS. The preservice teachers also had different cultural views of scientists, which might make it difficult for them to convey appropriate aspects of NOS to their students.

While this study used multiple sources of data to draw conclusions, it was weakened by the small population size. Additionally, the researchers were also teachers of the methods courses, which could have seriously biased their positions and interpretation of the data. Finally, the researchers could have used interviews with students to confirm the questionnaire results.

For students and teachers to enjoy a greater understanding of NOS, individuals must be helped through these early developmental stages of personal epistemology. Movement from an absolute knowledge stage to a multiplicative, subjective, or transitional stage can be considered counterproductive when teaching about NOS and science. This is because these stages often involve acceptance of a range of viewpoints without consideration of support for those views, in other words, adoption of the viewpoint that “all opinions are equally valid” (Clinchy, 2002, p. 69). Determining what counts as knowledge in science typically includes negotiating multiple claims that vary in their support, evidence, and justification. Individuals at these stages (multiplicative, subjective, or transitional) are unable, or may find it difficult, to engage in this aspect of NOS. This presents educators with a number of challenges - especially if students are moving *into* these stages before or during instruction in NOS. Abd-El-Khalick (2001) found that many students adopted an “’anything goes position whereby every scientist is entitled to his/her own view of the phenomenon in question” when they were confronted with making decisions in science (p.230). This was due to the fact that they failed to come to grips with the notion that there are no definite answers in science, yet scientists are able to negotiate between various claims – thereby attributing more “capital” to some over others.

At the heart of the issue is how these naïve, uninformed, and simplistic views of science come to be constructed and established. Personal epistemology provides one avenue for explanation and exploration. Another significant cause of these views may be attributed to the presentation of science in school classrooms. Elementary teachers are on the front line of this "war" of understanding, yet they tend to be the most unprepared. State education departments have rarely required extensive content knowledge in the sciences - New York State currently only requires six credits in science for elementary teachers. Content knowledge is not vital to teaching students about science, but it certainly affects comfort level. Elementary teachers, as well as other teachers with little science content background, are more prone to rely on the textbook. This reliance on the textbook creates a situation where both the teacher and the students start to view the book as a source of knowledge - something that provides "truths" and "facts." As pointed out by Abimbola and Baba (1996), "the textbook is usually regarded by educators throughout the world as a good source of information for teaching students" (p. 14). This is despite the awareness that science textbooks are notoriously plagued with incorrect information. Opening a current science textbook at any grade level will probably yield the incorrect portrayal of a single "scientific method". This is contrary to the NOS conception of multiple methods of solving problems (creativity). Scientific experiments in schools are dominated by verification labs - teachers know the outcomes in advance and the labs have a high degree of success. These verification labs may also be referred to as "cookbook" style labs – whereby particular steps are followed to generate a known result. Students' and teachers' understandings of science are thus a product of exposure to inaccurate views of the scientific enterprise. The result is an understanding of science that hinges on facts, truths, and experimentation. Researchers dealing with NOS conceptions have postulated a number of reasons for naïve understandings exhibited by individuals.

Tsai (2002) offered a possible explanation for the distorted epistemology of science that many students and teachers appear to develop. The consistency of these naïve conceptions of science points to something within students' backgrounds that is shared or common. One of these may be the prior experience with school science experiment which gives the false impression that there is certainty in science. To address the concern over students with inaccurate views of science, the NRC (2000) advocates a movement in science classrooms to more self-directed learners that rely less on the instructor and materials for knowledge. Our science classrooms are dominated by traditional, didactic instruction - *despite the call for a shift in the learning and teaching process that is more active and inquiry-based*. This movement may help students to better understand the generation of knowledge as a result of scientific inquiry, thus leading to more current conceptions of NOS.

Bell and Linn (2002) indicated that textbooks may have a role in students' misconceptions concerning NOS. Textbooks present information as "one advance followed by another" and may confuse students since they "emphasize the logical progression of straightforward discovery and the coherence of scientific knowledge" (p.324). Students are therefore not exposed to the controversies that swirl around new scientific knowledge creation. Hofer (2004) also indicated that instructional practices and presentation of the material in classrooms may influence students' scientific epistemologies. Specifically, the presentation of the textbook as the primary source of information can impact students' understandings.

Another factor that may influence an individual's conception of NOS is his or her academic background. Martin-Diaz (2006) surveyed a range of science-related professionals to determine their views of NOS. Interestingly a pattern emerged related to the educational background of individuals. Teachers who had "humanistic" backgrounds, as opposed to "natural science" backgrounds, were more in line with teaching aspects of NOS to their students. Again, these differences in views appear to be the result of the way that knowledge is presented in educational settings.

Approaches to teaching and learning - dependent on epistemology?

The research related to the connection between teachers' views of science and their classroom practice has generated discrepant findings. In Lederman's (1992) review, the research was conflicted in relation to the influence of a teacher's understanding of the nature of science on their class pedagogy. Some research studies supported a link, while others demonstrated no link. Other factors, such as curriculum constraints and administrative policies, have been identified as having a stronger influence on classroom practice (Anderson, 2002; Barrow, 2006). Abd-El-Khalick (2000) provided a summation of some of the major factors that can affect the conversion of an understanding of NOS into practice - pressure to cover content, classroom management and organizational principles, concerns for student abilities and motivation, institutional constraints, teaching experience, discomfort with understandings of NOS and the lack of resources and experiences for assessing understandings of NOS (p. 670).

Mellado (1997) discovered that a preservice student teacher's classroom practice was not related to their conceptions of the nature of science. Much of the problems in enactment may result from a lack of planning. The teacher who was the most positivist in conception was the most constructivist, whereas the "teacher with a relativist conception of science applied a traditional transmissive pedagogical model" (p.347).

Abd-El-Khalick et al. (1998), in studying preservice teachers who had been engaged in methods courses intended to change their views of NOS, determined that the teachers did not incorporate those new views into their instructional strategy. Their lesson plans rarely showed evidence of planning to teach NOS, and only a few teachers listed NOS as a topic they would emphasize in their instruction.

Lederman, (1999) found that although many teachers expressed a clear understanding of aspects of NOS, only two (out of 5) teachers demonstrated classroom practices that were consistent with their views about NOS. These two teachers also happened to be the most experienced. This lends support for the notion that preservice and beginning teachers are still developing their instructional practices even during overwhelming situations. The two were not trying to teach in a manner consistent with their views. NOS aspects were rarely considered when planning for instruction and making instructional decisions. Lederman (2006) stated that teachers' conceptions of NOS are not automatic, and not necessarily translated into classroom practice, nor do teachers regard NOS as an instructional outcome of equal status with that of “traditional” subject matter outcomes. Curriculum constraints have previously been mentioned as possible hurdles for implementing understandings of NOS into instructional practice - these teachers did not have constraints concerning curriculum. Their students, despite the teacher’s demonstration of an understanding of NOS, did not demonstrate adequate understandings.

Waters-Adams (2006) found that teachers’ practice was not related to their understanding of science, but “whether their actions accord with their beliefs about children, the curriculum, and appropriate pedagogy” (p.937). The link between understanding NOS and practice did not exist. Other considerations - such as teachers’ beliefs about teaching and learning and the curriculum appear to have a more direct influence on practice than understanding NOS.

Even when teachers demonstrate views of NOS that are in line with current reforms, their classroom practice may not reflect this. Interestingly, Trumbull, Scarano, and Bonney (2006) in a study of two teachers, found that a teacher espousing reform-based views of the NOS did not implement inquiry into their classroom, while a teacher espousing a traditional view of science was proactive in implementing inquiry in her course.

Akerson, Buzzelli, and Donnelly (2010) aimed to determine if preservice teachers' concerns about teaching NOS and their intellectual levels influenced whether and how they taught NOS. Four teachers, from a cohort of 14, were selected to be part of the study based on their views of NOS and their intellectual development. All four of the teachers held adequate or informed views of NOS at the end of their courses, which was before the internship they participated in. The intellectual levels of the teachers were: contextual relativism; multiplicity; dualism (that had retreated from multiplicity); and dualism.

Data sources for classroom instruction included videotaped classroom observations, lesson plans, and field notes. The teachers also completed the VNOS-B before the internship, the *Stages of Concern* instrument pre and post internship, the *Learning Context Questionnaire* pre and post, and interviews before and after the internship.

In regards to intellectual levels, the contextual relativism teacher moved to the dialectical position. The multiplicity teacher remained at this position, while the dualism teachers both moved to multiplicity positions. Their positions were not related to their teaching of NOS, which the researchers thought would have been present. Other research studies had shown a relationship between the position of a teacher and their NOS views. In this case, however, an individual's views did not translate into the teaching of the topic. Although three of the four teachers had a great deal of latitude in teaching science, none of them were observed including

NOS in their teaching or lesson plans. The single greatest factor that impacted whether or not NOS was taught was the level of cooperation of the teacher. The one preservice teacher with a cooperating teacher who advocated NOS was observed teaching lessons that included NOS.

The greatest limitation of this study was its small population size (four teachers) and the nonrandom selection of the teachers based on Perry's positions. The varied sources of data helped to strengthen this weakness, but it does limit the ability to generalize the findings to other study populations.

The recurrent theme among these research studies was the lack of translation of a teacher's understanding of NOS into their classroom practice. Unfortunately, learning about NOS in one context may not translate into another context. As a result, teachers may need to be provided with specific recommendations on NOS instruction if they are to be expected to implement it in their classroom.

Issues with views of NOS

Some issues do exist when considering elements of NOS. The tenets of the NOS include the tentativeness of scientific knowledge. This particular aspect of NOS can generate significant issues for students and individuals. While the point of this aspect of science is for students to understand that it is a body of knowledge that changes as a result of investigation, this does not provide students with a completely accurate view of scientific pursuits. In particular, not all scientific knowledge is equally tentative and it can be counterproductive to view it as such. This important issue comes into play with individuals who are assessing students' epistemologies. Science education researchers commonly identified individuals as having a sophisticated epistemology based on certain criteria and assessments of knowledge.

Elby and Hammer (2001) investigated some of these epistemological issues with NOS. Studies of students' and teachers' understandings of NOS often label the type of epistemology that individuals employ when considering scientific knowledge. The researchers indicated that some of the labeling that occurs when identifying individuals' understandings of NOS is inaccurate and counterproductive. One of the overarching aspects of NOS, held by many in the science education community, is the tentativeness of scientific knowledge. Elby and Hammer point out, rightly so, that not all scientific knowledge is equally uncertain and evolving. A case in point would be the understanding that the world is not flat, compared to another theory that is much less certain. Attributing this knowledge of the world to tentativeness would obviously not be productive. In the science education research literature, students are labeled with a sophisticated epistemology if they do indicate a tentative NOS conception. Elby and Hammer (2001) stated that a sophisticated epistemology would not consist of generalizations which "apply to all knowledge in all disciplines and contexts" but instead "incorporates contextual dependencies and judgments" (p. 565). For the researchers, instead of having a general tendency to view knowledge as certain or tentative, it is more sophisticated to take into account the discipline, the particular knowledge under discussion, and the intended use of the knowledge. This view is also held by Smith and Wenk, (2006) who acknowledge that "what counts as 'proof or evidence' is different in math, science, history, and literary analysis" (p.749).

Elby and Hammer (2001) argued that epistemological research does not adequately address two components - the correctness and productivity of an epistemological belief, as well as certain generalizations that fail to account for context. Elby and Hammer (2001) also identified three major issues when researchers label students with a sophisticated epistemology in science.

The first issue has to do with the certainty and tentativeness of knowledge and whether or not the view of a tentative construct in science is productive. The researchers correctly stated that knowledge is not equally uncertain and evolving, new ideas tend to have more tentativeness than more durable scientific knowledge, such as the earth being round or anatomical issues. Therefore, teaching an aspect of NOS that deals with tentativeness can create issues for students. If students were to view all knowledge as tentative they would be less able to appreciate the weight of evidence for certain theories, such as the evidence supporting evolution.   Elby (1999) found that physics exam scores were correlated with students views on the complexity and coherence of physics knowledge, but not with their beliefs about certainty or tentativeness.

The second issue identified by Elby and Hammer (2001) is the view that scientific truth is socially constructed and subjective, a position they label as "relativism" versus a view where scientific truth is waiting to be discovered, called "realism." Again, the researchers point out that the position of relativism may not be productive or correct. Individuals who approach science from a realism standpoint may be more able to construct knowledge on their own as opposed to depending on another source.

The final issue explored whether knowledge is constructed by the individual or if students accept knowledge from an authority. While epistemological researchers have labeled students naïve if they believe that information is received from authorities, this is again a counterproductive notion. Individuals commonly accept information from scientific authorities which does not make them more sophisticated in their epistemology. Concomitantly, accepting ideas about certain aspects of science from authorities does not make an individual less sophisticated. If a group of biologists provides certain information about anatomical structures, it is not more sophisticated to question that information rather than accept it.

Elby and Hammer (2001) do not abandon the notions that science is tentative, relativism is a component of science, or knowledge is generated by individuals without authorities. Rather, they are indicating that we cannot simply label a student's epistemological views as naïve or sophisticated when there are obvious issues with how we identify these epistemologies using various instruments. Simply using generalizations that science is tentative, without considering the standing of various theories in science, gives students an inaccurate view of science.

Other researchers have more recently taken issue with some of the tenets of NOS, including the tentativeness of science. For instance, Allchin (2011) advocated a reframing of the way NOS is characterized to include multiple dimensions of science. He places particular focus on the inclusion of the following foundational principle, "Students should develop an understanding of how science works with the goal of interpreting the reliability of scientific claims in personal and public decision making" (p. 521). This ties in directly with the various policy documents that have called for science literacy for all Americans.

Science literacy also includes judging the status of knowledge claims as well as the supporting evidence. As Allchin (2011) argued, the claim that science is tentative can be used to dismiss the scientific consensus of various theories (such as global warming or evolution). He also follows Elby and Hammer's (2001) arguments about the importance of context in judging scientific knowledge. Learning about the NOS tenet of tentativeness without the necessary science process skills, in this case assessing the reliability of evidence surrounding scientific claims, will not achieve the results one is hoping for. This is also a central theme in both the new K-12 science frameworks as well as *Taking Science to School*. In addition, this is a central element of this research study – providing students with the mechanisms to evaluate evidence, make scientific claims, and justify those claims to an audience.

Evaluating the merits of theories

Views of science also influence how individuals judge the merits of theories. In some cases, a scientific theory is viewed as a rather robust explanation with much support. In the case of evolutionary theory, however, it is common to hear "it's just a theory" as a critique of its status in science. Irez (2006) determined that when comparing atomic theory and evolutionary theory research, participants thought much more highly of atomic theory. Atomic theory, participants felt, was likely to be proven in the future as result of new technology, while it is "impossible to prove the theory of evolution since it is about the past" (p.1128). Additionally, 8 of 15 participants believed that science and the development of scientific knowledge relied "solely on direct evidence obtained from experiments or observations" (p. 1129). Participants described areas of science that they felt were suspect due to this lack of direct evidence - often using the example of evolution. Abd-El-Khalick (2001) found that teachers were not as successful in employing their understanding of NOS to unfamiliar subject matter, like the extinction of dinosaurs, as compared to more familiar subject matter like atomic structure. Students had difficulty in believing that scientists went beyond the data when examining dinosaurs and their extinction, and went insofar as to dismiss the extinction of dinosaurs since scientists will never fully know what happened. Based on this research, it appears to be important for students to understand NOS to also fully grasp the importance of evolutionary theory.

In fact, instructing students in aspects of NOS is touted as a way to achieve greater understanding of evolutionary theory (NAS, 1998). However, student understanding and acceptance of evolutionary theory continues to be a challenge for the science education community. One of the reasons relates to individuals' perceptions of the construction of scientific knowledge. Evolution is often challenged due to the lack of experimental data to support it - a theme that has existed since Charles Darwin first published *On the Origin of Species* (Rudolph & Stewart, 1998). Although religious reasons are often alluded to as the motivating factor for challenges to Darwin's theory, today we fail to realize that the concept of evolution had been primed in the minds of many individuals' decades prior to his publication of the theory of natural selection. Many of the challenges to Darwin originated from his lack of following the established scientific processes of the time (experimentation), rather than on the often thought of religious grounds. Darwin presented an overwhelming amount of observational data - yet it was not in the vein of the current scientific paradigm. The attacks on Darwin's theory of natural selection today parallel those of the late 1800's. These attacks appear to be the result of misunderstanding of the contextual nature of science. As Rudolph and Stewart (1998) indicated, current views of science are dominated by a physics orientation – heavily dependent on hypothesis testing and experimentation. This presents problems for scientific disciplines (paleontology, geology, evolution) that are historical in nature and are limited in the application of experimentation. Rather, these disciplines depend heavily on observations of occurring phenomenon rather than experimentation.

Evolutionary theory may also be more value-laden than other theories due to the religious implications for individuals. This again, however, should not be construed as an exception to the "rule" of science, but rather one of its inherent elements. The traditional view of a rational objectivity for science is highly inaccurate - science is a human construction, comprised of the thoughts and biases of a range of individuals. Although it is value-laden, many do not acknowledge or express this value unless it conflicts with one of their staunchly held beliefs. In previous research dealing with individuals' views of scientific theories (e.g. Abd-El-Khalick, 2001; Irez, 2006), students were less apt to acknowledge the values involved in atomic theory than evolutionary theory. Atomic structure and atomic theory have values that also may not be fully discernible to students. This is consistently evident when students are asked about models in science – they are viewed as actual representations as opposed to theoretical models that may be used to make predictions and which have been constructed by individuals. A more sophisticated understanding of NOS can provide students with the necessary understandings to evaluate a range of scientific theories, and to understand the process of theoretical development in science.

Disappointingly, instruction in NOS may also result in students using these concepts to downplay widely accepted scientific theories – especially evolutionary theory. Rather than fully grasping the importance of evidence, observation, and justification in constructing knowledge, students focus of the "tentativeness" of science. They fail to realize that tentativeness of scientific knowledge does not mean that it does not have strong support or wide acceptance. Science education research often refers to the use of the phrase "It's only a theory!" which demonstrates to researchers that a full grasp of NOS conceptions does not exist for students. Akerson and Buzzelli (2007a) recently showed that individuals who rejected evolutionary theory actually used aspects of NOS more frequently than evolution acceptors. It appears that instead of accurately incorporating NOS into their knowledge structure, they have created a false aspect of NOS to support their currently held beliefs. One may consider this an aspect of Piaget's accommodation and assimilation. Instead of shifting to a new knowledge structure, students may find it more comfortable to integrate new knowledge into existing schema. Evolutionary theory acceptance may have certain social stigmas attached to it (such as atheism) that impinge on an individual's consideration of it. These issues may be alleviated by modifying instructional practices to engage students in new and more effective ways. That is why this study focuses on inquiry-based pedagogy.

Inquiry-based pedagogy: What is inquiry?

Merriam Webster's Collegiate Dictionary (1993) defines inquiry as "examination into facts or principles: RESEARCH" (p. 604). In science education research there are references to inquiry, scientific inquiry, and inquiry-based instruction. One of the inherent difficulties in supporting inquiry-based instruction and learning about scientific inquiry is the range of components that they involve. AAAS (1989) in *Science for all Americans* states:

> Scientific inquiry is more complex than popular conceptions would have it. It is, for instance, a more subtle and demanding process than the naive idea of "making a great many careful observations and then organizing them." It is far more flexible than the rigid sequence of steps commonly depicted in textbooks as "the scientific method." It is much more than just "doing experiments," and it is not confined to laboratories. More imagination and inventiveness are involved in scientific inquiry than many people realize, yet sooner or later strict logic and empirical evidence must have their day.

The process of science and scientific inquiry are both complex endeavors involving observation, inference, experimentation, imagination, and creativity. The complexity of inquiry confounds the ability to provide a single, clear definition of it. The *National Science Education Standards [NSES]* (1996) note the multiple aspects of inquiry:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires

identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (p. 23).

Anderson (2002) indicated there are three main views of inquiry in the *NSES* - scientific inquiry, inquiry learning, and inquiry teaching. Scientific inquiry refers to how scientists study the natural world. Inquiry learning is an active learning process, which reflects elements of scientific inquiry. Inquiry teaching is not well defined in the *NSES* and includes both active teaching processes and active learning processes. Inquiry-based instruction would involve components of inquiry learning and teaching.

Abd-El- Khalick, Boujaoude, Duschl, Lederman, and Hofstein's (2004) description of an international symposium on science inquiry revealed "a variety of meanings associated with the term inquiry" (p. 411). Participants' mentioned curriculum from Lebanon, United States, Israel, Venezuela, Australia, and Taiwan. Images of inquiry ranged from "structured laboratory-activities-with-a-twist, all the way to ill-structured approaches for generating evidence based answers to ill-defined questions" (p.415). Almost as important to the issue of defining inquiry was the mention of how inquiry is conducted in classrooms. The researchers asserted that "what is enacted in the classrooms is mostly incommensurate with visions of inquiry put forth in reform documents" (p. 398). Part of this issue may be due to the problem with defining inquiry.

The educational field is full of buzzwords that have different meanings depending on the researcher and audience involved. Inquiry-based instruction has been referred to (in some cases possibly incorrectly so) as hands-on, problem-based, project-based, constructivist, and active learning. The major issue with the use of these phrases to describe inquiry-based instruction or science inquiry is that they have a variety of meanings. While inquiry-based instruction may be "hands-on," so can a traditional verification lab. The common interchange of these phrases in the research literature only serves to fuel the confusion held by teachers about what inquiry and inquiry-based instruction actually are.

The type of inquiry that may be utilized in the science classroom also varies. *Inquiry and the National Science Education Standards* (2000) states, "sometimes inquiries are labeled as either "full" or "partial." These labels refer to the "proportion of a sequence of learning experiences that is inquiry-based" (p.28). Partial inquiry would not engage students in all the essential components of inquiry-based instruction. These essential components are:

1. Learners are engaged by scientifically oriented questions;
2. Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions;
3. Learners formulate explanations from evidence to address scientifically oriented questions;
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and
5. Learners communicate and justify their proposed explanations.

(NRC, 2000, p.25)

In the 1950's and 1960's, educator Joseph Schwab viewed science as a reflection of a flexible process of inquiry, and not the pursuit of truth about the world. Schwab describes inquiry as either stable or fluid. Stable inquiry involved using current understandings to fill in areas that are missing in a segment of knowledge. Fluid inquiry involved the creation of new concepts that revolutionize science. In regards to K-12 education, Schwab believed that students should be placed in laboratory settings as quickly as possible. This would help give students a more accurate view of the processes that occurred in science and would allow them to start investigating questions and collecting data. Schwab described three levels of laboratory instruction. At the most basic level, the educational materials pose questions and provide methods for students to discover relationships for themselves. At the second level, the materials again pose questions, but the methods are left to the students to devise. At the highest level, the materials present phenomena without posing questions. The students are responsible for developing questions, designing experiments, collecting data, and evaluating that data.

Martin-Hauser (2002) defined four types of inquiry - open or full inquiry, guided inquiry, coupled inquiry, and structured inquiry. These types of inquiry depend on the involvement of the teacher and the students in the process. In open or full inquiry, the process is firmly centered on the student - they develop the initial questions and proceed with the investigation. Guided inquiry may have the teacher giving students a question, and then the students help the teacher proceed with developing the investigation. Coupled inquiry involves a blend of guided and open inquiry - the teacher provides the initial questions followed by students developing their own investigation. Structured inquiry is the most restrictive and is the most teacher-centered. Policy documents at the K-12 level advocate moving from classrooms that are more teacher-centered to classrooms that are more student-centered (NRC, 2000).

Inquiry, scientific inquiry, and inquiry-based instruction involve a focus on students that is vastly different than our current educational system of teacher-centered classrooms. If science education policies support a shift to new pedagogy, then research should exist to support this change.

Inquiry in the present study

An essential aspect of this research study is the assumption that inquiry-based instructional practices will be more effective than traditional techniques in helping students understand evolutionary principles. The predominant rationale from this comes from the view that participation in inquiry-based activities will allow students to construct their own meaning in association with data. Challenging existing epistemic frameworks requires that we not just show students information through lectures, but rather we engage them in analyzing data and developing arguments relating to the data. This cannot be effectively accomplished through the cookbook style laboratories that currently exist in K-12 and college science courses.

What do we mean by *inquiry*? A critical difference between the two classes will be the evaluation and examination of data in the inquiry-based class. Within this study we are drawing on essential features of inquiry, which can be found in the National Research Council's *Inquiry and the National Science Education Standards*. For instance, the NRC states that learners should be engaged by scientifically-oriented questions as a reflection of classroom inquiry. Students in the inquiry class will conduct research on bird data sets to answer two questions related to a decline in a bird population. The inquiry class will be involved in examining evidence as well as creating frameworks to evaluate evidence. Students will also have to develop explanations based on the data that they are examining. Students in the inquiry class will create presentations to communicate their findings and will use evidence to justify their claims. In addition, they will have to develop possible alternatives to their explanations. These aspects of inquiry will be addressed in the *Galapagos Finch Software Program*.

The inquiry class will also design and carry out an experiment to investigate goldfish behavior. All aspects of the experiment, including the hypothesis being tested as well as the experimental procedure, will be created by students in groups. Students will determine what constitutes data or evidence and collect that information. After data collection students will use this information to develop claims regarding goldfish behaviors, which they will support using the evidence that they have collected.

Students in the traditional class will not engage in these activities, but will instead be focused on answering questions posed to them in the laboratory manual and handouts. Some of the data will include observations of fossils – however no conclusions will actually be drawn from this information. Basic characteristics will be recorded for the fossils in the laboratory manual but students will not evaluate this information. Students will generate data when evaluating tool use to simulate bird beaks, but individuals will not draw conclusions from this data.

Research studies related to inquiry-based methods

To mirror the current research design, a review of studies that compared traditional and inquiry-based methods was conducted. Research articles were found by searching through major journals (*International Journal of Science Education, Journal of Research in Science Teaching*, and *Science Education*) and dissertation abstracts (for articles dealing with inquiry methods). Articles were primarily selected if they compared inquiry and traditional instructional techniques, as well as if they described assessments of inquiry-based instruction and implementation of inquiry-based instruction by teachers.

Rationale for including inquiry studies from K-12 settings

Although this research study is set in a community college with college-age students, the majority of the research comes from K-12 settings. There are a number of reasons why this is appropriate. Firstly, ignoring the primary source of research (K-12) on inquiry-based teaching would leave this research open to significant criticism. Since scientific inquiry has been part of national science education policy documents for more than two decades, the push for research has come at the K-12 levels. Each piece of research adds to the collective knowledge surrounding inquiry and inquiry-based learning, regardless of the age of the students.

In addition to this rationale is the understanding that teaching and learning do not vary significantly from the secondary to postsecondary level. Teachers and professors are responsible for conveying knowledge to students and students are involved in a range of activities to assist in their learning. An understanding of how students learn and how best to teach material is helpful at both levels. Findings related to teaching and learning at the K-12 levels has informed practices at the postsecondary level and has continued to elicit changes in the teaching of content material.

Finally, support for the use of these studies comes from national policy documents and their focus on science inquiry. One of the most significant of these is *Science for All Americans* (1989) from the American Association for the Advancement of Science. This document is primarily concerned with the necessary scientific understanding that all citizens should have to engage in a society infused with technology and science. Within its guidelines are the recommended understandings that Americans should have related to science and scientific inquiry. *Science for All Americans* also addresses teaching methods used and states that instruction should match the aspects of scientific inquiry (AAAS, 1989).

Using the K-12 Science Education Standards

One may question the use of K-12 science education standards for a research study with a community college setting. The use of these standards is appropriate as they are part of a collective body of science standards that are aimed at achieving outcomes that impact the American populace, not just K-12 students. The National Science Education Standards state that all students should achieve scientific literacy (NRC, 1996). The primary goal of the standards is to achieve a population that is scientifically literate. While the standards and discussions surrounding them are often fixed on K-12 education, it is clear that the standards do not have a sole focus on these levels. Rather, these are standards that should be achieved by all members of society. It is a natural progression to include college settings within these goals. In fact, one may argue that it might be more important to apply these standards to college settings, since this is often the last opportunity instructors have to impart critical elements of science to their students. The *National Science Education Standards* indicate "all members of the science education community have responsibility for communicating and moving toward the vision of school science put forth in the Standards" (NRC, 1996, p. 233). Strong support for the use of these standards in college settings can be found in the NRC document - "teachers need to be taught science in college in the same way they themselves will teach science in school" (p.238). Therefore, individuals who will be implementing science standards should be taught using those standards as well. In their book *College pathways to the science education standards*, Siebert and McIntosh (2001) expressed a need to examine how all college science courses are taught, since these courses impact the future citizens of America.

More recently a new set of K-12 science education standards has been developed, titled *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012). This new framework was developed to take advantage of a new impetus on common core standards that were being adopted in the fields of mathematics and English/language arts. In addition, the new framework was developed in recognition of new research on teaching and learning, as well as changes that have occurred in science. The framework's expressed goals for all students by the end of the 12th grade are that they will:

> Have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice (NRC, 2012, p.1).

Unfortunately we have not accomplished these goals with the previous standards. The authors feel that these prior outcomes have not been achieved for a number of reasons, including a disorganization of the K-12 science education system and a lack of systematic organizational structure across the years, placing too much emphasis on facts while not going into adequate depth on topics, and not providing students with experiences that show how science is actually done. The first point, a lack of systematic organization across education levels, applies to not only K-12 education but also the progression to college. In Kirst and Venezia's (2006) policy document on college readiness and student success, the authors noted "a profound organizational, political, and cultural chasm persists in most states between the systems of K–12 and higher education" (p. 3). Divisions exist between the two entities as a result of historical assumptions that each body should be controlled by policies that are exclusive to each area. Aligning high school and college curricula is one of four major recommendations made in this document. In 2004, the same researchers also advocated a correlation between K-12 standards and college entrance/placement exams. Recommendations to expand policy decisions to include a K-16 framework have also been made (Siebert and McIntosh, 2001; Kirst and Venezia, 2004).

A lack of continuation of science standards from high school to college will only reduce the chances of creating a scientifically literate society. Many students in colleges (particularly community colleges) may not have taken science courses since the tenth grade. Students in New York State are required to take three science courses at the high school level, but one of those courses may have been completed in eighth grade if it was approved by the local entity or state department. At the latest, students would have not completed science since eleventh grade. A K-12 framework does not adequately address these later grade levels and the common lack of participation in science courses. Students who are entering college probably have not sufficiently achieved the elements of all the standards. Kirst and Verenzia (2006) found that standard based instruction in K-12 educational systems stop at or before tenth grade, before many students have reached college placement standards. Continuing the standards in college science courses increases the chances of actually meeting the guidelines stated within them.

In addition to the argument of a learning progression from K-12 environments to college settings, the standards also make sense in their implementation at the college level. The ideas, concepts, and teaching recommendations in the standards are a product of research in science education settings over a number of decades. These research studies can only serve to augment the science education programs and courses that exist at the college level.

Inquiry in the new K-12 science education frameworks

A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (NRC, 2012) moves away from the term *inquiry* and instead shifts to *science practices*.

According to the authors, inquiry "has been interpreted over time in many different ways throughout the science education community" and practices "reflects the range of cognitive, social, and physical practices" that exist in scientific inquiry (NRC, 2012, p. 30). The use of the term *practices* reflects the integration of skills and an understanding of knowledge. Additionally, the authors felt that "a focus on practices (in the plural) avoids the mistaken impression that there is one distinctive approach common to all science—a single 'scientific method.'" (p. 48). The authors also put forth a list of the main practices involved in science, which are very similar to the essential features of classroom inquiry (NRC, 1996; 2000). These practices include:

1. Asking questions (for science) and defining problems (for engineering);
2. Developing and using models;
3. Planning and carrying out investigations;
4. Analyzing and interpreting data;
5. Using mathematics and computational thinking;
6. Constructing explanations (for science) and designing solutions (for engineering);
7. Engaging in argument from evidence; and
8. Obtaining, evaluating, and communicating information (p.49).

The new framework is not *abandoning* inquiry, but is instead slightly *reframing* the discussion surrounding the scientific information that all students should know and understand. The eight practices are very similar to the essential features of classroom inquiry:

1. Learners are engaged by scientifically oriented questions (Practice 1);
2. Learners give priority to **evidence**, which allows them to develop and evaluate explanations that address scientifically oriented questions (Practices 3, 4);
3. Learners formulate explanations from evidence to address scientifically-oriented questions (Practice 6);
4. Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding (Practice 7); and
5. Learners communicate and justify their proposed explanations (Practice 8).

Inclusion of new practices (models and mathematics) reflects more recent changes in science and its dependence on these processes. The new framework also attempts to clarify a difference in various fields of science,in particular that of engineering and other sciences. Stressing again the lack of a single scientific method, the frameworks separate some of the processes and procedures that occur in different scientific fields.

The major proliferation of inquiry-based pedagogy in the sciences can be traced back to the early 1950's, yet the push for inclusion of inquiry as a part of the educational system has been present since the early 1900's. John Dewey, the famous educational reformer and a former science teacher, strongly advocated that teachers should employ inquiry in assisting students in learning about science. Instead of merely learning information such as facts, Dewey felt that they should learn that science was a way of thinking and that it should be taught as a process. Dewey's words from 1910, over a hundred years old at this point, still resonate with the problems of today, that of issues with pedagogy and instructional practice.

> Almost every teacher has had drummed into him the inadequacy of mere book instruction, but the conscience of most is quite at peace if only pupils are put through some laboratory exercises. Is not this the path of experiment and induction by which science develops?
>
> (Dewey, 1910, p. 126)

He also clearly pointed out that a major goal should *not* be the learning of facts, but of the techniques for weighing evidence:

> I do not mean that our schools should be expected to send forth their students equipped as judges of truth and falsity in specialized scientific matters. But that the great majority of those who leave school should have some idea of the kind of evidence required to substantiate given types of belief does not seem unreasonable.
>
> (Dewey, 1910, p. 126)

One can see the direct parallels in today's K-12 science standards and the focus on evaluation of data, rather than the learning of facts. According to Barrow's 2006 article on the history of inquiry, Dewey's framework for learning was centered on the students and not the teacher. Today's inquiry standards find a similar theme with a shift towards students as the focus of instruction.

Unfortunately, the majority of science instruction remained fixed in place – that is until the launch of Sputnik in 1957. The space race created a renewed focus on science education and science instruction; it also spurred the development of a host of new curricula in the sciences. *The National Science Foundation* (NSF), established in 1950, became more heavily involved with the development of K-12 curricula. Many of these programs focused on students acting as scientists and developing science process skills (Barrow, 2006). In addition to new curricula, teacher training programs were established to assist educators with bolstering their content knowledge in the sciences.

As the United States progressed from the 1960's and 1970's implementation of science education reform did not occur as individuals had hoped. A number of reasons for this lack of implementation have been identified, such as a shift in focus of the federal government to societal issues, failure to account for professional development, an attempt to make teacher proof materials, and failure to consider science programs that already existed in schools (NIH, 2005).

The support for using inquiry-based pedagogy more recently gained ground from studies done in the 1980's, in particular the analysis of research conducted by Shymansky, Kyle, & Alport in 1983, who conducted a meta-analysis of the effectiveness of new science curricula developed after 1955 and compared them to previous science curricula. New curricula were defined as those courses or curricular projects which:

a. Were developed after 1955 (with either private or public funds);
b. Emphasize the nature, structure, and processes of science;
c. Integrate laboratory activities as an integral part of the class routine; and
d. Emphasize higher cognitive skills and appreciation of science. (p. s69)

Traditional curricula were defined as those courses or programs which:

a. Were developed or patterned after a program developed prior to 1955;
b. Emphasize knowledge of scientific facts, laws, theories, and applications; and
c. Use laboratory activities as verification exercises or as secondary applications of concepts previously covered in class. (p. s69)

A total of 302 studies were examined for the analysis with 105 of those studies included in the analysis. The total sample size was 45,626 students. The studies were analyzed by establishing coding variables which were compared across 18 areas. The meta-analysis found that students performed better in "general achievement, analytic skills, process skills, and related skills (reading, mathematics, social studies, and communication), as well as developing a more positive attitude toward science" (p.s68). The average student exposed to new science curricula exceeded the performance of 63% of the students in traditional science courses on aggregate criterion variable. Across all curricula students exposed to new science program showed the greatest gains in the areas of process, skill development, and attitude to science in achievement.

There are number of limitations of this study, some of which were addressed by the researchers. One of the main criticisms is the fact that the researchers did not adequately describe their coding process, although the researchers do indicate that the process is identified in another paper. This makes it particularly difficult to determine specifically how the researchers grouped the data. It also is difficult to directly compare the new and old curricula. Another area of concern is the lack of detail used in determining which studies were included and those that were not. Shymansky et al. identified 302 studies, yet only included 105 of those, stating that they were the only ones that contained sufficient data for the meta-analysis. The researchers do not describe the process of eliminating research studies and what data was necessary for inclusion in the analysis. Furthermore, they only included studies from the United States and not from international studies. However, the investigators stated that international studies were not used because the curricula could have been modified. A significant issue that the researchers discussed was the fact that traditional classes might have been taught in very creative manners that would mirror new curriculum, and new curriculum may have been taught in a manner more in keeping with traditional processes. Despite these issues, the number of studies and students included in the meta-analysis lends support to the use of inquiry techniques in science curricula.

Examination of inquiry-based techniques experienced resurgence in the mid-1990's with an emphasis on inquiry from the *National Science Education Standards*. In addition to comparison studies of inquiry-based and traditional techniques, a number of researchers focused on case studies of classroom environments where inquiry-based techniques were implemented. Both the comparison studies and case studies provide support for the implementation of these techniques.

Thacker, Kim, Trefz, and Lea (1994) compared the performance of students in an introductory inquiry-based physics class with three other introductory courses on two different examination problems. All of the students in the inquiry-based physics class were elementary education majors. The researchers used *Physics by Inquiry Modules* at Ohio State University. As part of the assessment in this course, students completed two problems on the midterm and final exam. The four courses included physics by inquiry, honors physics, calculus-based physics (engineering), and a nonscience major's physics course. The instructors of the courses reviewed the questions to make sure they were appropriate to be administered to their students. The honors and engineering course spent seven hours in class per week, with two hours in the laboratory. The inquiry class spent a total of six hours in class, all of which was in the laboratory. The engineering based physics course (calculus) spent a total of seven hours in class per week, three in lecture, two in laboratory and two in recitation. The nonscience major's physics course spent five hours total in class, with three hours in lecture and two in the laboratory. The inquiry class had 24 students, with three participating in physics before this. Twenty eight students were in the honors physics class, 239 in the engineering course, and 40 students were in the nonscience course. In the nonmajors course, 65% of the students had taken a high school physics course.

The students in each course were assessed on questions related to direct current (DC) circuit diagrams. Before the exam, the honors course and nonscience course each spent one week on DC diagrams, while the inquiry class spent 2.5 weeks, and the engineering course spent two weeks. For the problem, 29% of inquiry students were completely correct, while 4% of the honors class, 2% of engineers, and 0% of the nonscience class were correct. Seventy five percent of the inquiry class answered part A correctly, with 14% in the honors course, 3% in the engineering course, and 0% in the non-science course. Thirty three percent of the inquiry class answered part B correctly, 7% of the honors class, 2% of the engineers, and 0% of the non-science students. The inquiry class did significantly better than the other classes on the problem, while the other classes were not significantly different. Despite more students having taken physics in the non-science course, the inquiry class performed significantly better. The inquiry class also outperformed students in the honors class and in the engineering class, despite the fact that students in those classes were more prepared for physics.

With any study of this nature there are going to be significant issues. The classes were all taught by different instructors, covered the material in different timeframes, and had different classroom environments (laboratory, lecture, recitation). Sample sizes for the classes varied significantly – from 239 in the engineering course to 24 in the inquiry based course. The development of the question used was not discussed, nor was a description of any pilot-testing or validity/reliability discussions. An inclusion of the overall performance of the students in the course, or pre and post testing on various physics items, would have strengthened the conclusion drawn by the authors that the inquiry-based class seemed more effective in helping students understand physics problems.

The effects of inquiry-based teaching have also been compared to traditional pedagogy with earth science students at the secondary school level (Mao and Chang, 1998). Two hundred and thirty two students in six classes served as the participants in the study. Classes were randomly assigned to be traditional or inquiry-based. The two techniques had equal numbers of students. Instruction occurred over the course of two weeks with the same teacher. The inquiry instructional units were based on the parent motion of the sun in the sky, while the traditional method focused on the earth and sun system as well as demonstrations with an earth/sun model. Both classes used the same textbook, received the same amount of time on instruction, maintained the same group sizes, and had the same teacher. Prior to, and following instruction, students were given a test that included 27 questions derived from the *Taiwan Indicators of Educational Progress in Science Process Skills* and the *Taiwan Entrance Examination* for senior high school science subject. Student results on the posttests found those in the inquiry-based classes did significantly better in learning earth science concepts on comprehensive and integrated test items, but not on factual test items. The results suggest that inquiry-based instruction improves "higher level understanding of concepts amongst the subjects" (p.366). These results appear to support the difficult task that science education reformers have – given that fact-based assessments may not support inquiry-based instruction.

A significant limitation of this study is that the researchers did not thoroughly explain the instructional process that occurred in both classes. For instance, the researchers spent less than a paragraph describing the traditional instructional practice, and one long paragraph on the inquiry class. The researchers did not indicate the number of class sessions each group had, nor did they provide any information about the number of laboratory experiences the students engaged in. A breakdown of the amount of time spent on activities and lectures also would have been helpful. Additionally, a more detailed description of the instruction would have allowed greater discernment of whether the instructional practices ultimately targeted certain question types. It is difficult to determine if the instructional practices were actually equivalent based on the provided descriptions. To fully support their findings, the researchers should have provided more detail about the structural practices. The researchers also do not describe why they selected certain test items for assessment, however they did describe their assessment of content validity.

Von Secker and Lissitz (1999) investigated the impact of instructional practices on student achievement in science. While the researchers did not focus on inquiry practices, they did look at how science achievement varied between schools, how various demographic factors influenced science achievement, how instruction impacts achievement of students within the same school, and how instruction interacted with demographics to influence science achievement. They drew their data from the 1990 *High School Effectiveness Study* which included a total sample of 7642 students enrolled in 247 urban and suburban schools in the 30 largest metropolitan school districts. A sample of 2018 tenth grade students in 163 schools was derived based on the presence of science achievement data, student demographic data, science teacher questionnaire data, and at least four students per school.

In regards to their findings, the researchers stated that "the strongest empirical support for instructional recommendations set forth in the Standard was observed for instruction that emphasize laboratory inquiry" (p.1121). The researchers found that this practice was associated with greater overall student achievement as well as less separation in achievement for students of varying demographics. Unfortunately, critical thinking appeared to increase gaps in achievement between genders and minorities. The researchers also found that teacher-centered instruction appeared to help low achieving students more than high achieving students. This may be due to the fact that the low achieving students may not yet be able to work independently. The authors also highlighted the fact that support for new science programs is largely anecdotal rather than based on rigorous research studies.

Although this study supports inquiry teaching, numerous issues exist in the reporting of these findings. The researchers included four criteria for their selection of student data, but they did not provide a very detailed explanation of the selection process. They also do not break down the schools by urban or suburban locations; the final sample could be weighted more towards suburban or urban schools for instance. Even though they have a large sample size, the average number of students within the 163 schools selected for the study was 12. Therefore, sample sizes may not be representative of the actual school environment. The number of teachers was not included, either in a total number or per school. The teacher data was also self-reported which has inherent issues of reliability. Therefore, the instructional practices employed by teachers may not actually reflect what happens in their classrooms. In addition, the researchers reported that little difference appeared to exist among the teachers based on their responses to questionnaires. The researchers did acknowledge that more accurate methods of measuring the instructional practices should be employed to determine if the reports reflect what actually occurs in the teacher's classroom. They acknowledge their findings could be buttressed by using comparable data from national surveys – which could give a better view of the relationship between science achievement and instructional strategies.

Large scale studies supporting inquiry have been balanced by case studies examining instructional practices and the issues surrounding implementation of inquiry-based approaches. Crawford (1999) explored the ability of a preservice teacher to create an inquiry-based classroom. She examined the teacher's beliefs about science and teaching, how the teacher engaged her students in inquiry, the factors that helped or hindered the preservice teacher's ability to deliver inquiry-based instruction, as well as the implications for other teachers. The preservice teacher was in a Master of Arts teaching program at a university in the Northwest. The teacher had over 10 years of experience in commercial and university labs, she wrote proposals, carried out experiments, and presented the results. The school in which the teacher was placed was a small public high school of approximately one hundred and twenty students. This research study focused on the teacher's sophomore biology class. The preservice teacher designed and carried out two inquiry-based units during her time there. Data collection involved classroom observations, written observations of lessons once a week, handwritten and videotaped records of lessons, audiotapes of conversations, lesson plans, written reflections, videos of interviews, and students' final written reports and videotaped presentations.

The teacher engaged her students in inquiry through a number of methods. The preservice teacher designed a variety of inquiry-based lessons, the first of which was a project-driven unit whereby students designed and carried out hydroponic experiments. The teacher also created an inquiry-based lab testing nitrogen levels in manure and barn material. The teacher shifted from a common problem to individual student projects as she continued, culminating in presentations in a public forum. The preservice teacher acted as a facilitator and guide throughout the projects and offered support to the students. She also helped students gain ownership over their learning as they developed their own research projects.

Crawford identified a number of factors that helped and hindered the preservice teacher. Six factors emerged that helped the teacher which included prior research experience, volunteering in project oriented classrooms, clear vision of unit goals, strong relationship with mentor teacher, collaboration with experts outside the classroom, and reflection on practice. The teacher identified two areas where she had problems: struggling for clarity and her ability to involve all students in the project. She also encountered challenges later in the class which included supporting students who went in different areas, misjudging students' prior skills, and inadequate communication with parents. The researcher indicated that the teacher was an anomaly among the other Master's degree students, as few other students try to implement inquiry-based units. The researcher also identified areas that assist teachers in implementing inquiry-based design which included exploring teacher's beliefs, providing opportunities for authentic investigations, providing models of teaching inquiry, providing support for teachers when planning long-term units, and providing opportunities for preservice teachers to reflect on their practice. The researcher was surprised to learn that a preservice teacher could carry out inquiry-based units on a successful level due to the complexity involved. However, this preservice teacher appeared fairly unique amongst her contemporaries.

Case study research has inherent limitations, mainly which focus on the ability to generalize to other areas. The teacher had a large amount of research experience and was extremely reflective in her practice, which is very unique amongst preservice teachers. The high school was in a small rural area which demographically does not match the remainder of the United States. Although mentioned as a data source, student reflections on the units were not included and could have provided more support for the implementation of inquiry-based units. The perceptions of the students concerning the units and the preservice teacher could have been helpful in determining the effectiveness of the inquiry-based approaches. Additionally the student sample was very small at 20 students, which provided the preservice teacher with a more manageable population. This case study did provide an example of an effective implementation of inquiry-based approaches, both with the positive and negative implications.

Keys and Kennedy (1999) took a different approach in their examination of inquiry-based instruction, relying instead on a case study of a veteran elementary teacher involved in inquiry. The researchers considered how the teacher interpreted teaching science as inquiry as well as the challenges she faced and how she overcame them. The teacher had 11 years of experience and had been at the school for six years. She had been involved in a science and math education reform project for two years prior to the study. The classroom included 26 children of varying demographics. The school was located in a low-to- middle economic area that abutted a large southeastern city. The researchers observed two units on light and weather, each of which lasted for eight weeks. The researchers were participant observers, and helped with planning activities and facilitated group work with students during several lessons. Data collection included field notes from the class, field notes from informal interviews, and transcripts of three formal interviews. The researchers observed the teacher for 50% of the lessons during the two units.

The researchers identified four main themes related to the teacher's instruction. The teacher planned instruction to explore questions that arose in context and questions arose naturally from the science activities. Another aspect of the teacher's class was that she created independence in procedural and social skills related to science. Students were responsible for managing hands-on activities. The third theme was construction of explanations and concepts from data. The instructor used the students' observations and interpretations as a central method of teaching science. The fourth theme was providing opportunities to apply scientific knowledge, where students used scientific knowledge to interpret their observations.in addition to the themes identified the teacher also pointed out challenges in inquiry teaching. The three major challenges included lack of time, turning questions back to students, and teaching mandated concepts which were difficult to teach through inquiry. The teacher also identified another problem with inquiry-based teaching, the difficulty in not telling students how to do something and not providing them answers. The teacher also pointed out the process probably makes many teachers nervous because they have to rely on students to discover information on their own. She also felt that the district assessment tools did not effectively probe students' understanding of science concepts. The study provides some insights into the applications of inquiry-based teaching and factors that might be unique about this instruction. Inquiry-based instruction involves a greater focus on students and therefore can present hurdles to teachers. Furthermore, the focus on standardized tests can be problematic for inquiry-based teaching, as these assessments may not fully explore students' understandings.

This research study provides information about an actual teacher implementing inquiry-based instruction, yet there are some problems. For instance, no data was collected from the students concerning their perception of the activities or their understanding of related science concepts. The teacher may have been uniquely-oriented towards reform-based instruction, as she was already participating in reform programs and inservice. As a veteran teacher, she also had experience developing activities and managing students. The teacher was observed for 50% of the lessons, therefore some aspects of her instruction may have been missed. The data collection procedure, specifically coding, was not explained in sufficient detail - none of the codes or categories was described by the researcher.

Not all studies have involved comparisons between traditional and inquiry-based approaches. Some of them have provided informed views of what occurs during the instructional process in a greater amount of detail. Crawford (2000) examined the beliefs and practices of a high school science teacher to determine how this teacher created an environment which engaged students in inquiry-based activities. The researcher collected data for over a year on a biology teacher in a rural public high school of 300 students. The veteran teacher of 12 years was a former bee keeper and had a Masters of Arts in teaching degree. The researcher described herself as a participant observer in the teacher's college ecology and botany classes. The report was mainly focused on 20 students in the ecology class. The data included interviews with the teacher, notes of informal conversations, videotapes of the classroom and field trips, interviews of eight randomly selected students, student products, and an end-of-year anonymous student questionnaire. A number of key characteristics emerged about the teacher and his instructional practice, which the researcher described as situating instruction in authentic problems, grappling with data, collaboration of students and teacher, connected students with the community, modeled behaviors of a scientist, and fostered ownership by students. The researcher identified ten different roles that the teacher also took on as a result of the inquiry-based classroom, which included motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner. The role of students in the classroom varied as well, with some roles typically reserved for teachers being occupied by students. The majority of the students had positive views of the classroom experiences; however the most common criticism of the effectiveness of instruction centered on the pace and the number of projects.

Due to the limited size of the class, the uniqueness of the teacher, the high school setting, and the student population, it is difficult to generalize the findings to other areas of the country and to other high school environments. The teacher was a veteran teacher who also had experience performing actual scientific work. This sets him apart from other teachers in the sciences who may be engaged in inquiry projects. The student population also was highly selective -including juniors and seniors in advanced courses. The study could have been strengthened by including assessments of student learning related to content area, both pretests and posttests. The teacher-designed questionnaire asked questions about the effectiveness of the teacher and what students liked best and least about the course. The interviews with students provided a glimpse of content related data, but unfortunately inquiry-based teaching practices are often evaluated based on student performance on standardized exams.

Tretter and Jones (2003) explored inquiry-based instruction as it related to standardized physical science test scores. One of the authors was a physical science teacher at a high school in an urban school district in a midsize city in North Carolina. Seven different physical science classes were taught in the first two years of the study through a traditional approach. One hundred and sixty one students of varying backgrounds were involved in the first two years, with 94 students in the third and fourth year. The teacher modified his instruction to an inquiry-based approach after two years due to dissatisfaction with student achievement and student interest in the course. The researchers compared traditional classes (first two years of the study) to inquiry-based classes (last two years of the study) over the course of four years, with the second author acting as the teacher. The results demonstrated little effect of inquiry on students' scores on the standardized exams (in fact, the mean score was lower), but the researchers did report other positive outcomes - such as more student involvement and higher class grades.

As with any research study, improvements could be made. The inquiry class had twice the number of labs and almost three times the amount of time in the lab, both based on minutes and days in lab. The researchers do not indicate if the time on task was equivalent, which is a significant issue. Moreover, the researchers do not describe the exact nature of the instruction; therefore it is difficult to determine whether or not the class was truly inquiry-based in regards to instruction. It is critical when comparing classes that the teaching process be described in detail. Additionally, the student numbers varied substantially from the first two years of the study the last two years of study.

Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier, and Tal (2004) assessed the impact of an inquiry-based science initiative in the context of an urban systemic reform. The data for the study were from three years in the Detroit public schools with sixth, seventh and eighth grade students. There was one project in sixth grade, two in the seventh grade, and one in the eighth grade. Schools within the Detroit public system were invited to participate based on the ability of teachers to participate in professional development, sufficient computer infrastructure, supportive administration, and equity. Ten schools participated the first year and

14 schools participated in the second and third year. One to three teachers participated in each school that was selected. The teachers selected were comparable to other teachers in the Detroit public school population. The only significant difference was that the teachers had less experience than the general population, but they were still highly qualified at about 11 years of experience.

The curriculum projects were titled: How can I build big things?; What is the quality of air in my community?; What is the water like in my River?; and Why do I need to wear a helmet when I ride my bike? The sixth grade project looked at developing an understanding of simple machines and the relationship between forces. The two seventh grade projects focused on issues of air quality and pollution as well as watershed issues, erosion, and various chemical concepts. The eighth grade project focused on the physics of collisions, and an understanding of force, velocity, and acceleration. The curriculum projects lasted between eight and ten weeks and the researchers administered pretest and posttest for all students in the participating classes. The assessments were a blend of multiple-choice and free response items, and involved content knowledge as well as science process skills. These questions were categorized into three cognitive levels – low, medium, and high. A team of researchers developed the assessments with groups of three to five individuals scoring student responses. The attrition rate was reported as 20% across curricula and years.

All of the analyses except one, a process section, showed statistically significant gains. Effect sizes for the gains were strongest in content scores as opposed to process scores, and were larger in the second and third years. When the researchers examined the cognitive levels of the questions they found an increase in effect sizes for medium and high items across all three years while the below items had large increases for the first two years and then were studied in the third year.

While this research study offered support for inquiry-based approaches, it is not without hurdles. As is the common critique with educational studies, there was not a reported control group or comparison group. The reported gains from sixth grade to eighth grade could be simply attributed to learning gains as individuals grow older and have more exposure to sciences. The researchers also revealed that other science-related initiatives were ongoing in the schools. Therefore, some of the results could be attributed to those programs.

Trautmann, MaKinster, and Avery (2004) reported their findings in relation to the difficulty in enacting inquiry-based instruction. This research study stemmed from the *Cornell Science Inquiry Partnership Program*, which placed graduate students in schools as teaching fellows. The graduate students worked with teachers to create and implement inquiry-based lessons. The graduate students spent approximately five hours per week preparing and ten hours per week teaching collaboratively with a host teacher. The inquiry projects developed ranged in duration from a few days to a school year, and attempted to meet the needs of each of the classrooms. Graduate students developed open-ended research projects, remodeled labs, created nature of science lessons, and "inquiry moments".

The researchers investigated the barriers to implementing inquiry as well as the benefits of having the graduate teaching fellows in the classrooms. Data sources included interviews, the *Inquiry Teaching Belief Instrument*, recorded focus group sessions, and classroom observations. During the 2001-2002 and 2002-2003 school years, a total of 21 teachers who had participated in the partnerships were interviewed. Fourteen teachers were interviewed during the 2003-2004 school year.

The teachers identified four major areas that impacted their ability to engage in inquiry based instruction: state curricula; time constraints; student expectations and abilities; and teachers fear of the unknown. Teachers felt pressure to prepare students for high stakes exams, which reduced the opportunity to engage in inquiry-based labs. Teachers mentioned that it took a greater amount of time to conduct an inquiry-based lab as opposed to a traditionally-based lab. They also felt that it would take too much time for students to figure out answers on their own, and they felt that the time to develop inquiry-based laboratories was not available to them. The interviewees also mentioned that some students could not handle the independence of inquiry-based labs while strong students might become frustrated with inquiry since it is not dependent on the typical methods of performing on exams. Finally, the interviewees mentioned a concern over engaging in research projects, since some of them did not have the experience and felt unskilled to do so. The fellows allowed teachers who previously avoided engaging in these types of activities to be more flexible and try new things.

The teachers interviewed in year two and three expressed a willingness to engage in inquiry-based teaching, and many indicated they had learned new teaching strategies. Those teachers who were helped the most were individuals who did not have prior experience in scientific research. Individuals with experience benefited from exposure to new ideas and resources. The fellows also appeared to help teachers lead student discussions, which are important to inquiry-based environments. Individuals were willing to continue in the program because of the impact on students – teachers saw an increase in motivation and students appeared to enjoy learning more.

Twenty students from three different classes were also interviewed to determine the impact of the projects on their views of science. Students were drawn from low, medium, and high achievement groups as designated by their teachers. Despite differences in achievement level, all of the students reported that they found the projects fun and several said the projects were better than their typical experiences in science.

This research study demonstrated a positive model for increasing and implementing inquiry-based instruction, but it is not without challenges. The study population is not described – we do not know what the student demographics or school demographics are in this situation. Since it is in New York State, the study population is exposed to unique curricular requirements that may not be indicative of other parts of the country. The instruments used in the study (interviews and *Inquiry Teaching Belief Instrument*) were not described in sufficient detail, nor was there a discussion of the interview process or the questions asked.

Turpin and Cage (2004) examined the effects of an integrated activity-based science curriculum and student achievement, size, process skills, and science attitudes. Three schools in northern Louisiana served as the experimental sites and four schools served as control sites. Both sites used seven teachers and their students as research participants. Turpin established a control and experimental group of seventh grade students to examine the effect of the integrated, activity-based science curriculum. The experimental group was involved in the integrated curriculum, whereas the control group was taught in a traditional textbook and lecture fashion. Both curricula were similar in that they both contained science content for seventh grade as well as life science topics. The programs differed in that the integrated curriculum drew on areas such as physical sciences, engineering, and touched on how these disciplines were interrelated. Mathematics was also used to solve problems in the integrated curriculum and activities were used to help students learn content. Teachers in this curriculum engaged in at least two investigations per week. Five hundred and thirty one students completed both the pretest and posttest in the experimental group, and 398 students completed both the pretest and posttest in the control group. A number of instruments were used to assess students. Science achievement was measured with the science subtests of the *Iowa Test of Basic Skills* (ITBS). The *Science Process Skills Test* allowed researchers to examine the process skill level of their students. The *Serve Science Attitude Survey* was given to students to examine their science attitudes.

The experimental group had a significantly higher ITBS science posttest score than the control group. The *Science Process Skills* posttest was also significantly higher in the experimental group. The posttest science attitude means were not significantly different. Individual process skills were also examined to see if there were any differences. The experimental group had significantly higher means for identifying variables, designing investigations, and interpreting data. There was no significant difference between the two groups in formulating hypotheses or graphing data. The student data supports the use of activity-based approaches in assisting students in gaining better science process skills as well as in learning science content.

The study may have been strengthened through a number of different methods. Background information was not provided on the teachers with the exception that the experimental group had been involved in training for the integrated curriculum. A description of the actual instructional process was not provided; therefore it is difficult to draw explicit comparisons between the two groups. It is not clear if the students came from different schools or the same school, and no socioeconomic data is provided for either the experimental or control group. Therefore, students in the control group may have had experiences that resulted in lower scores. The study should have employed the same teacher for a control class and an experimental class to draw more definitive conclusions.

Cuevas, Lee, Hart, and Deaktor (2005) considered science inquiry with elementary students of diverse backgrounds. The researchers wanted to determine the impact of instructional interventions on students’ ability to conduct science inquiry and use various inquiry skills. They also wanted to examine the impact of intervention on narrowing gaps between students of different demographic subgroups. The study occurred in a large urban school district in the southeastern United States with a varied demographic population. Seven teachers were selected based on their effectiveness of teaching science, and their teaching experience varied from 7-34 years. A total of 28 students were selected by teachers to represent different achievement levels and gender groups. The instructional units involved measurement and matter in grade three, and the water cycle and weather in grade four. Teachers participated in four workshops during the course of the year to improve their expertise in science and literacy. The researchers collected data at the start and the end of the school year using an elicitation protocol that had students design an investigation to solve a problem related to surface area and evaporation. This data was then coded and scored using a rubric and paired sample t tests were conducted on 25 students who completed the pre-and posttest.

The results showed that students experienced a statistically significant change in their inquiry abilities, their ability to develop procedures, their ability to describe how they would record the results, and their ability to develop a conclusion. While not statistically significant, a small increase in students’ ability to apply the results was observed. Significant differences were not observed in their ability to create a problem statement or their ability to describe how they would use materials to conduct investigations. Some students continued to struggle in identifying the problem in the elicitation protocol. Low achieving students saw dramatic gains from the pre-elicitation session to the post-elicitation session, with an increase of 5.21 points compared to 2.73 points for the high achieving students. Both African-American and Hispanic students increased significantly in their ability to conduct inquiry male and female students were on par in their ability to conduct inquiry. As a result of the intervention there was a significant increase in students' ability to develop questions and participate in inquiry, regardless of a range of demographic factors.

As noted by the researchers one of the significant issues of the study was a lack of a control group. In addition, the sample of 25 students is relatively small. A description of how the students were actually selected was not described; as a result these students may not be truly representative of the total sample. Because of the small sample size, one cannot draw conclusions based on demographic differences. The researchers do not provide a review of the instructional process which would have provided a greater understanding of the type of inquiry processes students dealt with. Similar to the McCarthy (2005) study, the importance of this study is that its focus was a population of students that had not been thoroughly studied previously.

Lynch, Kuipers, Pyke, and Szesze (2005) discussed the results of a planning grant and its impacts on science skills with students. The researchers examined the curriculum *Chemistry That Applies*, a unit that had received acceptable ratings from AAAS' Project 2061. The research population included eighth grade students from ten schools in the Montgomery County Public School district.

The *Chemistry That Applies* curriculum included 24 lessons divided into four sections, although teachers for the study only taught the first 18 lessons. The *Chemistry That Applies* curriculum was compared to a variety of options that teachers could choose from including traditional textbook materials as well as reform-based curricula on chemistry. Some teachers drew on multiple curricula to develop their own units, but all teachers were required to follow the state's curriculum framework.

The researchers examined whether the *Chemistry That Applies* curriculum resulted in higher scores on achievement engagement and motivation measures compared to those in the comparison group. Students were given assessments as pretests, posttests, and delayed posttests administered after the chemistry unit was completed.

The *Conservation of Matter Assessment* was used to assess science knowledge and was developed as a result of the AAAS Project 2061. The pretest found no significant difference between the groups, and students showed little understanding of the topics. The posttests and delayed posttests offered a different picture – with a significant difference observed between the two groups. Students in the *Chemistry That Applies* curriculum increased their mean scores by 20 points while the other group showed a gain of 11 points. Students in the *Chemistry That Applies* group also had more students increasing from the lowest scores compared to the other curriculum group, with 22% still at a low level versus 38% below level in the group non-inquiry group. The most successful students remained equal for both groups although the *Chemistry Applies* students appeared to progress in their understanding of the conservation of matter.

Data from subgroups showed that individuals and of low socioeconomic status, African-American students, Hispanic students, and English language learners all scored higher in the *Chemistry That Applies* group versus the nontreatment group. More students in the treatment group moved to middle level of understanding while their peers, on average, remained the in the no understanding range.

Although not identified as an explicit inquiry study, McCarthy (2005) compared hands-on science teaching versus textbook instruction for students with disabilities. The study is significant in that it deals with a population that is not often considered when investigating the impact of inquiry-based instruction. In this study, 18 students, all of whom were labeled as seriously emotionally disabled, served as the research participants. Some students had additional disability classifications. The students were from a range of schools and were placed in their current setting – a self-contained special education unit. Demographically, the students came from variable backgrounds, including higher socioeconomic status, although most were from low-income families. Two special education classroom teachers and multiple aides were involved in the study. The researcher assessed scientific knowledge using three pretests and posttests, one multiple-choice test, one short answer test, and one hands-on test. The two special education teachers taught approximately 16 lessons on matter over the course of eight weeks. Students in the hands-on curriculum performed significantly better on the short answer and hands-on posttests, with no significant difference between groups on the multiple-choice test. Testing conducted 20 weeks later indicated that students in the hands-on classroom still performed better than the students in the textbook curriculum.

A number of factors are of concern in this study. Firstly, the population size is extremely small, only 18 students, with those students further separated into two groups. Statistical analysis in this case can be considered inappropriate due to the small population size. The researcher does not clarify how students were separated and a comparison between the two groups is not provided. Therefore, it is difficult to draw conclusions about the effectiveness of the hands-on curriculum since we do not know the ability level of the students in each class. Furthermore, the lessons were not fully detailed in the different classes. Despite these criticisms, the research does offer insight into a population that is not well studied.

Lee, Buxton, Lewis, and LeRoy (2006) explored the abilities of students of diverse backgrounds to engage in science inquiry. The researchers attempted to determine whether an intervention enhanced students' inquiry abilities and what kind of difficulties students continued to have. A description of the basic research study may be found in the earlier review of Cuevas et al. (2005). As a result of the intervention, most students were able to describe how variables are controlled in an experiment and most students used data to support their theories. High achieving students gave correct responses more often, but low achieving students showed larger gains, as did female students. Students who spoke Spanish had higher gains than English speaking students, and individuals in English for Speakers of Other Languages (ESOL) programs had higher gains than those not in such programs. Low and middle socioeconomic students had comparable gains. Students from non-mainstream and less privileged backgrounds had larger gains than those students who were in better positions. The results were the same for students' responses to the evidence in support of a theory category. The researchers found that the intervention had a greater impact on the inquiry abilities of older students as well as those students from diverse backgrounds.

As previously indicated in the Cueves review, this study was not without issues. In addition to the previously discussed items, the small sample size does not allow one to draw accurate conclusions based on demographic differences. A population of 25 students is highly problematic especially considering the large sample it was drawn from. The teachers selected students based on their perceptions of high and low achievers, and a framework for this decision was not clear. Thus, students may not actually be truly representative of these groups.

The impact of inquiry-based labs on community college students' understanding of anatomy and physiology served as the focus for Lyons (2006). Two classes were used - one participated in three “cookbook” traditional labs, while the other class participated in three labs in a guided-inquiry approach. Scores from quizzes, physiology questions, and lecture exams were examined to identify differences between the two groups. No statistical differences were found between the two groups, although both expressed interest in participating in inquiry-based activities. It is interesting to note that the researcher indicated that the inquiry group was “not harmed by participation in guided-inquiry activities” (p.48). A limitation that the researcher acknowledged is the limited examination of the inquiry effect (only three labs).

Pine, Ashbacher, Roth, Jones, Mcphee, Martin, Phelps, Kyle, and Foley (2006) conducted a comparative study of students involved in hands-on curricular versus textbook curricula in an evaluation of inquiry abilities. Approximately 1000 fifth-grade students from 41 classrooms and nine school districts were part of the data set. The school districts were from California, Arizona, and Nevada. The textbook materials came from McGraw-Hill, Harcourt, and Silver-Burdett, while the hands-on units were from FOSS, STC, and Insights. Students were given a 65-question short answer cognitive abilities test to determine basic aptitude in the areas of literacy mathematics and figure analysis. The researchers also used a 25-item test with questions drawn from the *Third International Math and Science Study Tests* (TIMSS) in 1995. The researchers found no significant difference between the hands-on and textbook students for both tests. The researchers then developed a number of performance assessments to measure inquiry skills. These assessments included a spring to estimate the weight of an object, paper towels to see which brand of paper towels would soak up the most water, ice cubes to examine the rate of melting water in a beaker of tap water versus saltwater, and an examination of the behavior of flatworms in various conditions. Seven hundred and twenty students completed all the assessments.

The researchers found no significant differences between the hands-on and textbook classes for three of the four tasks, all of which dealt with physical science. The only significant difference was found in the flatworm task where hands-on students performed 11% better than textbook students. On the TIMSS questions there was no significant difference between the two groups, although the researchers expected the textbook class to do better. The performance of students overall was low, with students on average scoring 45% and even lower on higher-level skills at 32%. The researchers argued that the results may be a consequence of how the hands-on approaches were being implemented, in that they lacked true inquiry-based instructional practices. The researchers indicated the hands-on students did better in the flatworm task for two reasons - that they may have spent more time on life sciences and that the task may have resembled the process in their classrooms. The researchers also found that students performed about the same level on the tasks across socioeconomic status. This may have been due to the fact that elementary teachers were not teaching the curricula well enough to help students develop basic skills.

The researchers identified a few of the problems and limitations of their study. A significant limitation is a lack of data on the classroom learning process that occurred. Researchers intended to follow up on teachers and students, but it was not addressed. The researchers only observed volunteer teachers once in their classes, and interviewed them by phone once to confirm that they taught science in a certain manner. Therefore, the differences in hands-on versus textbook curriculum depends on self-report data which is sometimes unreliable. As the researchers also note, the sample was nonrandom and participation in the study was voluntary. The sample therefore has inherent bias due to the selection process.

Ruhf (2006) compared preservice teachers enrolled in different instructionally geared earth science courses. This study tested whether or not preservice teacher education students enrolled in an inquiry-based earth science course gained a better grasp of the content than preservice teachers in a traditionally-based earth science course. Students were tested for content proficiency at the beginning and the end of the semester. The traditionally-based students demonstrated a statistically significant improvement in knowledge and comprehension on the posttest, while the inquiry-based students did not. This suggests that the traditional course was better in preparing the preservice teachers in content knowledge. A significant limitation in the study was that multiple instructors and courses were used and compared: Geography 1900; Geosciences 2900; Geography 1050; and Geography 1020. A major issue with the study was that the observation and interview data indicated the inquiry-based class did not match national standards of inquiry.

Implementation of inquiry-based instruction hinges on a variety of factors. Crawford (2007) explored prospective teachers and their implementation of inquiry-based instruction. The study involved five prospective teachers during the 2000 to 2003 cohort of a secondary science professional development school. Field placements included typical high school classrooms that were not funded by external grants. The researcher attempted to determine how prospective teachers went about teaching science as inquiry in classrooms and how mentor teachers supported or constrained prospective teachers. The prospective teachers participated in year-long field experiences that also involved weekly seminars in a conference room at the high school. The five teachers were preparing to teach biology, physics, earth science, and neuroscience. Prospective teachers were hand-selected by their mentors and the prospective teachers differed in their undergraduate science backgrounds. The data collected by the researcher included in-depth semi-structured interviews at the end of the school year, semi-structured interviews with mentor teachers, inquiry-based unit plans, and the researcher journal documenting meetings informal conversations and classroom observations.

The researcher initially reported that all five prospective teachers began the year with enthusiasm and appeared ready to develop inquiry-based lessons. However, this enthusiasm waned and in some cases disappeared. Prospective teachers identified a number of factors that dissuaded them, including more responsibilities, resistance of students to new methods of instruction, and the mentor's degree of openness to inquiry. Prospective teachers were also concerned and fearful about teaching their original lessons. The researcher indicated that the prospective teachers' reluctance can't simply reside on the mentor's instructional stance. Some of the mentors expressed openness to trying new teaching techniques. Despite this, the prospective teachers ranged from giving traditional lecture-driven lessons to open/full inquiry projects. Although the mentors' beliefs and instructional approaches influenced some of the prospective teachers, it did not explain the resistance of some individuals to trying inquiry-based approaches. Several of the new teachers did not know how to attempt science as inquiry in their classroom. This seemed to be a critical aspect of inquiry implementation as the mentors' views were not always the mitigating factor. For example, one mentor was very open to allowing a prospective teacher to try new techniques but the prospective teacher was not comfortable trying them. As time went on this prospective teacher became more focused on a traditional style instruction. Another prospective teacher fully implemented inquiry in their classroom despite her mentor's stance towards inquiry being only intermediate on a scale from closed to open.

As previously noted with other case study approaches, is difficult to generalize findings from these studies to other research settings. In particular, this was a unique research setting that included a university-school relationship that is not found in other areas. As the researcher indicated, labeling and identifying an individual's beliefs about teaching is a very difficult construct. However due to the length of the internship/placement, as well as the interaction of the researcher in the study, this study provides important information related to implementation of inquiry-based instructional practices.

Shaw and Nagashima (2009) investigated student learning in elementary schools during the 2004 to 2005 school year. The researchers wanted to discern if students performed better on assessments in inquiry-based classes. A total of 834 fifth-grade students from 14 elementary schools were assessed on three different performance tools to identify students' ability level. The data was generated from an NSF funded education reform known as STEPuP, which included efforts to improve student learning through teacher professional development and performance assessments. One elementary school was selected because of its diversity. Fifth-graders served as a focus because they would have had some exposure to similar inquiry assessments. The year selected was chosen because all three performance assessments were administered.

The elementary school taught three science units which included ecosystems, food chemistry, and microworlds. The units were from the *Science and Technology for Children Curriculum* developed by the *Smithsonian Institute National Science Research Center*. The curriculum is focused on improving students of variable backgrounds and demographics.

Student learning was measured using three performance assessments that corresponded with the science units developed for the study. The assessments for food chemistry and microworlds replaced end-of-the unit lessons and served as culminating activities, while the ecosystem assessment started in the middle of the unit and proceeded to the end of the unit. The assessments were designed two to three classroom teachers and a university scientist. Each assessment was designed through a three-year process with the initial design, pilot and field testing, and implementation. A manual was developed for each assessment to assist with teaching the unit. In the ecosystem assessment students researched an ecosystem and created a poster, for the food chemistry assessment they conducted physical and chemical tests on snack foods, and for microworlds they examined water samples with a microscope to determine which one was the safest to drink.

Teachers scored their own students and submitted that information to the school district's office. Students who missed more than 50% of a unit were not included in the assessment. Student scores were valued from one to four on the rubrics. A total of 2,155 scores were submitted from the school district, with 834 students serving as a sample. The mean for each of the assessments was 2.8 for the ecosystems, 2.81 for the food chemistry, and 2.8 for microworlds. Females and gifted students scored consistently above those of the total sample, with the reverse true for males and students classified in the special education category. African Americans underperformed their counterparts on food chemistry and microworlds; while Hispanics underperformed on food chemistry. No significant difference was noted for performance on the ecosystem assessment based on ethnicity. Low socioeconomic students underperformed versus high socioeconomic students, while special education students under-performed on each assessment compared to their counterparts.

This study was limited various aspects. The rubrics and scores were based on collaboration between pairs or small groups of students, and teachers scored the rubrics for their student. Due to possible differences in scoring (no information is presented about inter-rater reliability) scores can't accurately be compared against each other. The data only comes from one school year at one grade level and does not compare other curricula that were applied. Without a comparison group it is difficult to understand if students actually performed better in these classes or on these assessments than in other classrooms.

In a unique approach to the inquiry debate, Sadeh and Zion (2009) compared open inquiry to guided inquiry. The researchers examined the effect of different inquiry learning approaches on students' inquiry performances. The researchers hypothesized that open inquiry settings would allow students to develop better inquiry performances. Fifty Israeli high school students in eleventh and twelfth grades served as the research participants, with data derived from interviews, written summaries of projects, logbooks, and written reflections. These items documented every stage of the inquiry process. Israeli public high school students majoring in biology must pass a final exam that includes a practical section comprising lab work in an inquiry project. Half of the students were engaged in open inquiry and half in guided inquiry. Students came from middle-class neighborhoods and displayed no significant differences in inquiry skills on a pretest at the beginning of eleventh grade. No significant difference was found between groups in a similar inquiry assignment at the end of the twelfth grade. Students were taught by a total of four teachers, two for the open inquiry approach and two for the guided inquiry approach. The teachers had more than ten years of experience, multiple degrees, participated in professional development, and were highly regarded amongst their colleagues. Teachers were interviewed to determine what type of inquiry they engaged in, and discussions were held with the teachers every three months to make sure that they continued to employ the methods they indicated at the beginning the research study. After the data was collected from the students, the researchers created a personal report for each student which detailed their level of inquiry performances. Two senior biology teachers acted as judges in determining the inquiry performances of students and arrived at a 93% agreement level. Open inquiry students displayed a greater mastery of inquiry in two areas – changes occurring during inquiry and procedural understanding. There was also a significant difference between the groups of students at the level of procedural understanding, with students in the open inquiry group exhibiting a deeper understanding. There were no significant differences between the affective points of view and learning as a process category when comparing the two methods.

This research study was limited by the small size as well as the international setting that presented a unique category for this research. The researchers also noted that the student reflections at the end of the study were poor and could have been improved by engaging in a larger amount of reflective practice. The research study was limited to a certain number of classes, and students in the population did not represent a cross-section of an Israeli high school student population – instead it was focused on a specialized set of students, biology majors. It is not clear how the students were assigned to the open inquiry or guided inquiry groups. Finally, the teachers involved in the research program were uniquely qualified and do not represent typical teachers found in most high school settings.

Lee, Linn, Varma, and Liu (2010) explored the following research questions in their study involving technology and inquiry: What is the impact of typical versus inquiry instruction on student knowledge integration across science courses and teaching contexts?; and How do teaching contexts impact student progress in knowledge integration? Data for the study came from 27 teachers from ten middle and high schools in three different states. The teachers had taught for an average of 12.9 years, ranging from 1 to 35 years. Student data indicated that three schools were high-performing, five schools were average, and two schools were low compared to other schools in the state. Eleven of the 27 teachers were involved in creating inquiry units during a summer workshop.

Six tests were developed for each assigned subject; tests for the nontreatment group included 80 multiple-choice questions and 45 explanation questions. The inquiry group test had 63 multiple-choice items and 55 explanation items. Fifty questions appeared in both years of the assessment.

Teaching environments were evaluated using teacher surveys, interviews, and other project records. Surveys of teachers took place at the end of the school year and asked about teaching experience and beliefs. Twelve of the teachers were interviewed after the curriculum was implemented and each interview lasted approximately twenty minutes. The inquiry units in the study were developed around a single science topic and lasted for five periods. The science topics were chosen by the teachers, which were aligned with the standards that they needed to address in their classes. Technology features included probe ware, classroom experiments, interactive visuals, and other assessments. The units were developed on mitosis, simple inheritance, velocity, the rock cycle, and global climate change for middle school, and acceleration, electricity, chemical reactions, evolution, and meiosis for high school.

Overall, the inquiry units demonstrated better student results than the typical methods. The knowledge integration for the inquiry group was significantly higher than the nontreatment group. Students were more likely to develop an understanding of the science topics that were integrated. Some the inquiry units were more effective than others; for example, chemistry and physics units had a higher impact than physical science, life science, and biology units. Units that involved visualizations of difficult science topics had larger gains; both the physics unit and chemistry unit had interactive simulations.

In regards to teaching context, the impact of the inquiry units was greater in some areas than others. Three of the 27 teachers had negative gains between the two groups, and interview data showed that these teachers did not fully implement the units or assessments. One of the teachers only spent two days of instruction on unit rather than five days. Researchers found a significant relationship between teachers with more inquiry experience as well as more teaching experience. Individuals who had more inquiry experience had better student outcomes than teachers with less experience. In general, the units were not equally successful and teacher experience had a significant impact on the effectiveness of instruction on assisting student understanding.

The limitations of the study include the fact that they did not describe how the assessments were pilot-tested, while reliability and validity measures were established for these tests. The assessment tests were not equal in length and it was not reported how many questions were exact/similar. Direct observations of the teaching environment did not take place, making it difficult to discern the actual impact of the research materials.

Minner et al. (2010) offered a review of inquiry-based research from 1984 to 2002. The researcher initially shortened 1,027 documents to 443 research reports. Studies were included in the analysis based on a number of factors which included whether:

- They had sufficient information to clearly determine the presence or absence of inquiry-based science instruction, as operationally defined for this project;
- They had student understanding or retention of science facts, concepts, or principles and theories in physical science, life science, or earth/space science as a dependent variable for the study;
- They had explicit instruction in physical, life, or earth/space science;
- Multiple treatments were compared, one of them could be distinguished from others as exhibiting more inquiry-based instruction based on our coding protocols (i.e., a treatment of interest);

- They were not conducted in museum contexts; and
- They were not case studies of individual students.

Studies were considered inquiry-based if they included instructional treatments about life, earth or physical science, engaged students with scientific phenomena, instructed via some part of the investigation cycle (question, design, data, conclusion, communication), and used pedagogical practices that emphasized to some extent student responsibility for learning or active thinking. The researchers also stated that inquiry instruction has three major components:

1. the presence of science content;
2. student engagement with science content; and
3. student responsibility for learning, student active thinking, or student motivation within at least one component of instruction—question, design, data, conclusion, or communication (p.5).

The 443 research reports were reduced to 138 studies primarily in the United States (76%). Research instruction took place mainly in K-12 classrooms with a regular classroom teacher but little was known about the training and preparation of the teachers. Nineteen percent of the studies did not include information regarding the timeframe of treatment. The number of minutes of inquiry instruction varied widely between the treatments. The study populations ranged in size from 151-200 for quasi-experimental studies to 11-30 for nonexperimental studies. Research designs of the majority of studies were quasi-experimental, experimental, and qualitative. Little more than half of the studies had one treatment group while almost 30% had two treatment groups. In regard to instruments and data sources used, information was not well reported. A little more than half of the studies did not indicate if the research tools were new or existing. Of the ones that did report this information, 20% used new instruments that were not pilot-tested, 13% used instruments that were pilot-tested, and only 11% used established instruments. The vast majority of these studies, 62%, did not include whether the researcher determined the reliability of the research, and only 26% demonstrated any kind of measurement validity.

Fifty one percent of the studies showed positive effects of inquiry-based instruction on content learning and retention. Thirty three percent of the studies showed mixed impacts and 14% showed no impact. The general consensus of the study was that inquiry-based instruction showed positive impacts on student learning compared to non-inquiry treatments. Studies of low methodological rigor more commonly presented positive results than more rigorous studies, although the degree was not statistically significant.

Forty two studies had multiple treatment groups, which allowed comparison in the amount of inquiry instruction and its impact on student learning and retention. The majority of studies were in the moderate to high rigor category. In studies with higher and lower amounts of inquiry, 55% of the studies found students did better in higher treatments. These studies included 19 studies in which students had a statistically significant increase in conceptual understanding. Comparative studies showed a positive association and 51% of the studies showed that more inquiry-based instruction had a more positive impact.

The author noted that although the evidence is not completely positive, students who were engaged in instruction that involved generating questions, designing experiments, collecting data, and drawing conclusions demonstrated improved content learning. Hands-on experiences were also found to increase learning of student concepts.

A major limitation of this study is that it was restricted to the timeframe of 1984 - 2002. Although initially this may not seem significant, a great deal of research has occurred in the past 10 years on inquiry-based instruction and there is been a renewed focus on methodological rigor in developing studies. The publication of *Inquiry in the National Science Education Standards* occurred in 2000, and this resulted in the renewed focus on inquiry-based instructional techniques and a wave of research studies.

Wilson, Taylor, Kowalski, and Carlson (2010) compared the effects of inquiry-based methods in commonplace science teaching is related to students knowledge, reasoning, and argumentation. The researchers attempted to measure three outcomes, including scientific knowledge, scientific reasoning through application of miles, and construction critique of scientific excavations. Children between the ages of 14 and 16 were invited to participate in a research study would involve 14 hours of instruction and testing over the course of a two week timeframe in the summer. Eventually, 58 students were successfully recruited and then randomly assigned to either inquiry-based materials or instruction using commonplace materials. No significant differences were found in composition of the two groups, and students received compensation at the end of the study. Both the units were taught by the same teacher, who had 27 years of experience in public schools, a Ph.D. in curriculum and instruction, and experience teaching with traditional and inquiry-based materials.

The inquiry curriculum unit was titled *Sleep, Sleep Disorders, and Biological Rhythms* from the National Institute of Health curriculum supplement series. The commonplace unit was modified from the NIH sleep unit to focus on didactic approaches and timeframes that would reflect commonplace teaching. Both approaches were examined by curriculum developers to ensure the learning goals are aligned. Data collection included a pretest posttest, and an interview. The pretest and posttest included multiple choice items, true false items, and five constructed response items. The true false and multiple choice items focused on facts and vocabulary within the sleep unit, whereas the free response items dealt with reasoning about the data. Students also participated in a 30 minute open-ended interview that was designed to include the major topics within the units. The classes were observed by external researchers who took notes and completed the reformed teaching observation protocol for each unit. The teacher also took notes after each lesson, and each class was videotaped. Students also completed a survey of 17 questions from the *Constructivist Learning Environment Survey*.

The researchers reported found that the top scores were significantly higher in the inquiry class than for the commonplace unit. The mean constructivist *Learning Environment Survey* scores were also significantly higher in the inquiry class. Videotaped observations showed that the commonplace group spent more time on lecture, but the inquiry group spent more time in small group discussions. The inquiry group spent more time on writing scientific questions and procedures while the commonplace group did not. The commonplace group experienced a greater depth of the topics. Students did not participate in hands-on investigations in either group but instead kept a sleep diary in the inquiry class. Inquiry students had significantly higher posttest scores than students in the commonplace group. The commonplace unit demonstrated a significantly lower posttest score for nonwhites, yet no significant difference was found in the posttest of scores of students in the inquiry-based group. Students in the inquiry groups had significantly higher scores for claims, evidence, and reasoning. In general, students who participated in inquiry-based instruction earned significantly higher scores than students in the commonplace instruction.

While this research study provides evidence to support inquiry-based instruction it was limited by a number of factors. The researchers could not draw conclusions about demographics due to the small samples involved. As the researchers noted, the study was limited by a small sample size as well as the short length of intervention. A follow-up study was not administered to determine if long-term retention actually occurred. This would have addressed the issue of the short intervention time. Additionally, the short time between the pretest and posttest could have resulted in a testing influence. Students in the inquiry class may have remembered some of the questions as opposed to the commonplace class. The study was also subject to a great deal of bias, since the researchers designed inquiry-based instructional materials and the instructor was an advocate for inquiry-based teaching. The teacher was more comfortable in the inquiry-based setting which could have influenced the outcomes. The researchers did address this briefly by noting that the variables for the experiment were controlled.

Breslyn and Mcginnis (2011) compared the enactment of inquiry in science teacher classrooms, specifically how the discipline influenced their views and implementation of inquiry-based learning and how teaching in more than one discipline influenced these conceptions. Using a mixed-methods design, the researchers analyzed portfolio texts and participant interviews to discern individuals' enactment and views of inquiry. The study was carried out in three phases: phase I involved analyzing portfolios with a research instrument; phase II involved analyzing the text in the portfolios for themes; and phase III involved interviewing a selected group of teachers. Forty eight teachers who received national board certification in 2007 and 2008 were involved in the study, with phase III focusing on 12 of the 48 teachers. The sample for this study involved 48 nationally board certified science teachers with a pilot study of three teachers carried out before the study was implemented. The 48 teachers were selected randomly from a population of 282 teachers during the certification year of 2007.

During phase I, the portfolios were read and scored using the instrument from the pilot study. The portfolios were then read again to compare scores to the first reading and discrepancies were investigated. The portfolios were then read again to refine the scores. A final reading, the fourth time, was conducted by the first and second author to compare scores. Ten portfolios were randomly selected and scored.

During phase II the author read the portfolios four times and coded them by identifying emerging themes about teachers' goals and enactment of inquiry. Codes identified during phase two included: Students conducting scientific investigations (SCSI); Science content knowledge, modeling, problem solving; and Other.

After phases I and II, phase III involved recruiting a second group of teachers to serve as case studies. Interviews took place by phone and involved a discussion of an inquiry lesson of the teachers' choosing. Interviews found four of six biology teachers in the analysis tended to focus on SCSI, while two were placed in science content knowledge. A reason for this focus on SCSI was that the teachers perceived inquiry as being more difficult in biology. A biology and physics teacher believed that inquiry was easier in physics classes. Of the four teachers who taught biology and another discipline, three of them shared the view that inquiry was more difficult in biology).

In the portfolio text analysis, 10 biology teachers were in the SCSI category, one was in the content category, and one was in the other category. This analysis revealed that the teachers in biology were more likely to involve students in designing experiments by selecting the questions they would explore, as opposed to chemistry and physics teachers. There was a significant difference in teachers' support for student questioning, ability to choose the research question, and use of a hypothesis in the investigation. Teachers in biology appeared to focus on the process of the investigation.

As a result of interviews, chemistry teachers appeared more likely to be found in the content category, with two in content, one in content and SCSI and one in other. The portfolio analysis found eight teachers in the content category, four in the SCSI category, and one in the other category. Chemistry teachers were less likely than biology teachers to involve students in the investigative process of science, and also less likely than physics teachers to use mathematics and modeling.

Two of the three earth science teachers were in the SCSI category, with one in the content category. The portfolio text analysis demonstrated that six teachers were in the SCSI category, two in the other category, and one in the content and problem solving categories. The portfolio text analysis showed two differences with other areas, with biology teachers more likely to use questions to investigate, and physics teachers more likely to use mathematics and modeling.

Physics teachers were more likely to emphasize modeling as a theme in their inquiry instruction. All four physics teachers interviewed identified the theme of modeling. The portfolio text analysis found six teachers in the modeling category, four in the content category, two in the SCSI category, and one in the problem solving category. There was a statistically significant difference in their use of mathematics and models in their portfolios.

The main finding of this study was that the discipline to which teachers belong influences their views and enactment of inquiry. Two causes for this may include the context of the classroom teaching and the structure of each discipline. Their analysis revealed the structure of the discipline as the main influence on teachers' enactment of inquiry. Although biology teachers had a high variability of classes taught, they were consistent in their approach to inquiry. This appeared as a trend with the other teachers, in that curriculum was not a driving force in the differences in enactment.

This research study had a variety of limitations. The researchers did not describe how the instrument was developed for the pilot test or how that shaped their enactment of inquiry. The study depended almost entirely on self-reported data and views – in that no formal observations of the teachers' practice were conducted. This results in disconnect between the portrayal of inquiry in the teachers' portfolios versus the actual implementation in their classrooms. Without sending observers into the classroom, it is virtually impossible to draw significant conclusions about the actual classroom practice. However, this study did look at differences in views amongst teachers regarding inquiry; and therefore does have some application since discernible patterns did emerge.

Fogleman, Mcneill, Krajcik (2011) explored how curricular adaptations, teacher self-efficacy, and teacher experience influence student learning. Data was obtained from the 2003-2004 school year involving a unit called *Stuff*. The *Stuff* unit examined properties of substances, chemical reactions, the conservation of mass, and macroscopic phenomena in a total of 16 lessons which contained several different activities. The units included support for inquiry practices that would allow students to engage in inquiry activities. Teachers involved in the project participated in professional development activities which included a one-week summer institute and monthly workshops during the enactment of the unit. Five school districts and 19 teachers served as their data set for the research study. Videotaped lessons of teachers were examined and students were measured on pre and posttests. Teacher survey responses were compared to videotaped lessons (four teachers were involved in the videotaping).

The teacher survey involved 16 pages which corresponded to the unit's lessons and they were asked to indicate their comfort level with the activities and their students' understandings. The pre and posttests involved 15 multiple-choice questions and four open-ended questions which corresponded to the unit's goals. One rater scored the posttests and inter-rater agreement was reached for 96%. A total of 1,234 students completed both the pre and posttests. On average, students gained 7.49 points from pretest and posttest. Comparisons between teachers found that there was a significant teacher effect in regards to the learning gain of students. This suggested that each of the classrooms had occurrences that were influencing student learning. The differences could be attributed to factors such as the school, parents, and access to resources. The data suggested that teachers who had previously taught the units had greater student gains. Students who completed investigations themselves had greater learning gains compared to students in classrooms who observed their teacher completing the investigations as demonstrations. The number of days spent on the unit, the teacher comfort level did not significantly influence student learning.

Forbes (2011) examined teachers' adaptations of science curriculum material for inquiry-based momentary science. Specifically the researcher was interested in determining if preservice elementary teachers were able to adapt curriculum materials and what types of adaptions they actually made. The research study took place at a large Midwestern University United States during the third semester of undergraduate elementary teacher preparation program. During this semester preservice teachers were asked to develop to elementary science lessons and are referred to as reflective teaching assignments. The researcher also served as the instructor for one section of the course. Between the two sections there were a total of 46 preservice teachers and seven students from the section taught by the author were involved in case studies around their teaching. Data from the preservice teachers included reflective teaching assignments, interviews, observational data, and small group discussions.

Adaptations were coded around whether they added, deleted, substituted, inverted, or relocated items within the lesson plan. An inquiry scoring rubric was used to assess the lesson plans and was based on the National Science Education Standards. Inter-rater reliability was established by sampling 20% of the data; 86% achievement was originally achieved and 100% after discussion.

Based on the inquiry rubrics the preservice teachers were able to increase in their use of the five essential elements or features of inquiry. This data appeared to be statistically significant. Only four instances of lower inquiry scores were found for the five essential features (of 93 total lessons analyzed).

In regards to implementing adaptations, the researcher found that preservice students were able to consistently implement the five essential features of inquiry into their lesson plans. The preservice inquiry views focused on drawing out students existing ideas and explanations and provided ample opportunity for students to engage in data collection and evaluation of the data. Preservice teachers often adapted lesson plans to include questions that asked how a natural phenomenon occurred. Many of the preservice teachers thought that they were making their lessons more inquiry by modifying them to focus on students; but preservice teachers had difficulty distinguishing between the aspects of teacher directed or student directed inquiry elements.

This study has a number of shortcomings that limit its implementation. Although it did show that preservice teachers can implement inquiry-based activities into their classrooms through lesson development, due to the small data set it does not demonstrate if they all were implementing inquiry-based instruction. The translation from lesson planning to teaching the unit can be wrought with difficulty and modification. It is also not very clear as to how the scoring of the inquiry based assessments translated into confirming that preservice teachers were actually implementing inquiry. This is a significant issue with the current study as only six, of 46; preservice teachers were examined to see if they effectively implemented the adaptations. A more thorough discussion of the methods class that students were engaged in may help the reader understand what types of things that the preservice students were actually engaged with that group could cause these changes.

Maskiewicz and Winters (2012) examined how inquiry emerged in different aspects in different elementary teachers classrooms. This research study emerged out of a participation in *National Science Foundation* project to develop student teacher learning progressions and scientific inquiry. Thirteen third through sixth grade teachers in a large school district in Southern California participated in a professional development project as volunteers. The main goal of this project was to improve teacher's ability to involve students in scientific inquiry. Teachers participated in one to two week summer workshops, biweekly teacher meetings throughout the year, and some teachers participated in a full day workshop prior to engaging in the project curriculum. Teachers also engaged in science talks to develop scientific inquiry and discussed classroom videos.

The researchers developed a 15-20 hour unit for each grade level which involved opening questions with follow-up questions to engage students in thinking scientifically. The teacher for the study was a fifth grade teacher who had 17 years of experience and was willing to engage students in investigating their own questions. The two-year study found differences in the form of inquiry each year, with year one students involved in using empirical evidence to support their ideas, and in year two more time spent evaluating ideas in regards to their own experiences. The researchers were focused on trying to determine how the various components in the classroom added to the classroom inquiry practices.

The study took place at a public elementary school in southern California with 20% of students of Hispanic descent and one fifth of the students on free or reduced lunch. The first year of the study there were 32 students involved, and in the second year there were 38 students. During the first year, the teacher taught the modules during the spring semester in about 13 hours over the course of four weeks. During the second year of the study, the teacher started the module in the second half of the fall semester and spent about 13 hours over the course of five weeks. In both years the teacher started the module with the same question. Data for the study included video recordings from the modules, field notes, video and field notes from debriefing sessions, three interviews with the teacher, and student artifacts.

Due to changes in classroom practice between the years, the researchers wanted to determine if the teacher's objectives had changed. The researchers coded the classroom time using three coding categories: structured experimentation involving conducting experiments and discussing those experiments; discussion of everyday experiences; and discussion that was ambiguous.

Analysis of the data revealed that 85% of the time in the first year was spent discussing structured experiments, with only 14.5% of the time related to everyday experiments. In the second year of the study, 60% of time was occupied with everyday experience discussions and only 34% of the time in structured experiments or ambiguous related to experimentation. In year two, structured experiments were more scaffolded than in year one; this class spent a larger amount of their time on teacher-led discussions about a testable idea. Two structured experiments were inspired by students, but everything was coordinated by the teacher. In year two, there were long segments of the module whereby students were involved in everyday experience discussions. The teacher recognized that students in year two did not respond to experimentation prompts in the same way that year one students did.

In interviews, the teacher noted that students in year two did not initially think about or value testing, but over time that attitude shifted toward more involvement - with the students asking to test things. Students in year one were more open to testing and experimentation, and the students had just participated in science fair projects. Year two students had not participated in science fair projects prior to the module. Year one students were more likely to design an experiment while year two students used stories or anecdotes from their experience to discuss an idea or explanation. In year two, the teacher became more likely to explain what was happening, which triggered students to engage in investigations.

The differences in the two classrooms appear to stem from differences in intellectual and epistemological resources of the students, along with the changes in the teacher's response to students. The main point of this article was that the students had a significant impact on how science is actually implemented in the classroom. Although students in year one investigated experiments they did not use their findings to develop an overall explanation for evaporation and the water cycle, and as such the instructor demonstrated a lack of satisfaction with the class. In year two theoretical explanations were developed based on their own experiences and students appeared more likely to apply their knowledge to different settings.

One of the first critiques of the article is that the teacher volunteered to be part of the program, thus it was difficult to tell if a similar pattern would emerge in other classrooms. The researchers did not employ pre and posttesting, which would have been helpful in identifying differences in the classrooms in regards to their content knowledge surrounding the inquiry unit. It would have been beneficial to the study and the conclusions drawn from it to include more data on the students, since one of the points of the authors was that the students caused a shift in the instructor and her instruction. A more thorough description of the background of the students and their prior experiences is also important – one critique is that some students had already participated in the inquiry program.

Findings on inquiry-based instruction

In reviewing the literature on inquiry based instruction, a number of discernible patterns emerge. Large analyses of research studies over the past 30 years have consistently demonstrated inquiry based instruction as a more effective tool in helping students learn about scientific processes and science content (Minner et al., 2010; Schroeder, Scott, Tolson, Huang, & Lee, 2007; Shymansky et al., 1983). Although not on the scope of meta-analysis, other research students dealing with large student populations have found inquiry-based approaches effective (Geier et al., 2008; Marx, Blumenfeld, Krajcik, Fishman, Soloway, Geier, & Tal, 2004; Pine et al., 2006; Shaw and Nagashima, 2009; Turpin & Cage, 2004; Von Secker & Lissitiz, 1999). A number of these studies have taken place in the context of a large urban reform and have indicated the successful application of inquiry techniques on a large scale. The superiority of inquiry-based techniques has also been supported by results from numerous comparison studies. As opposed to larger scale implementation of reform-based teaching practices, these studies have involved smaller comparisons between inquiry-based and traditional classes or courses. These studies consistently demonstrate support for inquiry-based instruction as a more effective tool than traditional techniques in teaching a variety of science concepts (Lee et al., 2010; Lyons, 2006; Mao and Chang, 1998; McCrathy, 2005; Ruhf, 2006; Thacker, Kim, Trefz, & Lea, 1994; Tretter & Jones, 2003; Wilson et al., 2010). Researchers have also shown inquiry-based approaches to be superior to other approaches in reducing the gap between different groups of students (Cuevas, Lee, Hart, & Deaktor, 2005; Lee et al., 2006; Lynch et al., 2005; McCrathy, 2005; Shaw and Nagashima, 2009).

Implementation of inquiry-based instructional techniques involves certain commitments from teachers and instructors. These commitments sometimes are significant hurdles to implementation. Crawford (1999, 2007) has documented the successful efforts of preservice teachers as they engage in inquiry-based practices. The successes also are intermingled with failure, as some preservice teachers still find it difficult to attempt inquiry-based instruction. Anderson (2002) has documented a number of the barriers that exist in regards to inquiry; Trautmann (2004) also discusses some of the blocks to engagement. These barriers include time, comfort level with the instructional practice, fear of the unknown, existing curricular demands, and lack of familiarity with the techniques on the part of students and parents. Despite these hurdles, individual cases of successful inquiry implementation exist (Crawford, 2000; Keys and Kennedy; 1999; Maskiewicz and Winters, 2012). Research studies have also examined teacher adaptations made to curricula and its positive impact on students' learning (Fogleman, McNeill, and Krajcik, 2011; Forbes, 2011).

In addition to comparing inquiry versus non inquiry classrooms, some researchers are starting to explore the degree of inquiry in classrooms and its impact on students. Sadeh and

Zion (2009) found that students involved in open inquiry were more likely to display a greater mastery of inquiry in general and students in the open inquiry group exhibited a deeper understanding of science concepts as well as scientific procedures. This further strengthens the argument to employ more inquiry-based techniques in classroom settings.

From an epistemic standpoint, it is also important to note the possibility of differences in how inquiry-based approaches are handled by teachers of different science backgrounds. Amongst exemplary (National Board Certified) science teachers, Breslyn and McGinnis (2011) found distinct differences between the teachers based on content area. Biology teachers were more involved in science as a process, while physics teachers were more focused on modeling and mathematics. It will be very important as we progress in our research studies to acknowledge and consider the differences in science teachers based on their content backgrounds, as well as the other factors that are at play. Considering a science teacher's content background may be just as important as looking at research experience or teacher experience when evaluating inquiry-based teaching.

The wide range of studies presented here, both in scope and context, has consistently supported the pursuit of inquiry-based instruction in classrooms. This involves not only teaching through inquiry, but about inquiry, since it can yield a deeper understanding of content knowledge through investigative processes.

CHAPTER 3

METHODS

Theoretical framework

This research study will use a constructivist view of learning as a theoretical framework to guide both the design and data analysis. Cognitive constructivist views of learning (Piaget, 1953, 1955, 1973) and social constructivist views of learning (Driver, Asokoa, Leach, Mortimer, & Scott, 1994; Vygotsky, 1978) take into account the interactions and experiences of students as well as the social context of the learning environment, as students develop understandings of science concepts and the nature of science.

Two major paths of constructivism exist: cognitive constructivism and social constructivism. In the cognitive vein of constructivism, students "actively construct their ways of knowing as they strive to be effective by restoring coherence to the world of their personal experience" (Fosnot, 2005, p.39). The social constructivist path examines the social and cultural interactions that occur amongst individuals and how they shape learning and the construction of shared meaning. Cognitive constructivism and social constructivism are often viewed as in direct conflict. For instance, Vgotsky (1979), states "the social dimension of consciousness is primary in fact and time. The individual dimension of consciousness is derivative and secondary" (P. 30). However one cannot separate the context from the individual or the individual from the context when examining how an individual learns. In *Constructivism: Theory, perspectives, and practice* (2005), Cobb states learning is "both a process of self-organization and a process of enculturation that occurs while participating in cultural practices, frequently while interacting with others" (p.51). Thus, understanding of concepts is a process that involves an individual's own cognitive negotiation as well as generating meanings with other individuals.

For this study the primary focus will be on cognitive constructivism with recognition of the context in which students are learning. This decision was made since the research will explore an individual's understanding of evolutionary theory based on their experiences in a particular environment.

In the classroom, constructivism involves learning that will require negotiating meaning "through cooperative social activity, discourse, and debate in communities of practice" (Fosnot, 2005, p. ix). The authors of the book *In Search of Understanding: The Case for Constructivist Classrooms* state "each of us makes sense of our world by synthesizing new experiences into what we have previously come to understand" (Brooks & Brooks, 1993, p.4).

Piagetian principles of assimilation and accommodation are vital to consider when investigating evolutionary theory. Research study results appear to indicate that student and teacher understanding of evolution are a product of assimilation, rather than accommodation. In assimilation, new knowledge is incorporated into the existing cognitive framework of an individual. This would explain the continued reliance on teleological, anthropomorphic and Lamarckian explanations since they result in less cognitive distress than accommodation. Accommodation forces individuals to create a new framework as a result of knowledge acquisition. Meadows, Doster, and Jackson (2000) found that individuals often incorporated an understanding of evolutionary theory into an existing mental framework. In the case of evolutionary theory, students' belief constructs have been demonstrated to have a strong influence on understanding and acceptance of the theory (Bishop and Anderson, 1990, Settlage, 1994; Sinatra et al. 2003). Studies reviewed here also have stressed the importance of identifying and addressing student preconceptions/prior knowledge related to evolutionary theory– both by the student and the teacher (Zuzosky, 1994).

Study Design

The main purpose of this study was to examine the impact of different instructional strategies on students' understanding of science and evolution. A quasi-experimental research design, as described in Creswell (2003), was used with one intact class serving as a control group, and the other serving as an experimental group. Although a true experimental design could reduce numerous validity threats, random assignment of students was not possible. Inquiry-based instruction was implemented in the experimental group during the beginning of the course when the nature of science was discussed and approximately one month later during the instructor's unit on evolution. The control group was taught in the same manner as the instructor had previously done, except for the inclusion of nature of science at the beginning of her course. The two groups will be referred to as the Inquiry Class for the experimental group and the Traditional Class for the control group. Instructional and laboratory time was kept approximately equal for both classes. To assess student understanding of topics and the impact of the instructional techniques the researcher used the *Views of the Nature of Science Questionnaire Version C*, the *Conceptual Inventory of Natural Selection,* selected questions from Bishop and Anderson's 1990 study, student interviews, and student work products (including instructor generated exams). The instructor was also interviewed to assess her understanding of nature of science and inquiry. Both classes were audio and video taped during the study to help confirm the nature of instruction.

Site Selection

The study was conducted at a community college in New York State. The college serves a mostly rural and suburban student population. According to enrollment data as of fall 2007 (the time of the study), the college had 4,050 total students - 2,419 female students and 1,631 male students (59.7% and 40.3%). During the spring and summer of 2007, the researcher sent out flyers to science teacher professional networks as well as local school districts and colleges in a limited geographic area in New York. The instructor expressed interest in the study and was willing to try new instructional techniques, and she also had at least two sections of the same course being offered in the fall semester. The target course was introductory biology since it covered evolution and elements of sciences. Only one other instructor, a middle school science teacher, expressed interest in the study, but was not included due to scheduling issues.

Instructor Background

The instructor involved in the research study is (as of Fall 2011) an Associate Professor of Biology at the community college. During the study the instructor was in her fifth year at the college and had earned tenure the prior year. Her rank at the time of the research study was Assistant Professor. She had previously worked as an adjunct science instructor (primarily teaching laboratory sections) at a college in the State University of New York system for one year and as an adjunct science instructor at a liberal arts college for one semester. During her Master’s degree, she served as a graduate teaching assistant for undergraduate biology courses. She has earned a Bachelor of Science degree in Environmental and Forest Biology, a Master’s of Arts in Biological Sciences, and a Master’s of Science in Forensic Science. Although she had extensive science course work, she only had two classes that dealt with evolution directly: a class in the Evolution and Ecology of Mammals as an undergraduate student and a Human Paleontology course during her first master's degree. Her teaching preparation only included a science education workshop during her first master's degree. She had participated in some teaching assistant workshops during her first master’s degree but in her pre interview she

> Researcher: Did you have any education or TA development classes?
>
> Instructor: No, oh wait, yes we did - at SUNY Binghamton we did teaching seminars. We did things about capstone projects and leading discussions. I mean they were useful but they were so long ago that they weren't relevant to what I was doing then, they are more relevant to now but they were so long ago. So I would say very, very little. A lot of them were led by grad students. I mean even the people leading them didn't really know.
>
> (Pre Interview, Lines 45-50, 08/4/2007)

Teaching Responsibilities

The instructor was primarily responsible for the following courses at the community college (both laboratories and lectures):

Anatomy and Physiology I
Anatomy and Physiology II
Basic Nutrition
Biological Principles I
Biological Principles II
Forensic Chemistry

The instructor's course load is typically four courses per semester (a full load is 15 credit hours per semester). During the fall and spring semesters, the instructor usually has two sections of Biological Principles I, one section of Anatomy and Physiology, and one section of Basic Nutrition. Due to class space restrictions, courses that have a laboratory component (Biological Principles I and II, Anatomy and Physiology) are capped at 24 students, with non-laboratory courses (Basic Nutrition) capped at 32 students.

Instructional Style

The instructor's instructional style can be described as a traditional didactic (teacher-centered) mode of instruction. She delivered information in lecture almost entirely through PowerPoint presentations developed during her first four years at the community college. Her PowerPoint presentations contained numerous figures, as well as science related cartoons. When the researcher asked about her instructional style in the pre interview she was quick to answer.

Researcher: How would you describe your instructional style?

Instructor: Traditional and efficient.

Researcher: Why do you think you teach that way?

Instructor: I don't know. I guess it's quick. I know exactly what the students are writing down. It's very easy for me to reach my objectives for the day because I know specifically what I've covered. And once I have a good lecture prepared, it takes very little to prep now.

(Pre Interview, Lines 8-11, 08/4/2007)

In addition to the lecture component of the course, instructors at the college are responsible for teaching their laboratory sections. Unlike many four year institutions (and some community colleges) the students did not select separate laboratory sections from their lectures – the instructor remained the same as did the students in the class. The advantage of this is the instructor can review and discuss information that was brought up in lecture or lab. Students also get to know each other in both instructional settings and have more contact time if they need it for working on projects. The laboratories used in the course come from the laboratory manual the students purchase for the course. The manual and textbook are used for both Biological Principles I and II. The researcher also discussed laboratory activities with the instructor during the same interview. Based on this interaction the instructor is not fond of laboratory instruction.

Researcher: Why do you use the labs that you do?

Instructor: That's the lab I knew they use at the school, the one I used at Cortland, and I don't have enough experience for developing labs to know any different, manuals that would be more effective. I could download labs online, but again, I know we had all the material for these and I finally know how they work.

Researcher: Do you like teaching lab?

Instructor: No.

Researcher: Why?

> Instructor: I just don't like the sense of urgency that they have to get out of the lab. They complete the experiments as quickly as they can and it's very difficult to make them sit down and really think about what they're doing, so people **[inaudible]** because I feel like I'm always, always running around and explaining what they're supposed to be getting out of lab. A lot of that is my own fault because I don't give the pre-lab quizzes on what we're doing that day.
>
> (Pre Interview, Lines 12-21, 08/04/2007)

The research study would involve nature of science and inquiry activities; therefore the researcher asked whether the instructor was aware of nature of science instruction.

> Researcher: Had you heard about the nature of science?
>
> Instructor: Previous to this? I never knew it was called that. I knew things about it but I never knew it was called that. I teach my students that science, the information that we identify, is tentative. I taught aspects of it but I never called it the Nature of science. I do compare it to other disciplines and I just never have called it the nature of science.
>
> Researcher: Do you think it is important for students to know about aspects of science?
>
> Instructor: Some of them, yes.
>
> Researcher: Why?
>
> Instructor: So they know how science differs from other disciplines. There are no facts. I think it is so important for them to understand that there are no facts - that gravity is not a fact, evolution is not a fact. I think it is important for them to understand what scientists do to come up with their theories. The amount of time and effort and knowledge, experimentation and observation is also important.
>
> (Pre Interview, Lines 22-33, 08/04/2007)

Since the instructional sequence would be inquiry-based in the experimental class, the researcher also asked the instructor about her awareness of inquiry instruction prior to the study.

> Researcher: How would you describe your understanding of inquiry before today?

> Instructor: Like on a scale from one to ten?
>
> Researcher: Yes
>
> Instructor: I would say I was a two, maybe a three.
>
> Researcher: How did you know about it previously?
>
> Instructor: I spoke about it at the Sheldon Institute so I did have to bring it up. I probably read about it in articles but never paid attention to it because I really wasn't doing it.
>
> (Pre Interview, Lines 1-7, 08/04/2007)

The pre interviews indicated that the instructor was not very familiar with the concept of nature of science or inquiry, but she did discuss aspects of nature of science in her course. She did not consider herself well versed in inquiry and "really wasn't doing it."

Course

As described by the community college's catalog, Biological Principles I is a four credit course that has three class hours and one three hour lab weekly. According to the college catalog description the course:

> Deals with the fundamental concepts and principles of biology. Topics include cell structure and function, chemical concepts and energetics at the cellular level, a survey of kingdoms monera, protista, fungi and plantae as well as plant structure and function.
>
> (Cayuga Community College, 2007, p. 78).

The current textbook selected by the science faculty and used in the other sections of the course is *Biology with Physiology: Life on Earth* by Audersirk, Audersirk and Byers (2008). The laboratory manual used was Sylvia Mader's (2007) *Inquiry into life*.

Instructional Sequence Prior to the Research Study

In the four years prior to the study the instructor had addressed evolutionary theory over a duration of approximately 3-4 weeks, with the topic of evolution directly over two, one hour and twenty minute class periods. The amount of time the instructor spent on evolution is fairly consistent with other introductory biology courses at the college level (Jensen and Finley, 1995). In the past the instructor has engaged students in one laboratory session on the topic. The laboratory component, which consists of one three hour block, has involved watching the video "What Darwin never saw?" During this lab, students watched the video "What Darwin Never Saw" and filled out a handout based on the information provided in the video (See Appendix D for handout). Although students were required to purchase an accompanying laboratory manual for the course the instructor did not use the lab on evolution from the manual. The instructor mentioned in her post interview why she did not have students participate in that laboratory experiment.

> Researcher: Why haven't you done labs with evolution before?
>
> Instructor: I don't like the one in the lab manual. It is looking at a bunch of skeleton pictures and having them compare and it is so long. If they can't look at something and get it correct looking at the graph. It is tedious to grade and I don't think it does anything - they don't have to memorize what bones are the same in a primate and a cat. I think that lab could be done in ten minutes if you show - if you have real skeletons like a cat a frog and a pig and a human and you just have them go up and look at them.
>
> (Pre Interview, Lines 133-138, 08/04/2007)

The instructor placed little value on this laboratory, which is evident from the following part of her post interview.

> I wouldn't have them waste two hours filling out those long tedious labs. To me it is useless. It contains a lot of information that I actually don't want them to know. I don't make them memorize the time scale; they don't have to know when plants evolved. I find memorization of things like that useless. You could look it up so easily - its details that one, could change somewhat, and they're always

> changing. It's not important for them to memorize how many billions of years ago some epoch was.
>
> (Post Interview, Lines 143-148, 12/20/2007)

Although the instructor spent approximately 3-4 weeks on the topic of evolution, she did not have students complete an actual laboratory activity during the same time period. This mainly stems from dissatisfaction with the laboratory manual and the evolution lab contained within it. It is important to note that she did not want to waste students' time on activities that had information that she did not find to be valuable. However, the evolution lab from the manual was included in the study because the instructor valued the amount of money students spent on the materials.

Research participants

To ensure the protection of the study's participants, the researcher submitted the study for approval from both the community college's administration, as well as the Institutional Review Board at Cornell University. The study was given exempt status, however, the researcher and instructor decided to receive written consent from each participant. The researcher developed a written consent from using Cornell University's Institutional Review Board guidelines (Appendix). During the first day of the class, the researcher came into both classes and described the study and the expectations of the participants. In addition to taking pre and posttests, having their grades analyzed, and possibly participating in interviews, the researcher explained that the students would be audio and videotaped. Students were told at least three times during the initial overview that they could opt out of this portion of the research study. The researcher also provided monetary compensation in the form of ten dollars per student upon completion of the posttests at the end of the study. Students who were interested in participating in the study were asked to fill out a written consent form and return it to the instructor or researcher (See Appendix). All students from both classes agreed to participate in the study and no students opted out of the video or audio component.

Participant demographics

Before the start of the study the researcher had students fill out a demographic survey to collect relevant data on the students. The survey included nine open ended questions which are listed below:

1. Are you a part time or full time student?
2. What is your age? (Do not provide if you don't feel comfortable – this helps me in relation to previous science classes and knowing what high school biology Regents you took).
3. What is your current major?
4. What are your future career goals?
5. When was the last time you took a biology class?
6. What high school or home schooled science classes have you taken (list all courses – if you remember dates please provide them)?
7. Have you taken any college level biology classes? If yes, which ones?
8. Have you taken other college level science classes? If yes, which ones?
9. How would you describe your overall comfort level with/understanding of biology?

The open ended questions were developed to see if there was a relationship their comfort levels and their evolution test scores (including the *Conceptual Understanding of Natural Selection* (Anderson, Fisher, and Norman, 2002)).

In addition to these open ended questions, students were asked to rate their comfort level of the major topics that were going to be covered in the Biological Principles I course. Research studies have discovered that students often feel apprehension and concern over the topic of evolution, because of the perceived conflict between it and their religious beliefs (Brem, Ranney, & Schindel, 2003). The topics were: Microscopes and their use; biological molecules/chemistry; cell structure and function; classification/systematics; evolution; DNA, RNA, and genetics; mitosis and meiosis; photosynthesis; and cellular respiration. The topics were generated from discussions with the instructor and based on the topics covered in her syllabus. Students graded each of the seven topics on a scale from 1-5. The scale was developed by the researcher and was described as the following:

1 Not at all comfortable, I don't understand this topic well or haven not received instruction in it
3 Somewhat comfortable
5 Extremely comfortable, I understand the topic completely, I probably could instruct other students.

The research participants were students ranging in age from 17 to 43 in the traditional instruction class and 18 to 39 in the inquiry-based instruction class. The study ended up with 18 participants from the traditional class and 21 from the inquiry class. One male student in the inquiry class was not included in the posttest analysis as he did not complete the surveys. The traditional class had 11 females and 7 males (61% female, 39% male) while the inquiry class had 14 females and 7 males (66.6% and 33.3%). The percentage of females in the two classes was slightly higher than the college's average for total enrollment.

Data Collection Procedure

The researcher and the instructor discussed and decided on a data collection procedure that would have the least impact on the instructor's class time. Since survey completion and return rates are typically low (Creswell, 2003), the researcher administered the instruments during class and lab times. The sequence of data collection and the instruments used can be found in Table (1).

Table 1. Research instruments administered to Participants

Date	**Activity**
8/30	Research participant recruitment, consent forms filled out, demographic surveys completed, VNOS-C administered
10/9 – 10/11	Participants completed CINS, Gallup Question, and Cheetah question
10/30	Participants completed instructor generated exam
11/27	Participants completed Posttests – CINS and Cheetah question
12/3 to 12/12	Volunteers participated in interviews pertaining to evolution and NOS
2/08	Available students complete Post posttests – CINS and Cheetah question

In addition to the data collection instruments, the researcher also videotaped and audio taped all classes. One camera and at least two digital recorders were in the classrooms at all times. During laboratories two cameras were used in the front and back of the classrooms, situated in unobtrusive locations. The digital recorders were used to gather student/instructor interactions and to serve as a backup in case the camera failed. One of the cameras audio ability failed during a class session, but a loss of data was avoided due to the digital recorders. The instructor took field notes during the first class session and all the computer lab and laboratory sessions, but did not stay in the classroom during the evolution lectures. This was due to space issues and because the instruction felt it would be too intimidating. The size of the lecture classrooms only accommodated one camera on a tripod in the back right or left corner. The camera view in the classroom was situated on the instructor, the projection screen, and a portion of the whiteboard. Approximately 25% of the students were visible in the camera view. The video tapes and audio tapes were used to assess the actual instructional process employed in the classes.

Instrument Selection

Instrument selection was dictated by a number of factors, including: research supporting the instrument's use, what the instrument assessed, relationship to the instructional sequence, time required to complete the instrument, and the instructor's perceptions of the instruments.

Views of the Nature of Science Questionnaire version C

The researcher decided to use an instrument that was open ended to assess students' understanding of science. Although more time consuming than a multiple choice survey or Likert scale, open ended questions allowed the researcher to examine the response of students and the supporting examples they might provide. The *Views of the Nature of Science Questionnaire* has multiple versions (VNOS-Form A, VNOS-Form B, VNOS- Form C, VNOS-Form D, and VNOS Form E) that are intended to identify an individual's views of science (Lederman et al., 2002). The developers of the VNOS have administered the three forms to about 2000 individuals with 500 of those individuals also participating in interviews. The researchers have "high confidence level in the validity of the VNOS for assessing the NOS understandings of a wide variety of respondents" (Lederman et al., 2002). In this case the VNOS-C instrument was selected since it included more questions that pertained to the nature of science and biology than the VNOS-B. The VNOS-C also had been administered to college undergraduates as part of the field testing of the instrument. Although the authors recommend that researchers using the VNOS for the first time should interview most, if not all survey respondents, the researcher did not follow this exact protocol due to time constraints.

Conceptual Inventory of Natural Selection

The researcher used an instrument to assess students' understanding of natural selection before and after the evolution unit. The researcher wanted a multiple choice assessment tool as well as an open ended question. He also wanted an assessment tool that would match the instructional strategies employed in the study. The *Conceptual Inventory of Natural Selection* (Anderson, Fisher, and Norman, 2002) was selected not only for its ease in which it is administered and scored, but also because it has been field tested a number of times with community college students, the target population of this study. Additionally, the use of questions about the Galapagos finches lent itself directly to the instructional activities that were used – the Investigating Bird Beak Adaptations lab in the traditional class, and the Galapagos Finch software program in the inquiry class.

The *Conceptual Inventory of Natural Selection* (Anderson et al., 2002) is a 20 question multiple choice survey intended to elicit students' understanding of 10 main ideas related to natural selection: biotic potential, carrying capacity, resources are limited, limited survival, genetic variation, origin of variation, variation is inherited, differential survival, change in population, and origin of species. The *Conceptual Inventory of Natural Selection* was developed by Anderson, Fisher, and Norman – with the testing procedure detailed in a 2002 article in the Journal of Research in Science Teaching. The authors were attempting to find an instrument that could be used with large groups of students and that could use more concrete examples of evolutionary change. The inventory uses three scientific examples – Galapagos finches, Venezuelan guppies, and Canary island lizards, which offer it strength versus the use of hypothetical examples. The authors thought the test was designed to be less ambiguous by focusing on actual scientific data. The examples that are presented in the CINS are pulled from microevolution studies cited in the literature (Anderson et al., 2002).

In regards to reliability, the team who developed the survey measured the internal consistency with the Kuder-Richardson Formula 20. They arrived at a KR-20 value for two sections of respondents at 0.58 and 0.64, where a “good classroom test should have a reliability coefficient of 0.60 or higher” (Gronlund, 1993).

The CINS version one was field tested with approximately 100 students enrolled in nonmajors’ general biology courses in Southern California during the summer of 1999. Seven volunteers were interviewed from one class to determine their understanding of natural selection before and after instruction. There was a positive correlation between the CINS and student interview results (Anderson, et al., 2002). Five college biology professors took the test to validate the responses. After analyzing the data from the initial field test, items on the test were revised on second version of the CINS. Parts of the CINS were given to students in the fall semester of 1999 at a large urban community college in southern California. After this field test, the CINS was modified to include 10 concepts related to natural selection and some questions were changed to increase the readability. This updated test was given to 206 students in a nonmajors’ general biology course at a large urban community college in southern California. The authors found that the face validity was verified by independent content experts, the readability was at a reasonable level for first year college students and the reliability, determined by the KR20, was acceptable (p. 968). The authors indicated in their study “although the interview data reported here are limited, the results indicate that a high score on the easily administered CINS correlates with a high degree of understanding of natural selection during an interview. For this reason, the CINS should be a useful instrument for investigating student conceptions with hundreds of students." (p. 968). Each of the ten concepts is tested through two questions on the CINS, which are shown in Table 2.

Table 2. Concepts and corresponding questions on the CINS

Concepts	**Questions**
Biotic Potential	1, 11
Stable Population	3, 12
Natural Resources	2, 14
Limited Survival	5, 15
Variation	9, 16
Variation Inherited	7, 17
Differential Survival	10, 18
Change in Population	4, 13
Origin of Variation	6, 19
Origin of species	8, 20

Bishop and Anderson's (1990) Open-ended questions

The researcher used Bishop and Anderson's (1990) open ended questions to examine understanding of evolutionary processes prior to and after instruction in evolution. The following pre and post question was used:

> Cheetahs (large African cats) are able to run faster than 60 miles per hour when chasing prey. How would a biologist explain how the ability to run fast evolved in cheetahs assuming their ancestors could only run 20 miles per hour?
>
> (Bishop and Anderson, 1990)

Unlike the *Conceptual Inventory of Natural Selection*, this question is open ended, which allowed students to provide their own vocabulary and terminology. The questions are some of the most (if not the most) common research assessment questions used in evolution education research. Numerous studies over the past twenty years have used these questions with a variety of students in many different settings (Beardsley, 2004; Bizzo, 1994; Crawford et al., 2007, Crawford et al., 2005; Demastes et al., 1995b). The researcher decided to use one of the questions for the pre and posttests for both classes. The cheetah question was selected since the researcher had conducted a pilot study on instructional techniques and found it a more acceptable assessment tool than the question about blind salamanders. The salamander question was not included in the pre and posttest for a number of reasons. Anderson et al. (2002) dropped the salamander related questions from the CINS and explained the rationale for the exclusion:

> Significant problems were identified with the salamander questions during student interviews. The story is complex because the blind salamanders are actually born sighted and even appear to retain their sight mechanisms after a membrane forms over the eye during the development, making them effectively blind except for responsiveness to flashes of light. (p. 958)

Besides concerns over the phrasing of the question, a scoring rubric (with a framework for scoring and numerous student response examples) existed for the cheetah question (Jensen, Moore, Hatch, & Hsu, 2007) but not the salamander question. While the framework in the scoring rubric could be applied to the salamander question, the researcher felt that it would be more appropriate to limit the open ended question to only the cheetah question. The instructor also mentioned the need to limit the amount of time spent on the questions so that she could cover class material.

Finally, the researcher and the instructor both felt that the salamander question was slightly confusing and could be troublesome for some students who were answering the question. As a result the salamander question was not used on the pre and posttest for both classes. The instructor chose to include it on her evolution exam to examine students' understanding of natural selection.

Gallup Poll Question

After discussions with the researcher's committee, it was decided to include a method of assessing individuals' beliefs in evolution. The instructor requested that the belief survey be short since students were already filling out the Bishop and Anderson (1990) question, as well as the CINS, during her class time. In a prior pilot study the researcher's participants had taken approximately 10 minutes to complete the Bishop and Anderson question and the CINS could take between 15 to 30 minutes (Anderson et al., 2002). The selection of the Gallup poll question was made for a number of reasons:

1. It had been consistently administered since 1982 (1982, 1993, 1997, 1999, 2001, 2004, 2006, and 2007).
2. Class results could be compared to a larger, national population. According to the June 2007 Gallup summary "These results are based on telephone interviews with a randomly selected national sample of 1,007 adults, aged 18 and older, conducted June 1-3, 2007. For results based on this sample, one can say with 95% confidence that the maximum error attributable to sampling and other random effects is ±3 percentage points" (Newport, 2007). The national sample has been approximately 1000 adults each time the survey has been given.
3. It was easily administered and could be completed in a short time period, as requested by the instructor.
4. Results are often described as an individual's belief in evolution (Newport, 2007).

The researcher could have used a direct question, such as "Do you believe in evolution?" but he decided to use the Gallup question since it could be easily compared to a national population.

Interviews

In addition to the quantitative assessments used in the study, the researcher decided to employ interviews to fully explore the instructor's views as well as students' views. Qualitative research, according to Creswell (2005), enables researchers to gain an understanding of some phenomenon as a result of a detailed understanding of people and/or a particular site. Since the instructional sequence is such a central focus of this study (whether or not it will impact understanding of evolution) it is imperative that it be identified through appropriate means.

Quantitative assessments will not capture the details necessary to replicate the study in other sites or to fully grasp the connections between various aspects of the study. Open-ended questions in interviews allow individuals to discuss their experiences unconstrained as well as provide researchers with an opportunity to respond to material brought up by the participants (Creswell, 2005). Simple classroom observations of an instructor will not reveal the rationale behind the decisions that they make in the classroom. Interviews will provide the researcher with a means to understand whether or not the instructor and the students felt that the instructional strategies were worthwhile. Additionally it is very difficult to capture an individual's complete view and understanding of evolution through quantitative assessments. For instance, the researcher will use a multiple choice question to ascertain an individual's belief in evolution. Depending solely on this question would not allow researchers to learn how an individual's personal experiences influenced their belief in evolution. The interviews provide an opportunity for both the instructor and the students to express their views about the inquiry-based instructional techniques.

Instructor interviews

The instructor participated in two semi-structured interviews before and after the semester. The pre interview took place in early August and the post interview took place in late December. Each interview lasted approximately 40 minutes. The pre interview allowed the researcher to gather the following information about the instructor's

1. Background, including education and teaching experience.
2. Instructional style and types of activities used.
3. Familiarity with and understanding of NOS/ Inquiry.
4. Methods of student assessments.

The post interview gathered information using questions that asked about the instructor's:

1. Understanding of inquiry and NOS.

2. Views on the activities and their benefits.
3. Views of the inquiry class and their understanding of NOS and evolution.

In addition to the interviews, the researcher asked the instructor to write up her thoughts on the various activities and the instructional sequence. She submitted this to the researcher in January and it can be found in Appendix (F).

Student interviews

Interviews with students from both classes were conducted in December, following the completion of the posttests. The researcher chose this time to avoid influencing posttest results. The interviews were aimed at discovering students' preference for learning activities, their thoughts on the instructional sequence and choice of activities, their understanding of natural selection, evolution, the nature of science and their views on the connections of activities with each other and the lecture material. Interviews were semi structured since an interview script was used with all of the students and additional questions were asked by the researcher as dictated by the students' responses (See Appendix E for interview script). Students were recruited by the researcher at the end of November for the interviews. The researcher passed out a paper to each student in both classes asking if the students would like to be involved in an interview. The paper stated that interviews would last between thirty minutes and one hour and students would receive ten dollars for participating in the interview. Students were asked to fill out a schedule on the paper to indicate at least three times when they would be available. The instructor collected the papers and then gave them to the researcher. Seventeen students (9 inquiry and eight traditional) between the two classes expressed interest in participating in the interviews, however, after email and phone correspondence only eleven students participated in interviews (9 inquiry and 2 traditional). The interviews took place during the first and second week of December of 2007, and lasted between 25 and 61 minutes. The researcher digitally recorded each of the interviews in addition to taking notes while the interview was taking place. The recorded interviews were then sent to a transcription service to be transcribed. The researcher read each transcribed interview and listened to the interviews to confirm the accuracy of the transcription.

Deciding on the instructional sequence

NOS activity selection

The researcher met with the instructor approximately one month before the start of the college semester to discuss the research study and any modifications in the instructor's teaching process. The instructor had sent her syllabus to the researcher prior to their meeting in August. The instructor asked the researcher to try to work the research study into her existing framework of topics and activities. The instructor spent one class session discussing aspects of science at the start of the semester. Keeping this timeframe in mind (an 80 minute class session) the researcher looked for activities that would fit into the instructor's course schedule. Due to the researcher's prior teaching experience, as well as participation in an inquiry-based evolution institute, the researcher had experience teaching about evolution using inquiry and non-inquiry activities. The researcher selected a number of inquiry-based activities to teach about nature of science and two laboratories that were inquiry-based to implement in the course. The National Academy of Sciences released a publication in 1998 titled *Teaching about evolution and the nature of science* which includes eight activities to help individuals teach about inquiry and evolution in an inquiry-based manner. The researcher selected two activities that he felt would teach about inquiry and aspects of nature of science – The cube activity and Tricky Tracks! (Lederman and Abd-El-Khalick, 1998; National Academy of Sciences, 1998). The cube activity involves a cube that has names on each side with numbers in the bottom left and top right corner of each side (National Academy of Sciences, 1998, p. 72). According to the Lederman and Abd-El-Khalick (1998), the cube activity:

> Aims to convey to students the notions that scientific knowledge is partly a product of human inference and creativity, is empirically based (based on and/or derived from observation and experiment) and tentative (subject to change).

The cube activity is presented in *Teaching about evolution and the nature of science* (1998) as the first activity that introduces inquiry and nature of science. The researcher felt that this was an appropriate activity to convey aspects of NOS at the start of the semester.

Tricky Tracks! is an activity that has three frames of footprints that are presented one panel/frame at a time to students (National Academy of Sciences, 1998, p. 89). A number of elements of nature of science are conveyed through this activity:

> Tricky Tracks! Conveys to students the message that every ideas counts irrespective of it being the 'correct' answer. Students completing this activity will gain experience in distinguishing between observation and inference and realizing that, based on the same set of evidence (observations, or data), several answers to the same question may be equally valid. (Lederman and Abd-El-Khalick, 1998, p. 85).

After discussing the activities presented in the National Academy of Sciences publication and the 1998 Lederman and Abd-El-Khalick article, the instructor decided to implement two activities when teaching nature of science – the cube activity and Tricky Tracks. The instructor felt that these activities were the most interesting and could be completed in the time frame of her class session, without taking away from instruction in other topics.

Evolution activity selection

During the initial meeting with the instructor, the researcher brought examples of inquiry and non-inquiry-based laboratories to show the instructor. To keep the inquiry class and the traditional class as identical as possible in content and time, the researcher tried to find a laboratory that was similar to the inquiry-based activity (the *Galapagos Finches* software program). The researcher decided to use the *Galapagos Finches* software program, which he had previously used in a graduate course and in a pilot study (Crawford et al., 2007). This program was selected because it provided students with an opportunity to deal with actual scientific data. As a result of engaging in scientific inquiry, the students would use the data as evidence to support claims they generated to explain observations of bird populations in the Galapagos. The researcher would be able to identify with the students involved in the research study as he had been in their position in the past. A number of research studies have used the software program to help students (and teachers) understand the concept of evolution (Crawford 2005). The topics covered lent itself to preparation for students taking the CINS. It is also is one of the few evolution activities that relied on an actual data set without having to do field research.

The Galapagos Finches Software

The software was part of the *Biology Guided Inquiry Learning Environment* (BGuILE) project directed by Brian Reiser at Northwestern University and supported by LeTUS (Learning Technologies in Urban Schools). Currently the program is free and available for download at http://www.iqwst.northwestern.edu/finchesdownload.html and on the web at http://bguile.northwestern.edu/. The software program includes a subset of actual finch data from Daphne Major in the 1970s. Students can explore the background on the island's environment, weather, food sources, and predators. Field notes are included in the program from the scientists who were collecting the data. The most powerful part of the program is the ability of students to compare a variety of physical traits with each other. They can also examine their prevalence in the members of the population that survived and those that died during different time periods. Students can also look at single physical traits such as weight, beak length, wing length, and leg length or they can compare two of these traits. Unlike other software programs that deal with evolution, this is not a simulation but rather a manageable data set that is open to student interpretation.

The program starts off with a short video that describes the island and the inhabitants, and then poses two questions:

1. Why are so many finches dying?
2. Why did some finches survive?

The video also indicates that there may be more than one explanation and that students need to support their argument with data.

Traditional class, Non inquiry-based lab dealing with natural selection and evolution

The researcher selected a comparable lab to the inquiry program Galapagos finch software program that had students simulating the beaks of various birds on different islands. This selection was a result of the researcher's background as a high school science teacher and his own experience using the New York State lab titled "The Beaks of Finches." A number of versions of this lab exist, some use candy and household tools to simulate beaks, and some use seeds and household tools. The version that they used came from a laboratory kit that had been purchased by the college's science department from WARD'S Natural Sciences titled "Investigating Bird Beak Adaptations" (WARD'S Natural Science Establishment, 2002).   The lab included a two page background section that discussed the beaks of finches on the Galapagos Islands and the competition for resources occurring between various species of birds. Students used tools to simulate bird beak types and various materials simulated food sources. The tools that simulated beaks were pipets, pliers, tweezers, and a dip net. Four separate tables served as “islands”, one with nectar, one with seeds, one with pipe cleaner worms, and the last with floating vegetation in water. At each island students were given 15 seconds to collect as much of the material as possible. This data was recorded in tables and used to help students answer 10 analysis questions that dealt with components of natural selection.

Additional inquiry-based lab

The instructor expressed interest in implementing another inquiry-based lab in her laboratory sessions. Prior to the meeting, the researcher had searched the internet and a variety of websites including evolution and the nature of science institutes (ENSI web) for inquiry-based laboratory activities appropriate for a college level introductory biology course. After using the search terms “inquiry” “natural selection” and “lab” “laboratory”, in different search engines the researcher arrived at Cornell University’s Science Inquiry Partners page. This National Science Foundation funded program was “designed to embrace the philosophy set forth by the creators of the National Standards, which is that students of science must have both "hands-on" and "minds-on" experiences” (Cornell University, 2006). Fellows were placed in K-12 classrooms to assist teachers with scientific topics and research. A part of their fellowship included the development and field testing of inquiry-based laboratory activities. The researcher went to the site with the instructor and showed her some of the possible labs. The instructor’s interest was peaked the most by a lab titled “Natural Selection and Adaptive Behavior in Goldfish” developed by Troy Murphy. Students would have to develop their own experiments and they would be working with living organisms – something they (and the instructor) had not done before. Goldfish were readily available from local pet stores and the science laboratory already had materials to care for the fish (including three aquariums). The instructor selected this lab for implementation after the *Galapagos Finch* software program.

Additional non inquiry lab Traditional Class

The researcher and the instructor made strides to keep the instructional time as close as possible between the two classes to equate time on task. With the addition of the goldfish activity the inquiry class would have an additional laboratory session on evolution concepts that the traditional class did not. To alleviate the problem of unequal time, the instructor and the researcher decided to add an additional laboratory on evolution topics for the traditional class. The instructor requested that the lab selected be on the topic of evolution and that it could be covered in one laboratory session. After examining a number of laboratories the instructor decided to use the evolution lab in the laboratory manual, since students already had purchased it for the course. Although the instructor did not use the laboratory typically, she felt that it was appropriate since students had made a sizeable investment in the manual (over 100 dollars).

Role of the researcher

During the research study the researcher was in the classroom and laboratory to adjust the camera and audio equipment. The instructor asked the researcher to assist with the laboratory as she had not used the computer program before or the carried out the goldfish activity. At the start of the evolution unit in the inquiry class the researcher went over the computer program with the students on an LCD projector after the instructor had introduced the problem. While students worked on the activity the researcher was available to assist with questions concerning the program.

Sequence of instruction

During their meeting prior to the start of the semester, the instructor and the researcher discussed the research design and the instructional sequence. The instructor requested that the research instruments would take as little class time as possible, and that the sequence would fit into her current instructional process. At the time of the study, the instructor discussed elements of science at the beginning of the course and evolution about a month later after going over chemistry and biological molecules (see Appendix B). The instructor and researcher decided to implement the VNOS-C and the demographic survey at the start of the semester. Following this, the instructor would cover elements of the nature of science in both classes during her lecture.

Evolution Unit

The evolution unit began about one month after students went over the aspects of NOS. Before any instruction on evolution began the instructor administered the *Conceptual Inventory of Natural Selection*, the Gallup Poll Question, and the Bishop and Anderson (1990) cheetah question. The sequence of the evolution unit in both classes was determined by discussions between the researcher and the instructor. The traditional class sequence was almost entirely the same as the instructor had previously done, except for the laboratory activities the students participated in. The sequence of activities in the inquiry class was dictated both by the instructor and by recommendations from research on inquiry-based instruction and the theoretical aspects of constructivism.

As previously stated in beginning of the theoretical framework section, two major paths of constructivism exist: cognitive constructivism and social constructivism. Cognitive constructivism deals with individuals generating knowledge based on their own prior experiences and social constructivism states knowledge is a product of social and cultural interactions. In the case of this study the researcher decided to involve students in the construction of new knowledge, rather than having them simply memorize learning material. Having students engage in the inquiry activity first was a reflection of our understanding of constructivist theories of knowledge construction. Another key component of that learning would be the social interactions that occurred in the classroom, and laboratory. A critical aspect of science is the ability to communicate findings to other individuals. While individuals were dealing negotiation of their own mental framework, they would also have interactions with colleagues participating in the same environment of learning. Student presentations at the end of the finch activity and the development of experiments to test behaviors in goldfish were two important elements of social constructivism in this setting.

Bell, Smetana, and Binns (2005) presented a table indicating four levels of inquiry, based on the amount of information provided to students by the instructor (the question, methods, and solution). Activities at level one provided students with all three pieces of information, while level four activities provided students with none of the information. One of the key differences in the evolution unit between the inquiry and the traditional class was the way in which they started. According to Bell et al. (2005) the level of inquiry in a laboratory or activity may be increased by changing the sequence` of the laboratory presentation “a confirmation lab can become a structured inquiry lab simply by presenting the lab before the target concept is taught" p.32). Science sequences in secondary and post secondary education often follow a pattern of the introduction of concepts followed by confirmation acitivities. Inquiry-based activities often turn these frameworks around – knowledge acquisition is driven by engagement in activities before the concepts are introduced in the classroom.

Using this information as guidance, the inquiry-based class started off with the Galapagos Finch activity, while the traditional class started with a lecture on evolution. A brief description of the activities and information covered in each class can be seen in Table (3).

Table 3. Instructional sequence for the evolution unit

Date	Inquiry class activities	Traditional class activities
10/09/07	Finished an exam on chemistry.	In the laboratory: Took belief and evolution surveys (Cheetah question and CINS). Participated in lecture on evolution for one hour – covering the definition of evolution, natural selection and examples of adaptations in organisms (see Appendix C for lecture notes). **Lab: Bird beaks lab activity – using tools students performed different activities that simulated competition for resources**
10/11/07	Spent 30 minutes reviewing chemistry exam. Reviewed the nature of science and the inquiry activities that were completed at the beginning of the semester. Talked about what a theory was and different theories in science. Students took belief and evolution surveys. Moved to computer lab, handed out Galapagos Finch activity sheet and had students start to work on it after watching introductory video.	Reviewed topics covered in lecture on 10/9 – evidence of evolution, ended with sexual selection (see Appendix C for lecture notes).
10/16/07	Instructor briefly reviewed the project expectations. Students worked on Galapagos Finch projects in the computer lab.	Reviewed evolution definitions, natural selection, and evidence of evolution. Lectured on Darwin and his voyage, discussed individuals that influenced Darwin, talked about artificial selection. Evolution debate, origin of species and species definitions, isolating mechanisms. (see Appendix C for lecture notes) **Lab: Students worked on an evolution lab from the**

		laboratory manual (Mader, 2007). The laboratory dealt with geologic time scales, fossils, homologous structures and DNA sequencing.
10/18/07	Students gave finch presentations as others graded their presentations. Instructor discussed what they learned about finches and science. Watched the video "What Darwin Never Saw". Talked about the video for ten minutes.	Briefly reviewed prior two lectures for about ten minutes, discussed isolating mechanisms, hybrids, adaptive radiation, extinction and the origin of living things. (see Appendix C for lecture notes)
10/23/07	Started lecture notes on evolution – covered same material as traditional class using instructor provided handouts. Ended with the evolution debate. (see Appendix C for lecture notes)	Reviewed for 20 minutes on prior material and then started the origin of life. **Lab: Students watched the video "What Darwin Never Saw".**
10/25/07	Covered origin of species notes, origin of life notes. (see Appendix C for lecture notes) **Lab: Students developed experiments investigating goldfish behavior.**	Finished origin of life notes, spent time reviewing the material learned in prior classes for approximately 30 minutes (used a review sheet). Started new material not on the exam after 30 minutes.
10/30/07	Teacher generated evolution exam	Teacher generated evolution exam

Method of data analysis

Demographic Surveys

Demographic information was collected and entered into a spreadsheet. Students were assigned alphanumeric designations depending on their class – IS for inquiry student and TS for traditional student. Students who participated in interviews were assigned pseudonyms. Comfort level means for both classes were calculated and graphed for comparison purposes. The researcher hypothesized that belief responses, prior college biology classes, age, gender, and comfort level scores for evolution could be used to predict the instructor generated evolution exam scores and the posttest CINS scores. The relevant data was transferred into Minitab a statistical software program used to for data analysis.

Views of the Nature of Science Version C questionnaire

The researcher read all of the student questionnaires and then transferred responses to a word processing program. Pre and post responses were separated into each class – for comparison purposes responses were only included if students had filled out a pre and post questionnaire. A total of eight students (five from the traditional class and three from the inquiry class) were not included since they did not complete post questionnaires. Although 38 students were included in the study, thirty students total (13 traditional and 17 inquiry) were included in the assessment. Using the framework from Lederman et al. (2002) the researcher examined the responses for the accuracy of NOS aspects. The main NOS aspects were: Empirical basis, tentativeness, theories and laws, subjectivity, social/cultural embeddedness, observations and inferences, and creativity. Donnelly (2007) provided a more detailed framework for further analysis of NOS responses by breaking students' responses into major categories. For instance, in her assessment of whether students had an accurate view of the empirical aspect of NOS she looked at the use of terms and phrases. Those students using evidence, proof, studies, experiments, tests, facts, research, observations and other means of figuring out answers reflected informed views of NOS. The researcher used this information as a guideline for analyzing the VNOS-C responses. Student responses were read and then categorized as either supporting or not supporting the NOS aspect. Dominant themes (both supporting and not supporting NOS) in student responses were identified and quantified. Percentages of students engaging in certain themes were calculated and then recorded in Excel. The instructor also participated in rating the students – she and the researcher arrived at a 93.2% inter-rater reliability in how students were classified (either supporting or not supporting the specific component of NOS). A total of 720 classifications were possible (30 students, 6 categories, 4 instruments). Agreement was reached after a discussion of the scoring and references to Lederman et al. (2002) and Donnelly (2007).

Conceptual Inventory of Natural Selection

The *Conceptual Inventory of Natural Selection* pre and posttests were scored using the answer key presented in Anderson et al. (2002). Student tests were only included if they had completed both the pretest and post; two students were excluded from the analysis in the inquiry class due to this (one completed only the pretest and one only completed the posttest). One student was also excluded in the inquiry class since they only completed three questions on the pretest. Descriptive statistics (mean, median, standard deviation) were generated using Minitab, a statistical software program. An item analysis was completed on each pre and posttest to determine which questions were answered incorrectly by students and the alternative choice selected. The CINS was designed with specific alternative conceptions for each question. Correct and alternative selections were entered into Excel and graphs were generated from this information to compare the results from both classes. Questions testing similar concepts were displayed on the same graph. The graphs displayed the number of students choosing each multiple choice answer. Before comparisons were conducted on the CINS, histograms of pre and posttest scores for both classes were created to determine if the scores followed a normal distribution. After normality was determined, statistical testing was completed on the pre and posttest means for each class using Minitab, a statistical software program. T tests were chosen over ANOVA since an ANOVA is more appropriate for multiple group testing. This study involved only two groups and two measures, a pre and posttest. Two hypotheses were tested, the null hypothesis and the alternative hypothesis. The null hypothesis assumes that there is no difference between the means of the two groups, while the alternative hypothesis indicates there is a difference in the two hypotheses. The null hypothesis is accepted if the p value is greater than 0.05 and rejected if it is less than 0.05.

> Null hypothesis: the difference between the two groups is 0. The difference between the CINS mean of the inquiry class and the CINS mean of the traditional class is zero.
>
> Alternative hypothesis: the difference between the observed CINS mean of the inquiry class and the expected CINS mean of the traditional class is not zero.

A paired t test was used on student pre and posttest results to determine if they were statistically significant. The paired t test was chosen since it can determine significance in pre and posttest measures. Difficulty values (the percent of correct responses) were calculated using Excel and Minitab. These values were then compared to the reported values of the CINS (Anderson et al., 2002).

Bishop and Anderson (1990) open ended questions

An article by Jensen, Moore, Hatch and Hsu (2007) in the American Biology Teacher detailed a method of analyzing the Bishop and Anderson cheetah question for the number of Darwinian components contained within the student responses. According to the authors, “the rubric has been used by different instructors, who established an inter-rater reliability of 85% (Jensen&Finley, 1996)” (Jensen, et al., 2007). The four Darwinian components are variation, genetics, differential survival and reproduction, and change over time. Students receive one point per component that is expressed in their response, but points are not simply awarded for using terms (such as adapt). The authors provide an example of where using a term does not garner any points, “Cheetahs adapted to their environment” (Jensen et al., 2007). Since the term adapt can be used in a number of ways and is a complex topic, the authors did not feel this question earned any points. Students can receive a score from 0 (no components) to 4 (all four components in the response) based on each of their pre and posttest responses. The authors included 8 examples of student responses, the scores they received, and the rationale for that score. This system of scoring allowed the researcher to quantitatively assess students’ understanding of natural selection on the pretest and posttest. In an earlier research study the researcher had examined students’ responses for terms reflected in the research literature to determine whether students held an uninformed or informed view of science (Humphrey, Crawford, Vaccaro, 2007). The researcher found this to be cumbersome since students often reflect multiple conceptions of natural selection in their responses. Conversion to quantitative values allowed a direct comparison between both classes, including the net increase from pretest to posttest. However, this study did not focus on the number of misconceptions or the types of misconceptions that students held.

Scoring of the pre and posttests took place after both tests had been administered to remove the possibility of influence of the instructor on her instructional methods. In addition, it allowed all responses to be scored at one time to ensure consistency. The instructor and the researcher independently read the Jensen et al. (2007) article and scoring rubric, briefly discussed the scoring technique, and then separately scored each pre and posttest result for Darwinian components. After scoring the items separately the researcher and the instructor compared their scores for each student. Of the 77 student responses (39 pretests and 38 posttests), the instructor and researcher had identical scores on 72 of the 76 student responses, a 94.7% inter-rater score. After a brief discussion of approximately 5 minutes, the final four response scores were agreed upon between the instructor and the researcher. In each of these cases the scores were examined against the rubric and the authors' student examples. Agreement was reached between the instructor and researcher on the student scores – in each case they only varied by one point. A biology instructor at the college who was not a part of the research was asked to independently score 20 random student responses using the framework described in the article. Each of the 20 student scores was identical to the researcher and instructor's scoring.

Analysis of Darwinian components

Scores for each student's response were recorded in a spreadsheet. The total number of components used for each class was recorded, as well as the total net change. The number of students using 0, 1, 2, 3, and 4 components on their pre and posttests was tabulated for each class in a separate table. The net change for each student was also calculated and this value was placed in a table as well. Tables were used to generate graphs of these values.

Terms used

The researcher compiled the pre and post responses of students into a word processing program. The researcher then searched for common terms that are used in student responses including: adapt, adaptation, evolve, mutation, natural selection, offspring, reproduction, and survive. These terms were selected based on a prior study (Humphrey, Vaccaro, Crawford, 2007) and since they are commonly used in student responses when discussing the development of traits (Settlage, 1994). Some of the terms (mutation, offspring, reproduction, and survive) convey a more accurate understanding of natural selection than terms like adapt or evolve. In addition, the Jensen et al. (2007) article indicates some of the terms in the scoring rubric: survive, offspring, mutation, and reproduction. The number of times each term was used by a student was tallied for their pre and post responses and then entered into a spreadsheet. A bar graph displaying the number of times the term was used was created to compare each class.

Gallup Poll Question Responses

Student responses to the Gallup poll question were entered into a spreadsheet with the other demographic data. The student responses were converted into pie charts to compare them to the national data at the time of the research. Percentages were created by examining the number of students who responded in a particular manner compared to the total class population.

Interviews

The researcher read each of the transcripts and generated codes based on the information contained within the transcript. Transcripts were read first twice to get the general sense of the ideas that were put forth by the students. On the third reading the interviews were coded. The researcher initially had brain stormed some themes based on the dominant areas in the research literature (after the first reading). For instance, issues with evolution are commonly attributed to beliefs, understanding of natural selection, and understanding of science (Allmon, 2011). Each of the interviews was coded initially with approximately 15 codes. Creswell (2003) describes this as "lean coding", where the researcher only assigns a few codes to avoid unwieldy numbers of codes when transitioning to themes. These codes were further reduced to themes after the researcher reviewed the transcripts again. The impact of the instructional style and student learning preferences were thought to also play a role in the study, and codes were assigned based on these elements. Some major themes emerged out of the student interview transcripts; the themes included instructional preference, views of activities, understanding of theory, views of science, and understanding of natural selection. The instructor's pre and post interviews, as well as the instructor write up, were examined and the following themes were identified: inquiry, issues with inquiry, perceptions of students, perceptions of activities, understanding of inquiry, and understanding of NOS.

Video tape analysis

Video tapes were used to confirm the sequence of instruction and to determine the extent to which inquiry was used in the classroom. For the instructional sequence the researcher watched all the video tapes and identified sections that would be reflective of the research study. These sections were repeatedly watched and transcribed; this information was used to assist in a description of the instructional sequence. In addition to this, the researcher watched all the video tapes and recorded the time and types of activities that occurred. The video tapes were analyzed to determine the level of inquiry instruction in each class. There were two main approaches used in assessing the instructional process exhibited by each section of the course. The first method involved looking at the activities used and how they were classified in the research community. The inquiry class used the cube activity and Tricky Tracks!, both of which are recommended in documents about teaching using inquiry and about inquiry (Lederman & Abd-El-Khalick, 1998; National Academy of Sciences, 1998). The Galapagos Finch activity has been classified as an "example of guided inquiry" by the researchers who designed it (Sandoval & Morrison, 2003). Finally, the goldfish activity was found on the Cornell Science Inquiry Partnership page. The lab activities used in the traditional class would not be classified as "inquiry" – both the beaks of finches' lab and the laboratory manual activity were "confirmation" or cookbook style laboratories. According to Bell, Smetana, and Binns (2005) confirmation activities are those in which "students are provided the question and procedure, and the expected results are known in advance" (p.32). Cookbook labs are activities in which the driving force is the instructor or manual, which provide the questions being researched, the process for researching the questions, and possibly the answers before the activity begins. The evolution lab from the manual used in the traditional class can be defined clearly as a confirmation lab by this passage found on p. 325:

> Experimental Procedure: Protein Similarities
>
> The experiment tests this sensitized rabbit serum against the antigens of other animals. The stronger the reaction (determined by the amount of precipitate), the more closely related the animal is to humans.
> (Mader, 2007, p. 343)

This passage was found at the beginning of the experiment, before it had been conducted. Students already know the outcome before they immerse themselves in the activity. This is a confirmation lab, as it is confirming a quantity or idea already known.

In addition to using the research community's assessment of the activities, the researcher also used the "Essential features of classroom inquiry and their variation", presented in *Inquiry and the National Science Education Standards* (NRC 2000, p. 29, Tables 2–6), to assess activities. This table served as a framework for analyzing the videotapes for the extent of inquiry in the activities. A number of other sources were used to determine the level of inquiry involvement of students in both classes. An internet search was conducted to locate tables that could be used to rank inquiry activities – search terms included "levels of inquiry", "inquiry chart", and "inquiry-based science rating". This search resulted in the identification of three additional rating scales.

Sutman (1998), Rezba, Auldridge, and Rhea (1999), and Bell et al. (2005) have all presented frameworks for rating the level of inquiry exhibited by science activities. Sutman's scale ranges from zero to 5 based on the role of students or the instructor in the activities. “Full” inquiry activities would have students: proposing the problem or issue, planning the procedure, carrying out the procedure, supplying answers and conclusions, and using lab outcomes for further exploration. Activities at the zero level involve the teacher doing all the aforementioned aspects. Sutman’s level 3 activities are described as “cookbook”; these activities are proposed and planned by the instructor. Rezba, Auldridge, and Rhea (1999) described a method of rating an effervescent antacid tablet activity that included four levels of inquiry: confirmation, structured inquiry, guided inquiry, and full inquiry. As in the case of Sutman (1998), the level of inquiry was dependent on the involvement of students in the activity – open inquiry activities are completely at the discretion of the student. According to Bell et al. (2005) Rezba, Auldridge, and Rhea’s level 1 and 2 activities are “commonly referred to as “cookbook labs,” because they include step-by-step instructions, but Level 2 activities answer a research question” (p.32). Bell et al. (2005) more recently described a modified four level rating system for assessing inquiry. In their scale they examine the amount of information that is given to students in the form of: the question(s), methods, and solution. Since it is similar in many respects to the other scales it also ranks high level inquiry activities as those that are focused on the student and low level activities as those focused on the instructor. Sutman’s (1998) chart and the chart in *Inquiry and National Science Education Standards* ended up being the main driving force behind the video tape analysis since they were both very detailed in their descriptions of what constituted inquiry-based activities. Sutman’s scale allowed for a more nuanced rating since it had a greater number of categories than the others – it could also rate “demo activities” separate from other instructional components.

The rating scales were used to determine the type of instruction that took place in each class. The researcher watched all videotapes and recorded the start and end times for activities he believed were inquiry in nature. After times were recorded the researcher watched the video taped sessions to categorize the level of inquiry represented in the instructional sequence. Since an initial assessment of the inquiry levels of the activities had taken place before the start of the research study (using the general consensus in the research literature) the investigator already had a general idea of the level of inquiry in each class. Despite this prior bias, the researcher used Sutman's (1998) rating scale to identify the amount of time spent engaged in inquiry-based instruction by both classes. The level of the activity, the time spent on the activity, and representative examples of the inquiry level were recorded and placed in a table so that the two classes could be compared. The videotapes also allowed the researcher to confirm the amount of instructional time that both classes spent on the evolution unit.

Limitations of the study

There are a number of aspects of this study that limit its effectiveness. The research was a quasi-experimental approach that introduces a number of threats to internal validity, including "maturation, selection, mortality, and the interaction of selection" (Creswell, 2003). This is a result of using intact groups instead of randomly assigned groups. This can also be considered convenience sampling because the instructor was willing to participate in the study and had two intact classes. While the study can provide insights into students' understanding of evolution, the researcher cannot "say with confidence the individuals are representative of the population" (Creswell, 2003, p. 149). It is recommended that experimental studies contain at least 15 participants in each group, which this study did, but the total population was fairly homogenous.

Both classes had a higher percentage of females and a lower percentage of males than the college's student population. One may question whether these findings are generalizable to a different study population due to these differences.

Limitations also stem from the assessment tools used in the study. The developers of the VNOS surveys recommend that at least 15% of participants be interviewed (Lederman, 2002). The researcher partially addressed this by discussing aspects of science with students in their post interviews, but this only accounted for about 25% of the student population. Interviews did not follow the protocol that is suggested in Lederman (2002). Lack of complete class data on NOS views also challenges the finds of this research study. Only 13 students were used in the traditional class, while 17 students were used in the inquiry class. Drawing conclusions based on this data is therefore problematic since it is not the complete sample used in the study.

The Gallup poll question was not given as a posttest question, since it was questionable whether the beliefs of students would change in such a short time period (approximately three weeks). It would have been useful to examine the possibility of a change in students' beliefs over the short time period. The Gallup question may not have been the most effective assessment tool when considering students' beliefs in evolution and it is questionable whether the Gallup poll effectively measures an individual's beliefs in regards to evolution. However, student interviews confirmed that the beliefs selected represented their views on human evolution. Finally, the classes reported much higher beliefs in human evolution than the national averages that are reported in the Gallup poll results.

The whole Bishop and Anderson (1990) instrument was not used in the study. As a result, one can't assume the same reliability and validity that was calculated when the complete instrument was used. Other studies have used a similar framework; therefore it is not as much of an issue if this was a first time study of using the instrument. The use of a pilot study using this instrument also reduced the negative impacts of this.

Since there were only two intact classes, the researcher could not create an instructional scheme that examined whether explicit discussion of NOS components helped students understand evolution better than implicit understanding of NOS. The research study initially proposed included a four class design which looked at the following:

Traditional teaching techniques, with implicit NOS

Traditional teaching techniques, with explicit NOS

Inquiry-based teaching techniques, with implicit NOS

Inquiry-based teaching techniques, with explicit NOS

Without separating the implicit and explicit NOS classes, the researcher could not determine with certainty the explicit discussion of NOS in the experimental class resulted in more robust understandings of evolution.

CHAPTER 4

RESULTS AND ANALYSIS

The demographic surveys completed by the students allowed the researcher to compare and contrast the two classes. The research participants were students ranging in age from 17 to 43 in the traditional class and 18 to 39 in the inquiry instruction. The mean age for the traditional class was 21.67, while the mean age for the inquiry class was 22.38. Median ages were 19.50 for the traditional class and 21.00 for the inquiry class. The study ended up with 18 participants from the traditional class and 21 from the inquiry class. The 21st student did not complete the posttest, but they were included since they had completed the instructor's evolution exam and the pretests. The student's information was not used in the analysis of the CINS or the Bishop and Anderson question. The traditional class had 11 females and 7 males (61% female, 39% male) while the inquiry class had 14 females and 7 males (66.6% and 33.3%). The percentage of females in the two classes was slightly higher than the college's average for total enrollment (approximately 60% at the time of study). Seven students in the traditional class indicated they had previously taken a college level biology course, while 5 did so in the inquiry class.

Table 4. Inquiry class demographics

Student	***Gender***	***Age***	***Major***	***Prior college level biology classes?***	***Belief in human evolution response***
IS1	Female	20	None	No	2
IS2	Female	18	Math and Science	No	2
IS3	Female	18	Liberal arts	No	3
IS4	Female	18	Psychology	No	1
IS5	Female	34	Math and Science	Yes	1
IS6	Female	21	Liberal arts	No	3
IS7	Female	21	Business	No	3
IS8	Female	20	Nursing	Yes	1
IS9	Female	24	Liberal arts and humanities	No	1
IS10	Female	17	Liberal arts	No	
IS11	Female	31	Psychology	No	1
IS12	Female	39	Education	No	3
IS13	Female	20	Bio and Chem	Yes	2
IS14	Female	24	Math and Science	No	2
IS15	Male	22	Math and Science	Yes	2
IS16	Male	22	Natural sciences	No	2
IS17	Male	18	Business	No	1
IS18	Male	22	Liberal arts	Yes	2
IS19	Male	18	Liberal arts	No	1
IS20	Male	19	Criminal justice	No	
IS21	Male	24	Liberal arts	No	1

Seven students in each class were in science fields – each class had one student from the sciences in a health related track (nursing in the inquiry class and health professional track in the traditional class). Since the students major might influence their openness to evolution it is important to note that both classes had an equal number of students in this field. Two students did not select a choice in the Gallup question; therefore their belief in human evolution could not be determined.

Table 5. Traditional class demographics

Student	***Gender***	***Age***	***Major***	***Prior college level biology classes?***	***Belief in human evolution response***
TS1	Female	25	Math and Science	Yes	
TS2	Female	18	Business Administration	No	2
TS3	Female	17	Lliberal arts and humanites	Yes	2
TS4	Female	21	Liberal arts	Yes	2
TS5	Female	19	Liberal arts	No	2
TS6	Female	19	Biology education	Yes	2
TS7	Female	18	French	No	2
TS8	Female	24	Forensics/criminal justice	No	1
TS9	Female	20	Physical/massage therapy	No	1
TS10	Female	32	Science	No	2
TS11	Female	18	Liberal Arts	No	1
TS12	Male	43	Health Professional Track	Yes	2
TS13	Male	17	Biology	No	2
TS14	Male	18	Liberal arts	No	3
TS15	Male	20		No	1
TS16	Male	20	GIS	No	2
TS17	Male	23	Liberal Arts	Yes	2
TS18	Male	18	None	Yes	2

Community colleges also tend to enroll greater numbers of nontraditional students. According to the U.S. Department of Education (2002, 2005), students who possess one or more of several characteristics can be classified as nontraditional, including delayed enrollment, part-time student status, full-time employment, financial independence, responsibility for dependents, and enrollment after the twenty-fifth birthday. Using only age as an indicator, three students in each class were 25 or older and could be classified as non traditional. Extending the age range to 23, outside the range of most traditional students, each class had five students in the non traditional category. As the U.S. Department of Education indicates, one category alone may not define a student as non-traditional; therefore age alone should not be the only metric in making this decision. In general the two classes were fairly similar in age ranges, degrees, gender composition, and the number of nontraditional students.

Research Question a: How was the inquiry carried out (what was the nature of the instruction)?

The critical component of this study involved the actual implementation of inquiry-based methods and the nature of the instruction. The instructional sequence will be discussed in more detail here. While this sequence may have been appropriate for the methods section, it was an integral part of the research study and may be reproduced in other settings to achieve similar changes in understanding. The design of the research study was supported by a number of research studies as well as the publication *How people learn: Brain, mind, experience, and school* (Bransford, Brown, and Cocking, 1999). This document identified a number of factors that are important in the implementation on the instructional sequence. A major factor is recognizing that students enter classrooms with preconceptions about how the world works and they need to have their initial understanding engaged to help them grasp and understand new information (Bransford, Brown, and Cocking, 1999). Schools have to be learner centered and teachers must be able to draw out the current understandings of their students. Using traditional approaches in science classrooms, such as lectures and verification labs, may be insufficient in doing this. Bransford, Brown, and Cocking (1999) also point out that a learner centered classroom is not sufficient, but that it also needs to be knowledge-centered. For science this means a shift away from a curriculum that focuses on facts to one that emphasizes "doing science" to examine and test ideas. Inquiry-based approaches create learner and knowledge-centered classrooms that focus on the activities of science rather than just learning facts.

Nature of Science

The instructor added the components of the NOS to her PowerPoint presentations for both classes (Appendix C). The components of the NOS were taken from Lederman (2002). The instructor began both classes by going over the definition of biology and then what defined something as living or not living. She went over the levels of organization in biology – cell, tissue, organ, organisms, species, etc. Students were shown pictures of the representative levels of organization. After this both classes were engaged in covering the components of NOS.

Traditional class

The traditional class completed demographic surveys and the VNOS C, after which the instructor went over a PowerPoint presentation about the definition of biology, the characteristics of living things, and a list of the components of NOS. During this time frame the instructor did not ask any questions of her students. The instructor went over the information on the PowerPoints and did provide some further examples and explanations of the terms. However, students were not asked questions and they were not asked for any information or for their thoughts about the subject matter. This is a significant, as inquiry-based activities have a focus on the student, rather than the instructor (NRC, 1996; 2000). The notes the class took and descriptions of the slides may be found in Appendix (C).

Inquiry class

After completing demographic surveys and the VNOS C, the instructor went over the definition of biology as well as characteristics of living things using her PowerPoint presentation. The instructor's actions were almost identical to that of the traditional class with no questions asked of students and the instructor providing all the information. The instructor went over the information on the slides and provided some additional examples and clarification. At this point the inquiry class diverged sharply from that of the traditional class. During the traditional class the professor had gone over the definitions of observations and inferences. Students were passive, with no interaction between them and the instructor. The students simply took the notes and did not explore the information. Instead of providing students with the definitions of observation and inference, the instructor had students participate in the Tricky Tracks! activity. This activity was centered on students providing information about what they believed was going on in a set of slides. To elicit a response from her students, the instructor started off by saying:

> Instructor: Now we are going to do this activity to learn more about doing science. I am going to show you three slides, one at a time. For each slide I want you to take a couple of minutes and write down your thoughts about what is going on in it. Write anything that you think applies – I am not looking for a right answer here but what your thoughts are. So take out a sheet of paper or use your notebook to write your thoughts.
>
> Instructor lecture (Field notes, August 30, 2007)

The instructor put the first frame up on the PowerPoint and asked students to write down their thoughts about what was happening. The instructor gave students approximately two minutes to do this. The second frame and third frames were then shown following a similar format – students took approximately two minutes to write down what they thought was occurring on each frame. After the final frame was shown, the instructor asked:

Instructor: Okay, who would like to share what they had for the first slide or frame?
Student 1: Two birds, one running at the other.
Student 2: A mother and her baby walking at the sea shore.

Instructor lecture (Field notes, August 30, 2007)

These two responses were included as representative of the statements by students. The instructor took about a minute and writes down ten more student thoughts on the whiteboard. The second frame is then examined.

Instructor: What does someone have for the second frame?
Student 3: Two birds fighting.
Student 5: Two animals investigating food.

Instructor lecture (Field notes, August 30, 2007)

The instructor then writes down six more student responses. She continues with the third and final frame:

Instructor: Finally we have our last slide, what did people think about this one?
Student 8: One of the birds killed the other one.
Student 6: One of the birds flew off and the other stayed on the ground.
Student 2: The baby jumped on the mother's back.

Instructor lecture (Field notes, August 30, 2007)

Students continue to share their thoughts about each of the frames and what they thought was going on in. The instructor wrote responses on the board and then asked students:

Instructor: What is an observation?
Student 3: Something that you can see.
Instructor: Is that it? What else?
Student 4: It could be something you measure.
Instructor: Okay, we can use that – observations would be information that you collect using your senses – seeing being one of them and the most common. What would be some observations about this room?

Student 10: There is a clock in the room.
Student 7:   There is a computer in the room.
Instructor: Yes, those are things we can identify or measure using our senses. Now what would the definition of an inference be?
Student 5: Something you come up with.
Student 6: Yeah, something you come up with using your observations or data.
Instructor: All right, let's take a look at what we have written down. For slide number two I had some people say that the two animals were fighting or interacting. Would that be an observation or an inference?
Student 1: An observation.
Student 3: An inference.
Instructor: Well, let's vote on this, how many people say that it is an observation? (About one third of the class raises their hand). How about inference? (the remaining students raise their hands). All right, somebody who said it was an inference, why did you feel that way?
Student 5: You are making an assumption about what happened based on what you showed us.
Instructor: Exactly – do we know if this is two animals of different size? Do we know if they are mother and offspring? We don't. Therefore these are inferences based on our observations. In this case the observation might be that the footprints are of different sizes. We can directly see or measure that. However, we are inferring that it is two different animals. If we look at the list that we compiled, what are most of these?
Student 6: Inferences.
Instructor: Right, somebody point out an observation about these slides.
Student 7: The footprints are in a circle pattern in slide 2.
Instructor: Yes! What can we say an inference is then?
Student 6: A statement based on information you can see.
Instruction: Basically, it is a prediction based on observations. When we see large spaces between footprints, which is an observation, we can infer that the organism is running. So does everyone get the difference between an observation and inference?
Class: Yes.
Instructor: Okay, then we are going to take a look at another activity about science.

Instructor lecture (Field notes, August 30, 2007)

The total interaction lasted approximately fifteen minutes, with the instructor stressing the differences between observations and inferences (a key component of NOS). The instructor next had students break up into groups of four and she explained the directions for the cube activity.

> Instructor: In a minute here I want you all to break up into groups of four – I will let you choose how to do it. Before we do that I want to go over what we are doing next. I am going to give each group a cube that has names and numbers on it. One side of the cube is covered. It is your job to determine what is on the bottom of the cube using the evidence from the other sides. I want each group to designate someone as the recorder who will write down all the observations. Remember that you are creating an argument for what is on the bottom of the cube, so you are using your observations to essentially create what?
> Student 7: An inference.
> Instructor: Right. Do not pull the paper off the bottom of the cube. So is everyone clear on what they are doing? You are going to identify your observations and record them, then you are going to tell me the name and numbers that are on the bottom of the cube. I am going to write down three questions on the board to help guide you with this. We are going to take about ten minutes to do this – go ahead and get into groups.
>
> Instructor lecture (Field notes, August 30, 2007)

The goal, as indicated by the instructor, was to determine what name, number, and shade was on the bottom of the cube. They were asked to write down what evidence they used to support their selection of a particular name and number. The questions on the board were:

1. Do the numbers and letters correspond to each other?
2. What's on the bottom?
3. Why are there different colors?

The instructor gave students about seven minutes to work on the cube activity and moved around the classroom checking in on students.   Below is one example of an interaction that the instructor had with a group of students:

> Instructor: How are we doing here?
> Student 10: All right, I think we are figuring it out.
> Instructor: So, what are your thoughts?
> Student 10: Well, we believe the name is female since the names on opposite sides are male and female.
> Instructor: What is that information called that you just mentioned?
> Student 11: Data or evidence.
> Student 10: Observations.
> Instructor: You are both correct – your observations count as data. That is what scientists are using to come up with their own inferences. You look like you are on the right track.

Instructor lecture (Field notes, August 30, 2007)

The instructor had similar interactions with each of the six groups in the classroom. At the seven minute mark, the instructor randomly asked each group what was on the bottom on the cube, which she listed on the board. She asked each group to explain why they decided on the name that they picked. The possible names, numbers and colors of the bottom were written down on the board from each group. After each groups' information was recorded, the instructor asked students if they saw any connection to this activity and what scientists did in their work.

> Instructor: What does this activity have to do with what we just talked about?
> Student 2: We made observations and inferences.
> Instructor: What were your observations?
> Student 6: The other sides of the cube and the names and numbers.
> Instructor: How about inferences?
> Student 8: The name that we came up with for the other side.
> Instructor: What was the point of this activity?
> Student 9: To see how observations lead to inferences.
> Student 3: To find out what is on the bottom.
> Instructor: Do you all want to know what is on the bottom?
> Class: Yes.
> Instructor: Unfortunately I am not going to tell you.
> Multiple students: why?
> Instructor: Well think about it, how is this like the work scientists do?
> Student 4: Scientists come up with inferences.
> Instructor: Okay, what else?
> Student 7: Scientists make observations.
> Student 10: Scientists don't always find the answers.
> Instructor: Exactly! For instance, scientists make observations about the world and often don't find out the exact cause for something. But what they have done is come up with an explanation based on the observations. That could change with more data. Do you see the relationship between this activity and the work that scientists do?
> A number of students in the class: Yes, you don't know or figure out the outcome.

Instructor lecture (Field notes, August 30, 2007)

The instructor asked about conducting experiments and talked about data collection in science after this to stress the empirical nature of science. The instructor wanted to make sure students understood that it did not depend on experiments:

> Instructor: Think of astronomy, can you really conduct an experiment to confirm the origin of the sun or how the sun originated? There are some times you really don't manipulate nature. Jane Goodall did mostly observations. There really is no true scientific method. What we did today wasn't really the scientific method; there is not really a scientific method. Think of what we did with cube today, it was based on evidence, your observations. Anything in science has a natural cause.
>
> Instructor lecture (Field notes, August 30, 2007)

She referred two more times to science having natural causes. After this she introduced the concept of a theory in science and how it differed from a law.

> Instructor: If you have enough data for a particular explanation it is given the term theory. There are not facts in science – example of that is evolution. Even scientists call it a theory and those opposed to evolution say "no it's just a theory." Think about crime shows – the police will say "my theory about the crime." Its everyday usage is different than how science uses it – there are all kinds of theories in science – theory of evolution, cell theory. There is enormous support for evolution – most (99%) of scientists supports it, but there is always that chance it is going to change. A theory has a lot of evidence and most of the scientific community accepts it. Previously you might have learned that things become laws – that is not true. Highly supported theories don't become laws. Also science cannot answer philosophical questions and it doesn't deal with the supernatural.
>
> Instructor lecture (Field notes, August 30, 2007)

Identifying the inquiry class as inquiry: Nature of science

Examining the actions of the instructor allows us to more fully identify the differences between the inquiry class and the traditional class. The *National Science Education Standards* (NRC, 1996) define inquiry as the following:

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is

> already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (p. 23).

When the instructor first asks students to provide observations about the tracks, she is starting to engage her students in the basic elements of inquiry (making observations).

> Instructor: Now we are going to do this activity to learn more about doing science. I am going to show you three slides, one at a time. For each slide I want you to take a couple of minutes and write down your thoughts about what is going on in it. Write anything that you think applies – I am not looking for a right answer here but what your thoughts are. So take out a sheet of paper or use your notebook to write your thoughts.
>
> Instructor lecture (Field notes, August 30, 2007)

In the case of the traditional class, the instructor is not asking feedback from her students, they are not engaged in scientifically oriented questions, they are not giving priority to evidence, they are not creating explanations from evidence, and they are not evaluating or justifying their data and explanations (NRC, 2000). An inquiry-class often involves actively engaged students, not individuals passively writing notes listening to the instructor (NRC, 2000). For instance, in the inquiry class the instructor solicits students for their views:

> Instructor: Okay, who would like to share what they had for the first slide or frame?
>
> Instructor lecture (Field notes, August 30, 2007)

Later, after students have been engaged in the activity, she asks them to differentiate between the two concepts. This did not occur in the traditional classroom with the limited interaction and passive nature of the students.

> Instructor: All right, let's take a look at what we have written down. For slide number two I had some people say that the two animals were fighting or interacting. Would that be an observation or an inference?

Instructor lecture (Field notes, August 30, 2007)

The involvement in inquiry becomes more apparent when students work on the cube activity. During this process, the instructor asks students to make observations, develop a prediction, and justify their prediction using evidence.

> Instructor: In a minute here I want you all to break up into groups of three or four – I will let you choose how to do it. Before we do that I want to go over what we are doing next. I am going to give each group a cube that has names and numbers on it. One side of the cube is covered. It is your job to determine what is on the bottom of the cube using the evidence from the other sides. I want each group to designate someone as the recorder who will write down all the observations. Remember that you are creating an argument for what is on the bottom of the cube, so you are using your observations to essentially create what?

Instructor lecture (Field notes, August 30, 2007)

The instructor asks them to create an argument using their observations about what is on the bottom of the cube. In the traditional class students simply write down the components of NOS into their notebooks, but in the inquiry class they are engaged in an activity mean to simulate aspects of science. The publication *Inquiry and the national science education standards* (NRC, 2000) also supports an inquiry classroom as one with less emphasis on the teacher and more on the student. In the traditional class the entire focus was on the instructor, while in the inquiry class the focus shifted for part of the time onto the students.

Evolution Unit

The evolution unit began about one month after students went over the aspects of NOS. Before any instruction on evolution began the instructor administered the *Conceptual Inventory of Natural Selection,* the Gallup Poll Question, and the Bishop and Anderson (1990) cheetah question. The sequence of the evolution unit in both classes was determined by discussions between the researcher and the instructor. The traditional class sequence was almost entirely the same as the instructor had previously done, except for the laboratory activities the students participated in. The sequence of activities in the inquiry class was dictated both by the instructor and by recommendations from research on inquiry-based instruction and the theoretical aspects of constructivism.

As previously stated in beginning of the theoretical framework section, two major paths of constructivism exist: cognitive constructivism and social constructivism. Cognitive constructivism deals with individuals generating knowledge based on their own prior experiences and social constructivism states knowledge is a product of social and cultural interactions. In the case of this study the researcher decided to involve students in the construction of new knowledge, rather than having them simply memorize learning material. Having students engage in the inquiry activity first was a reflection of our understanding of constructivist theories of knowledge construction. Another key component of that learning would be the social interactions that occurred in the classroom, and laboratory. A critical aspect of science is the ability to communicate findings to other individuals. While individuals were dealing negotiation of their own mental framework, they would also have interactions with colleagues participating in the same environment of learning. Student presentations at the end of the finch activity and the development of experiments to test behaviors in goldfish were two important elements of social constructivism in this setting.

Description of the inquiry-based sequence

The inquiry class started the evolution unit on October 11th. The researcher asked the instructor to make explicit connections to nature of science before she started the unit on evolution. The classes had both discussed NOS at the start of the semester, August 30th. The instructor began class by asking students what they learned from the box activity during the first week of classes.

> Instructor: Do you remember the first couple of days that we had class and we talked about what science is, I gave you a list of things that every person should know about science? That was the same week that we did the box activity –we had boxes taped to the desk, what did you learn from that activity?
>
> Male student: That it's impossible to infer things.
>
> Female student: There are no facts. (Overlapping with male student response).
>
> Instructor: Not so much that it's impossible to infer things, but you have to observe. So you make an observation where you're using your senses to make an observation then you're drawing inferences from that observation. So your observations of that box were you saw patterns and numbers and colors and names. You observe that and you used that to make inferences about what was on the bottom. So you guys were like scientists. The reason I'm telling you this I want to remind you of the process of science. What science is like.
>
> (videotape 10/11/2007)

The instructor attempted to reiterate the differences between observations and inferences in this exchange and she also wanted to identify components of NOS with students. She also made connections to the footprint activity, Tricky Tracks!, which students had also been involved in at the start of the semester. This activity was aimed at helping students understand the differences between observations and inferences.

> Instructor: Remember when we looked at the footprints on the board and I said tell me what you're observing and you said you're observing marks of different colors. Then I said what can you infer about them and you said well they look like footprints based on what I know about footprints and I can the footprints are going in a certain direction. So we made inferences and then we added

> information to the picture and your inferences changed. You guys remember all of that.
>
> (videotape 10/11/2007)

Following this the instructor also talked about how the activities reflected aspects of NOS.

> Instructor: That is the nature science and I want to just review with you a little bit how science works. That it's tentative. Remember when we were looking at the footprints and I said just tell me what you observe. And then when we added a little piece to the puzzle we might have changed what we said. So where we thought maybe they were footprints were walking towards each other they were moving in the opposite directions. That's how science is it can change. As new data becomes available it can change. Just like the box example, we got to look at the bottom of the box at the end when I picked it up and most of us were right, however in science you were never really get to look at the bottom of the box. Where you can't really see a lot of phenomenon and you only have what's in front of you to deal with.
>
> (videotape 10/11/2007)

The instructor continued her discussion by connecting evolution and the term theory. One of the main tenets of this research study is that an understanding of NOS will translate into an understanding of evolution.

> Instructor: So I wanted to review that because the next topic that were covering is evolution. Evolution is a theory which means what? Can you guys tell me what it is? The word theory…. All right, five points on the next exam for the first person to raise their hand and tell me what a theory is. Are you serious!!!
> (Male student responds)
> Instructor: Thoroughly tested not so much a thought but an explanation that can't be proven. All right so what we said, a theory is an explanation that has a lot of data that supports it. So would we call a theory a fact?
> Three students: No
>
> (videotape 10/11/2007)

Addressing the tentative nature of theories was also realized when the instructor gave a hypothetical example of a theory and the data that could or could not support it. Recognizing that gravity is often viewed as a theory of higher standing, the instructor made a point to include it in her discussion.

> Instructor: There can be data that disproves a theory. I can say there's a theory that says green pencils never fall towards earth, gravity does not affect green pencil. Let just say that there is a lot of data that supports that. Every time I drop a green pencil it never falls towards the earth. And one day somebody picks up a green pencil and it falls. Did that just disprove the theory? Yes it did. Now did me finding a lot of green pencils and every time dropping them did that prove the theory? No it only supported it, that's one of the big deals in science - theory is as high as you can get no facts in science. There are no facts in science. You can't say there is a fact because you can't test every possible scenario.
> (videotape 10/11/2007)

The instructor brought in other theories that are considered fairly concrete. Earlier in the course the instructor talked about the cell theory. She pointed out the tenuous nature of scientific knowledge with both the cell theory and the theory of gravity. This was an intentional direction as the researcher and instructor had discussed the weight given to the theory of gravity versus the theory of evolution.

> Think of the cell theory. Chances are every living organism that has ever existed on this planet and exists now is composed of cells. It is highly likely that there are no organisms that are not composed of cells. How do we know, can we say it is a fact? Because there could be an organism that we have not discovered. Same thing with the theory of gravity. Can we say pretty much for sure there is a lot of data that supports there is some force pulling objects towards earth? Yes, it is highly supported and there is tons of data that supports it. But how do I know that I am not going to find somewhere on this planet where I drop this pencil and it just stays in the air? Is it likely, no, but can I say that it is a fact, no. I just keep collecting data that supports it.
> (videotape 10/11/2007)

While examining the theories she mentioned the work of scientists. She continued to stress the tentative nature of science and again made a point to introduce the theory of gravity.

> That's the way science works – you make observations and collect data. That's what scientists do. They make observations, they perform experiments, they collect data and then they use that data to explain what happened. All right, so I wanted to go over that, the very tentative nature of science.   That it is always changing, what could almost be considered a fact today new data could emerge tomorrow to disprove it. How do we know that we are not going to wake up

> tomorrow and they are going to say gravity is a myth, there is no such thing as gravity we found a place where there is no gravity.
>
> So what we are going to do for the next week or two, we are going to talk about evolution. I have a couple of surveys that I want you to fill out on evolution.
>
> (videotape 10/11/2007)

After reviewing the prior information covered at the start of the semester the students filled out the Gallup poll question, the Bishop and Anderson question, and the conceptual inventory of natural selection. The students then went to the computer lab for their laboratory session. At no point did the instructor go over evolution, the processes of natural selection, or any notes related to evolution. The instructor then briefly discussed the assignment related to the Galapagos finches in the computer lab. During this introduction she again stressed the tentativeness of science, as well as the differences in ideas that can be generated when looking at the same data set.

> Instructor: The intro tells you that on an island in the Galapagos one of the finch populations has suffered a decline. So you are going to look at actual data that's been collected by the scientists that have been studying that island in the Galapagos for 30 some odd years. You are going to look at that data they have collected so that is what your job is today. You can either work singly or in pairs, no more than two though. Today you are going to gather data and you're going to present that data to the class next week. Today you're gathering it, then on Tuesday where we normally have class time you are going to come back here to so you can finish up whatever you needed to do. Then on Thursday during class you are going to give between five and seven minute presentations to the class about why you think the finch population declined based on your data. So I want you to keep in mind some of the concepts we went over in class how science is tentative and you're all going to be looking at the same data but you're probably going to be coming up with the different ideas about what happened.
>
> (videotape 10/11/2007)

The instructor played a brief introductory video that came with the Galapagos Finch software program. The researcher went over how to navigate within the software program – showing them each of the main sections of the program, where data could be found, and how to compare data sets. Midway through the researcher demonstrating the software, the instructor gave a little background about the setting of the computer program.

> Instructor: Here's what you guys are doing. A finch is a type of bird and what the Galapagos Islands is it's a cluster of about 20 islands off the Western coast of South America. So there's a cluster of islands and on one of those islands, it's called Daphne Maj., scientists have discovered that, what they said, the finch population has drastically declined. So they collected data over 30 years and you are actually going to look at the actual data that they collected. So this isn't like a made-up project that you guys are doing, this is the real data that you'll be looking at. Scientists are essentially trying to figure out what actually caused the finch population to decline in the data that they have is what you guys get a look at.
>
> We want you to feel like scientists, sit and look at data and draw conclusions from it.
>
> (videotape 10/11/2007)

The instructor wanted to make sure that students understood they were looking at a real data set, as opposed to a simulated data set. After the introduction students worked individually or in pairs on the software program for an hour and ten minutes. During this time the researcher and the instructor moved around the classroom and helped students with the operation of the program.

The inquiry class met again on October 16 in the computer lab to work on the Galapagos Finch program. The instructor started class by reminding students that they were acting as the scientists. She asked them to make observations and include data to support their hypotheses in the presentations.

> Instructor: You guys are the scientists; you are looking at actual data. Keep that in mind as you're doing it. I want you to do what a scientist would do. I want you

> to look at data collected and try and figure out what's happening. Make observations, look at the data, and draw your conclusions based on that data.
>
> (videotape 10/16/2007)

During the remainder of the class the instructor and the researcher walked around the room to assist students who had any questions.

Students gave presentations on the Galapagos Finch program during class on October 18th. Presentations lasted for an hour and 20 minutes and students were asked to peer review each presentation on a supplied sheet of paper (see Appendix G). This information was shared with each person or group after the instructor compiled it. After class students watched the video "What Darwin Never Saw" from 1 PM to 1:55 PM. The instructor followed this up by spending about 8 minutes discussing evolution and the processes that went on in the Galapagos. Following this brief discussion the instructor said "You know what scientists do; you really are what scientists are!" (videotape 10/18/2007).

On October 23 the inquiry class started notes on evolution – up until this point the inquiry class had not been engaged in any lectures on the topic of evolution. To ensure that both classes participated in the same lectures the instructor provided the class with handouts of her PowerPoint lectures from the traditional class. The instructor started the class by summarizing what the students gleaned from the Galapagos Finch software program over the prior week and a half.

> Instructor: Here's what's nice about what we are going to cover today and Thursday for the exam that is next week - you already known a lot of it just from what we have been doing the last couple of weeks. This is one of those times where you don't really have to do a lot of reading and memorizing because by now you guys should be a little more comfortable with evolution. So based on the activities that you guys did, you guys looked at data, the finches, and you came up with these hypotheses, what is evolution? What is a good definition of what you think evolution is?

> Female student: Change over time.
>
> Instructor: A change over time. And the beaks were a good example of the finches because... What was it about the beaks; I mean you guys saw it in the movie as well, what was it that allowed some of the finches to survive the weather changes? Some of them had… what was it about their beaks?
>
> Male students: Inaudible response about the size of the beaks
>
> Instructor: Some of them got big depending on – so like if the food source was hard nuts those who couldn't eat the hard nuts because they couldn't crack them died off, so those with the bigger beaks survived. Let me say that again. Those who had beaks that allowed them to eat the food source available were the one's who survived - that's what the process of natural selection is. So not only did you guys look at the data on that and came up with hypotheses and kind of explored it on you own you also watched a movie on how the Grants collected that data.
>
> So you guys already have a good idea about it, so every time we mention something today I want you thinking back about what we have done over the last couple of weeks.
>
> (videotape 10/23/2007)

Multiple connections were made to the prior activity and the instructor used these situations to make a more distinct connection to the theory of natural selection and evolution. She followed this by beginning the PowerPoint notes on evolution which included the definition of evolution, discussions about antibiotic resistance, and examples of various traits. Throughout this discussion she made five separate references to finches, their, beaks, and the impact of environmental changes on the population. Towards the end of the class the instructor introduced the evolution debate and how it often centered on the term theory. She mentioned some of the problems that individuals have with the theory of evolution.

> Instructor: One is that damn word theory – nonscientists really don't grasp the concept that a theory is such a big deal in science. You'll often hear anti evolutionists say well even scientists say it's only a theory. There's no such phrase as it's only a theory in science. So that's one, it is really hard to debate when you don't know about it. Again, there is no such thing as believing evolution, it is not a belief concept it is a scientific concept. But even if you don't

> want to accept it you should know something about it. Nothing is more infuriating when somebody says I don't want to hear about evolution because I just don't want to know about it. Well what is it? I don't know. There is nothing worse than that – where you don't know about something and you try and debate why it is wrong and you don't know what it is. That's how I feel about the word theory. Nothing is only a theory – I have never, ever heard anybody say gravity is only a theory.
>
> (videotape 10/23/2007)

The instructor tackled the statement "it's just a theory" by applying it directly to gravity and the lack of disagreement with this theory. Since the certainty of the theory of evolution is challenged, but others are not, it allowed the students to see the discrepancy that existed in science. The instructor followed this by addressing the differences between beliefs, religion, and science.

> Instructor: Evolution is not a belief system, you don't believe in gravity, you don't believe in the cell theory, you don't believe in evolution- it is a scientific concept. I want to make sure that is straight you have to understand that science is very different from religion. It's like apples and oranges, one is based on a belief system that you can never test. There's no way to test it, prove it and one is based on data and evidence. That goes with all matters of religion versus science.
>
> (videotape 10/23/2007)

On October 25 she continued with the evolution notes the traditional class had already covered, including topics on coevolution, evidence for evolution, sexual selection, Charles Darwin, origin of species, speciation, and the origin of life. At the end of the class the two sections (inquiry and traditional) had covered equivalent topics in the notes. During lab the instructor connected the topic of natural selection to fish behavior and had students develop their own laboratory experiment to examine fish behaviors. The introduction of the activity started with the instructor handing out a guideline sheet (see Appendix). The genetic cause of behavior was a focal point of this activity. During lecture the instructor had talked about cuckoos, the behaviors they exhibited, and the genetic determination of these behaviors.

> Instructor: Today actually is going to be really interesting. We did this in class where we said with natural selection our genes are responsible for morphology, the way our body is arranged, physiology the way our body works, and our behavior. I said there is always debate with nurture versus nature. But there certainly is a genetic component to behavior. Natural selection is a process that pretty much works on our behavior as well. Basically you're going to design an experiment. We are going to give you fish, as many fish as you want I think up to a point. You guys have beakers and fish and a bunch of materials.
> I want you to come up with a hypothesis about fish behavior and then I want you to test it. Then you want to test your hypothesis. It could be anything.
>
> (videotape 10/25/2007)

The instructor gave an example of testing whether fish liked yellow water or not as a hypothesis, followed by a brief discussion of the format of the laboratory.

> Instructor: Does everybody have the handout? You can see it is really vague. It's purposely vague for you. In your group develop a hypothesis or hypotheses you want to test. So write down your hypothesis on a sheet of paper and then design an experiment that would test it. Consider things that might be impacting it, like the time consideration, the room, anything - any variables that might be impacting your experiment. Think about what data you want to collect, collect it, then analyze the data and then come up with a conclusion about whether you hypothesis was supported.
>
> (videotape 10/25/2007)

It is clear from this response that the activity was inquiry-based, since students were designing experiments to test hypotheses that they had constructed (NRC, 2000). The instructor provided students with a very brief outline of her expectations, and students were left to produce most of the activity on their own. The last step of the activity involved writing a laboratory report, which the instructor spent a few minutes going over using an example format in their laboratory manual.

> Instructor: I want to know that you can design an experiment, you can obviously analyze data you proved that last week. I want to know if you can design an experiment on your own, if you can come up with a hypothesis. Genuinely I want this to be enjoyable for you, I want you to learn from it, and actually so pick something you are interested in. So sit and think about hypotheses for awhile, don't just jump at the first things to get this over with.
>
> (videotape 10/25/2007)
>
> Student: Do we all do a separate lab report?
>
> Instructor: Yes, even though you can do the same experiment. Yeah write the reports on your own. Write it on your own. One of you just might have different ideas from another, remember how you analyze data is going to vary, another thing that was proven last week.
>
> (videotape 10/25/2007)

Students proceeded to work on the activity for the remainder of the laboratory session. Both the instructor and the researcher made themselves available to assist students with the experiments and data collection.

Identifying the inquiry class as inquiry: Evolution

It is more readily apparent that the inquiry-based class was engaged in inquiry in the evolution unit than in the beginning of the semester. Although the students were provided with an overarching question in the finch activity, they identified the relevant data and used it to generate hypotheses about what happened to the finches. They were responsible for providing justification for their hypotheses by using evidence. Students were engaged in communicating their results after they completed their presentations. These are all aspects described in the *National Science Education Standards* (NRC, 1996) as essential features of classroom inquiry. The focus was predominantly on the learners, which is also emphasized in the policy documents (NRC, 2000). Learners spent class sessions going through the data, analyzing it, and generated explanations of patterns they saw. While the learners were doing this, the instructor was moving around the classroom helping students with their

<u>*Videotape analysis*</u>

Table 6. Inquiry assessment of class activities and time of activities

Class	***Activity***	***Inquiry rating (0-5)***	***Representative Example***	***Activity time***
Inquiry	Cube activity and Tricky Tracks!	4 – guided inquiry	Instructor provided students with cubes and asked them to figure out what was on the bottom.	32 minutes
Inquiry	Galapagos Finch program	4 – guided inquiry	Students generated hypotheses in response to the program questions: Why are so many finches dying? Why did some finches survive? Students planned their research process, assessed data, justified their explanations and communicated their results to others.	Lab session 1 70 minutes Class session 1 - 75 minutes Class session 2 -74 minutes
Inquiry	Goldfish lab	5 – full inquiry	The instructor gave students a general topic (natural selection and goldfish behavior) and students generated questions to explore. Students were responsible for developing hypotheses, research design, data collection procedures, and analysis.	122 minutes
Traditional	Investigating bird adaptations lab	3 – cookbook style	Research questions and procedures were provided to students. Students participated in a simulation which involved picking up seeds with tools.	63 minutes
Traditional	Lab 22 from the laboratory manual – evidence of evolution	3 – cookbook style	Research questions and procedures were provided to students. Students answered questions based on a timeline, students looked at pictures of skeletons and compared the bone	120 minutes

	structures, and students confirmed stated results in the laboratory manual.

The total class time for each section was kept approximately equal to avoid impacts of time on task on the student results. Based on the analysis of the videotapes, the inquiry class was engaged in inquiry-based activities for 373 minutes (6.22 hours), while the traditional class was not classified in activities above a level three for inquiry – falling in the range of "cookbook" style laboratories/activities. Sutman's (1998) scale ranges from zero to 5 based on the role of students or the instructor in the activities. "Full" inquiry activities would have students: proposing the problem or issue, planning the procedure, carrying out the procedure, supplying answers and conclusions, and using lab outcomes for further exploration. Activities at the zero level involve the teacher doing all the aforementioned aspects. Sutman's level 3 activities are described as "cookbook"; these activities are proposed and planned by the instructor. Although they were engaged in science investigations, the level of the traditional class activities would not fall into the category of "inquiry-based activities". They were provided with the questions, procedures and goals of the laboratories. During the evolution unit the traditional class spent 183 minutes (3.05 hours) on laboratory activities while the inquiry class spent 192 minutes (3.2 hours). The traditional class had six lectures (80 minutes each, except for the first lecture of 60 minutes) covering evolution related topics, while the inquiry class only had two lectures (80 minutes each). This confirms that the instructional strategies employed in the study were inquiry-based in the experimental class and traditional approaches in the control class.

Research question b: What is the influence on students' views of nature of science?

The data from the VNOS-C and student interviews allowed the researcher to determine the influence of the inquiry-based activities on students' views of nature of science. Students interviewed from the inquiry class responded to the researcher's question concerning the inquiry activities at the start of the semester. The researcher asked "Do you think you got what the instructor was trying to convey to you by doing the activity?" and "Did it help you understanding what scientists actually do?" and "Do you think you got the connection that she was making to science and what scientists actually do?" The researcher referred to the cube activity and the tracks activity. All of the students felt that the activities were effective in conveying elements of science to them.

Table 7. Student responses about whether the activities conveyed aspects of science.

Student	Code	Response
Janet	Activity worked conveys NOS	Yeah, they kind of like put you in that mindset that it's to focus on something and not look at it so quickly. I mean you really had to look at it to say, hmm, I wonder what's going to be underneath there, to look for patterns, I guess.
Dawn	Activity worked conveys NOS	Yes.
Alissa	Activity worked conveys NOS	I thought they were good because I think it really showed the point of what she was trying to do, and we figured out what was gonna be on the back, so –
Kim	Activity worked conveys NOS	Yeah.
Sharon	Activity worked conveys NOS	The cube one I liked. I think it was done like the first day or the second day maybe. I'm not sure, and I think that it helped to really understand how you're going to have to think and problem solve the correct way. Some of the people in my group just weren't

		getting it at first so I think it was a good activity.
Jill	Activity worked conveys NOS	I think it did, yeah, I guess it made a connection.
Mark	Activity worked conveys NOS	Yes. It was kind of this – observation with that, do you remember? I can't remember; that was the beginning of the semester.
Bethany	Activity worked conveys NOS	Yeah, they just observe and they visualize it and make hypotheses of what they can until they can determine it better. But like in the beginning process they just check everything out to see what it's about. Like the footprints, like they weren't necessarily footprints, but if you looked at them like they kind of resembled them. That's what you would think if you looked at them, like they looked like a pig or a herd or something, it looked like they went off, like attacked each other or something, and then one went away. Or they came at different times or something, but you could never tell that because there wasn't enough information.
Helen	Activity worked conveys NOS	Yeah. I think it was a good introduction to the course.

The researcher followed this question up by asking students if they felt they would have learned as much if the instructor had just lectured on the topic. Student responses are found in Table 8 and show that none of the students would have preferred just engaging in a lecture on the NOS topics.

Table 8. "If the instructor just lectured on science would you have learned as much?"

Student	**Code**	**Response**
Janet	Not just lecture	I don't think that I would have learned as much because there were a lot of other characteristics in doing the research that you need, that I found out that I wouldn't have.
Dawn	Not just lecture	No.
Alissa	Not just lecture	Definitely not.
Kim	Not just lecture	Myself, probably not.
Jill	Not just lecture	I think if she just lectured, we probably wouldn't have learned as good as we did with this because I guess now that looking back, I

		did remember that – what it was supposed to be about.
Mark	Not just lecture	I would’ve been lost because science is definitely not one of my big subjects.
Bethany	Not just lecture	No.
Helen	Not just lecture	No.

Eight of nine students felt that the inquiry-based activities were more effective as compared to lecture alone. Sharon’s response is not included as she was not asked to comment on this question. Some of the students were also asked if they felt that the connections made to science before starting the evolution unit were helpful. Each of the students asked this question reacted positively and they believed it did help.

Table 9. Students’ views on whether discussing NOS before evolution helped or not.

Student	**Code**	**Response**
Dawn	Connection helped	I guess it probably would have helped. That way you could relate it better and –
Alissa	Connection helped	Yeah. I do. Just because it was kind of like a background on it, like the different – because they're not gonna be differences unless they have the different, like, I don't know how to explain it.
Kim	Connection helped	I think it did. You had to use your own fact that you took and be open-minded and take everything as a whole. Yeah. I felt like I definitely retained better.
Jill	Connection helped	I don’t (remember). Yeah because I guess that they had to figure out how evolution happened by using scientific methods.
Mark	Connection helped	Yeah.
Bethany	Connection helped	That helped because you had to figure out what was going on; you had to figure out the different levels of where you’re going about, like your observation – I can’t think of the other ones.
Helen	Connection helped	Yeah, I think so.

Janet and Sharon were not asked this question, however, all the other students interviewed from the inquiry class believed that the connections made helped in their cases.

Table 10 summarizes where or not students demonstrated an accurate consensus view of the aspect of NOS. Individual class results as well as total class data are included. Each component is listed and then broken up into student responses to the relevant question. The most common concepts articulated within the question are presented. The inquiry class consistently outperformed the traditional class in all NOS categories. Additionally, the gains from pretest to posttest were much greater in the inquiry class. In some cases the traditional class increased in incorrect perceptions of science.

Table 10. VNOS-C results

	Pretest inquiry (n=17)	**Posttest inquiry (n=17)**	**Pretest traditional (n=13)**	**Posttest traditional (n=13)**	**Pretest total (n=30)**	**Posttest total (n=30)**
Science is empirically based	82.35%	94.11%	76.9%	84.6%	80%	90%
Science is tentative	94.11%	100%	92.3%	92.3%	93.3%	96.7%
Differences between theories and laws	0%	6%	0%	0%	0%	3.3%
Knowledge is subjective	23.5%	41.1%	30.7%	38.5%	26.7%	40%
Science is socially and culturally embedded	47%	64.7%	38.5%	46.2%	43.3%	56.7%

Science is a product of human imagination and creativity	76.5%	100%	84.6%	84.6%	80%	93.3%

NOS component: Science is empirically based. The empirical aspect of NOS means that science is based on and/or derived from observations of the natural world (Lederman, 2002). Although no students stated science was "empirical" 80% of students on the pretest and 90% of students on the posttest could be classified as describing science as empirical. The most common responses in the pretests were science is the study of life (36.6%), science is learning about how things work (23%), proven (16.6%), tests (13.3%), explanations of nature (13%), observations (6.6%), aspects of earth/the world (6.6%), and facts (3.3%). Posttests were more evenly distributed, students stated that science was the study of life (16.6%), facts (16.6%), tests (13.3%), explanations of nature (13.3%), experiments (10%), aspects of the earth/world (10%), proven (10%), observations (6.7%), and how things work (6.7%). This question also asked what made science or science disciplines different from other disciplines like religion and philosophy (Lederman, 2002). When students mentioned how religion was different from science they commonly indicated that it was because religion was about beliefs (23.3% pre and post) and that science is not supernatural (20% - posttest). The descriptions of supernatural came entirely from the posttests in the traditional class.

Although not a direct component of NOS, an understanding of the role experiments play in science is a reflection of an individual's understanding of science. Students responded to the question "What is an experiment?" in a fairly consistent manner. A large percentage of students (70% pre and 86.6% post) believed that experiments were tests or processes to test hypotheses.

Thirty percent of students thought experiments proved scientific ideas in the pretests and 26.6% in the posttests. A small percentage of students articulated the consensus NOS view that experiments were not the only means of gaining scientific knowledge (6.6% pre and 16.6% post). Only 3.3% of students in the pretests and 13.3% of students on the posttests identified controls or controlled variables as a part of scientific experiments. A significant increase in the number of students identifying a hypothesis as part of an experiment was noticed – moving from 26.6% in the pretest to 63.3% in the posttest. An interesting trend was observed in regards to students who stated experiments were "proving scientific ideas" – it dropped from 35.3% to 17.6% in the inquiry class but increased from 23.1% to 38.5% in the traditional class. While "proof" or "proving" were used to show an accurate representation of the NOS aspect of science being empirical, the terms were not accurate when looking at the tentative NOS component.

NOS component: Science is tentative. According to this aspect of NOS, scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations (Lederman, 2002). A significant portion of students were able to describe science as tentative in both classes. Pretests in both classes found 93.3% of students indicating that theories change, while 96.6% of the students on the posttests did so. One student in the inquiry class stated that theories do not change on their pretest. Some students stated reasons for how theories could change. Change in theories (and science) came about as a result of new information (20% pre and 33.3% post), experiments (13.3% pre and 3.3% post), technology (6.6% pre and 10% post), and new research (3.3% pre and 0% post).

NOS component: Differences between theories and laws. Only one student in the sixty pre and posttests accurately described laws as regularities (or predictions of outcomes under certain conditions) and theories as explanations. More than one third of students on the pretest

(36.6%) thought that theories were someone's opinion, idea, belief, or thought. This nonconsensus NOS view of theories successfully dropped to 10% of students on the posttest. Students commonly differentiated between theories and laws on the pretest by stating that theories are not proven or need to be proven (26.6%) and laws are proven (46.6%). This dropped to 13.3% and 10% on the posttests. There also was a difference between the two classes when it came to theories being not proven and laws being proven. No inquiry students thought/stated that theories needed to be proven and laws were proven on the posttest. This dropped from 17.6% (theories need to be proven) and 41.1% (laws are proven). The traditional students started out with higher values for these categories (38.5% - theories not proven and 53.8% laws proven). In addition, 30.8% of students still indicated that theories are not proven on the traditional posttest (dropping from 5 to four students), and laws are proven (23.1%) dropping from 7 to three students. A high number of students from the traditional class (46.15% and 61.54%) had the perception that laws are facts or are certain. Only two students (11.76%) from the inquiry class thought that laws were facts/certain on the posttest. Six students on the posttest (three from each class) accurately pointed out that there is data and much support for theories.

NOS component: Knowledge is subjective. This aspect of NOS was actually the lowest recorded value after distinctions between theories and laws. A little more than one fourth of the students (26.6%) specified that knowledge was subjective on the pretest; this increased to 40% on the posttest. People differ (20% pretest and 36.6% posttest) was indicated as an accurate aspect of subjectivity. Inaccurate views of the subjectivity of science were represented by the ideas that many explanations were possible (33.3% pretest and 36.6% posttest), scientists could find different evidence (3.3%) and no one saw dinosaurs go extinct (3.3%).

NOS component: Science is socially and culturally embedded. The third lowest number of students accurately describing the consensus view was found in this aspect of NOS. Less than half (43.3%) of the students on the pretest thought that science was impacted by social and cultural factors. This increased slightly to 56.6% on the posttest. Students who did not represent this aspect of NOS accurately commonly thought of science as universal (43.3% pretest and 36.7 posttest). Ten percent of students on the pre and posttests thought that science was both socially embedded and universal.

NOS component: Science is a product of human imagination and creativity. Students on both the pretest (80%) and posttest (93.3%) indicated that scientists use creativity in their work. On the pretests, individuals thought that scientists used their imagination and creativity before they experimented when they were making hypotheses and planning/designing experiments (33.3%), during the hypothesis and experiment (16.7%), throughout the process (16.7%), and after they experiment (6.7%). The posttest saw increases in before the experiment (36.7%), throughout the process (20%) and after they experiment (10%). These values can be attributed to the inquiry class, which increased in these categories, whereas the traditional class stayed the same or dropped (before the experiment).

In summarizing the data, it appears the inquiry class had a stronger grasp of the various aspects of NOS. In no cases was the inquiry less understanding of the NOS components, and while the traditional class was static in two aspects, the inquiry class increased in their understanding in all areas. The inquiry class also had significant reductions in the misconception that theories were unproven and laws were proven, as well as the misconception that laws are facts or certain. One particularly interesting aspect of this area of the research study was the traditional classes' differentiation between science and religion. Every instance of references to religion dealing with the supernatural comes from the traditional class. Based on videotape analysis it appears that the instructor referred to this at a higher rate in the traditional class as compared to the inquiry class.

Research question c: What is the influence on students' understandings of evolutionary concepts?

Numerous pieces of data were used to explore students' understandings of evolutionary concepts.

Comfort Levels

The research literature has indicated that students often link negative consequences to acceptance of the theory of evolution (Dagher & BouJaoude, 1997, Brem et al., 2003; Griffith & Brem, 2004; Winslow et al., 2011). In the initial demographic survey students were asked to indicate their comfort level with topics in the biology course. Comparisons of the comfort level means for each topic are found in Figure (1).

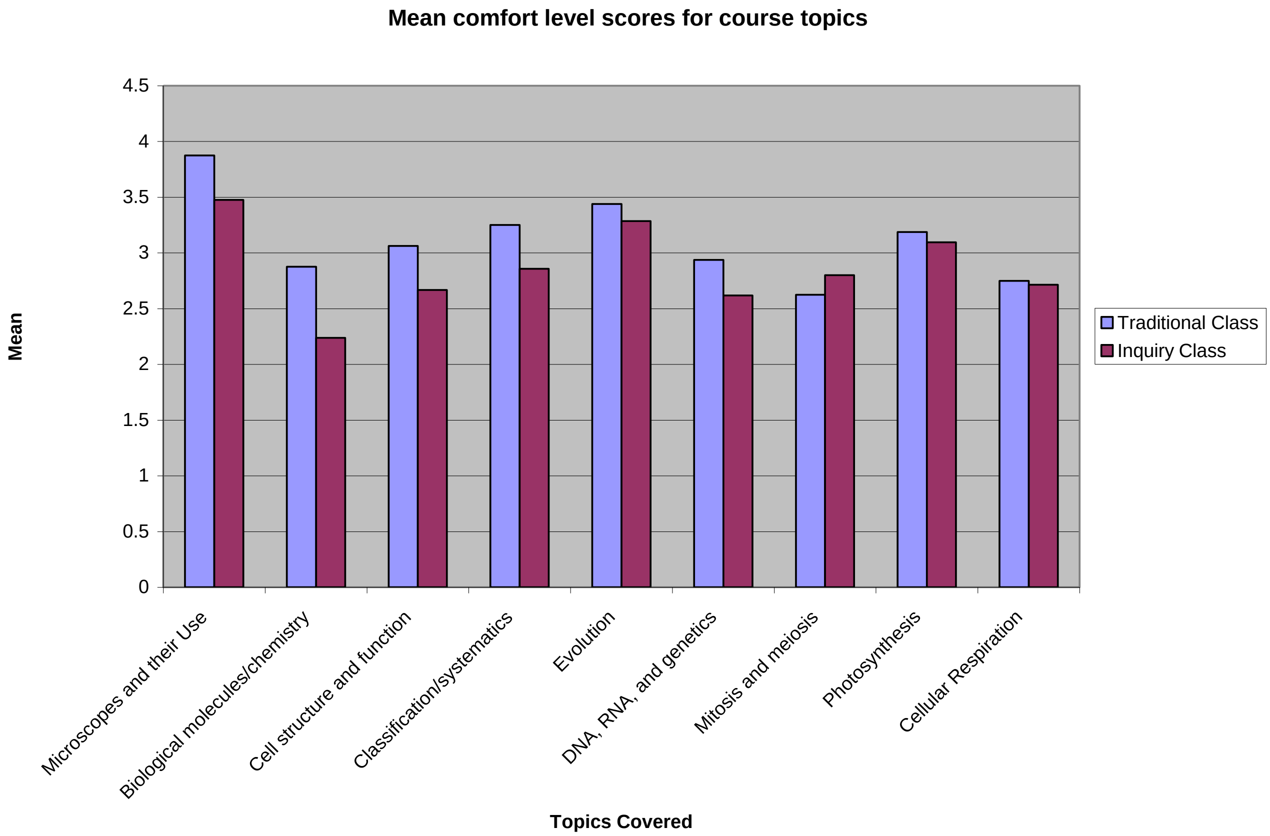

Figure 1: Mean comfort level scores for course topics from the demographic survey

The traditional class reported higher comfort level means for all topics except for mitosis and meiosis. The topic of evolution was the second highest comfort level score for both classes (3.44 traditional versus 3.29 inquiry) after "Microscopes and their use" (3.88 traditional and 3.48 inquiry). The inquiry class had more students reporting a comfort level of 5 for the topic of evolution (3 students versus 1) on the demographic survey but they also had more students expressing less comfort and understanding of the topic at the level of 2 and 1 (six students versus two students). The traditional class had more students in the 3 and 4 category (5 and 9 respectively) compared to the inquiry class (4 and 8).

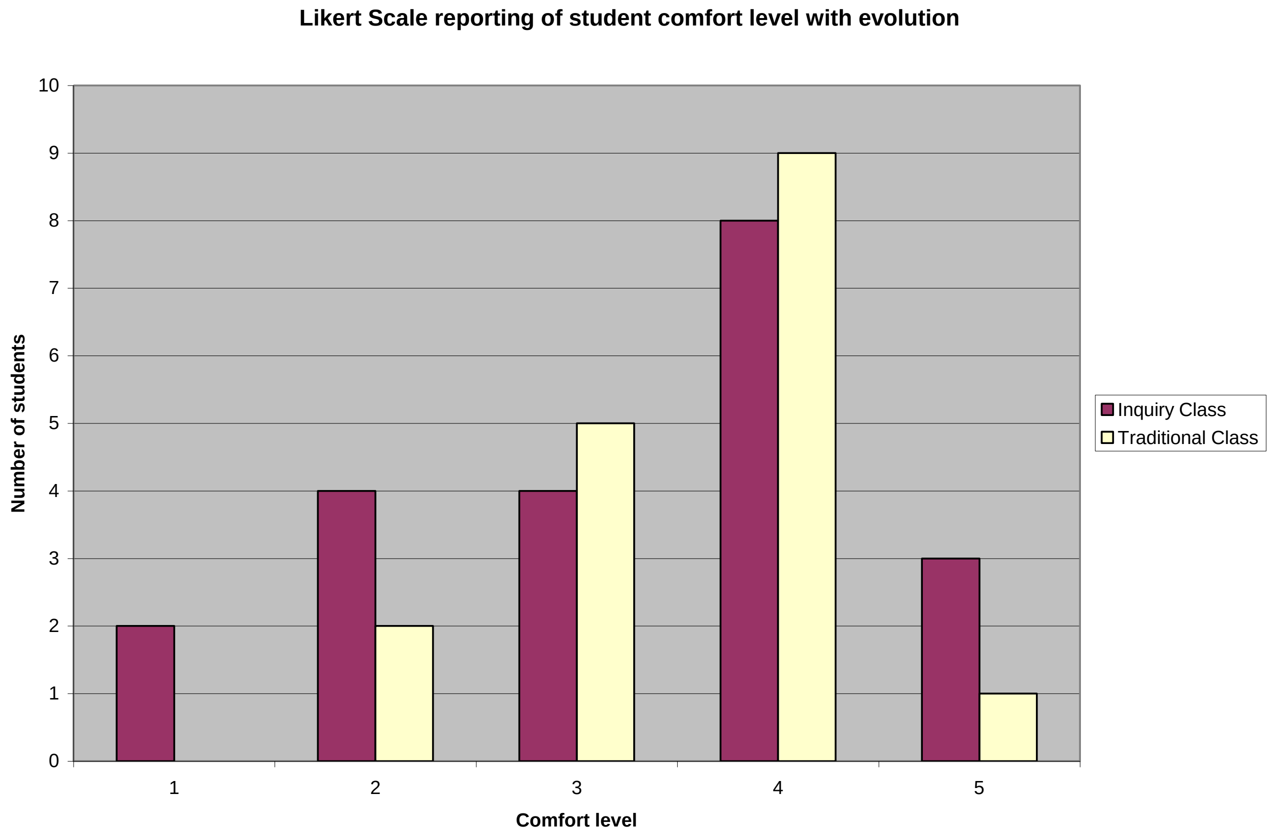

Figure 2: Student comfort level with the topic of evolution reported on the demographic survey

Reported Beliefs of Participants

The following Gallup poll question was used to identify students' beliefs in evolution:

> *Which of the following statements comes closest to your views on the origin and development of human beings -- [ROTATE 1-3/3-1: 1) Human beings have developed over millions of years from less advanced forms of life, but God guided this process, 2) Human beings have developed over millions of years from less advanced forms of life, but God had* no part *in this process, 3) God created human beings pretty much in their present form at one time within the last 10,000* 3, and *years or so]?*

Based on the polling at the time, 38% of those polled indicated that they selected choice one, 14% chose choice 2, 43% chose choice 3, and 4% had no response or a different response.

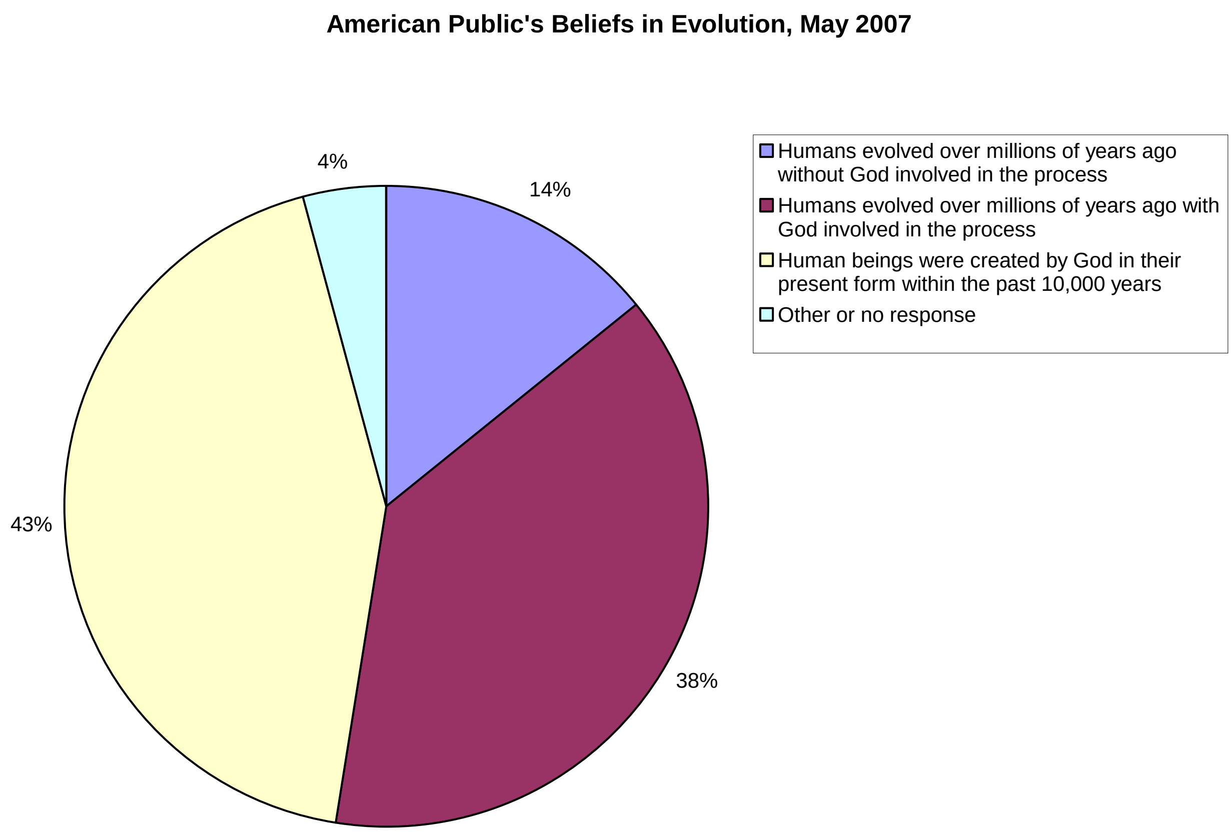

Figure 3: Gallup results for beliefs in human evolution, May 2007

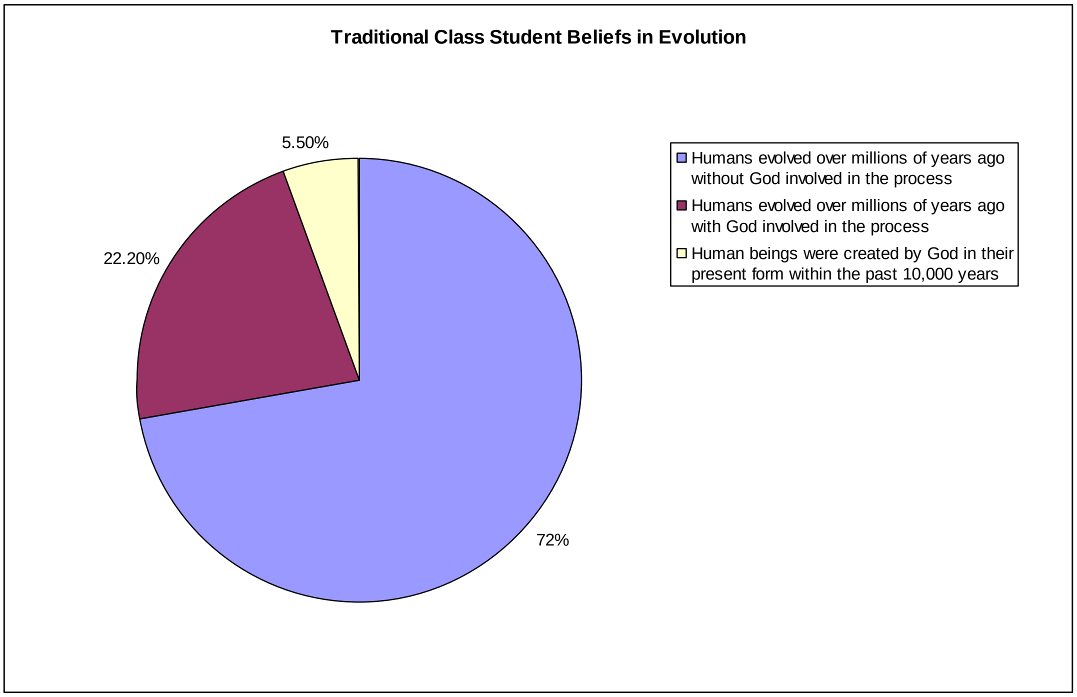

Figure 4: Beliefs in human evolution of the traditional class students

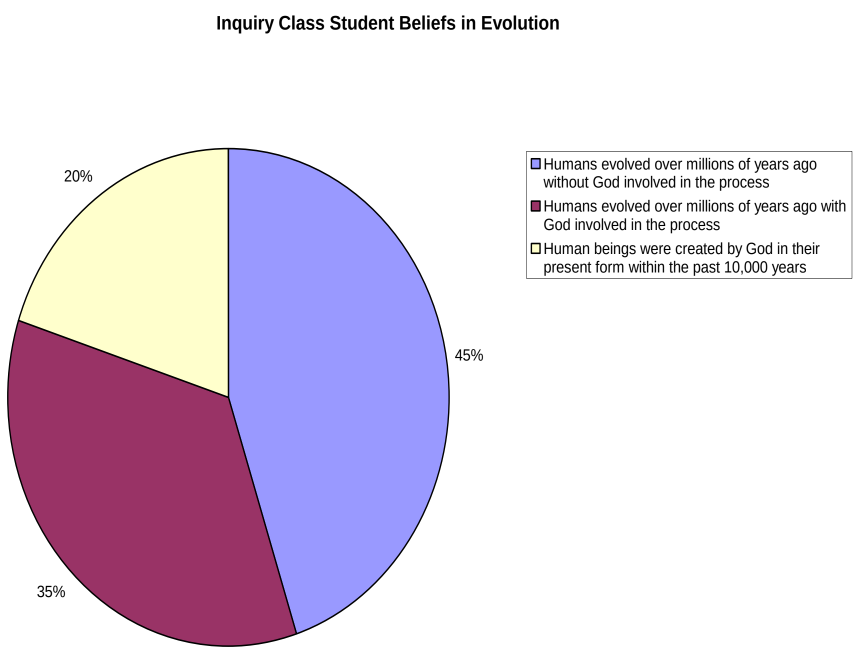

Figure 5: Beliefs in human evolution of the inquiry class students

Students' beliefs in evolution (identified by a Gallup poll question used over the past twenty nine years) showed that 13 students in the traditional class believed human evolution occurred without God in the process. Four students indicated that human evolution occurred over millions of years with God involved in the process, and one student believed that God created human beings pretty much in their present form at one time within the last 10,000 years or so. These responses were very different from the American public's responses, which had the largest percentage of students in the third category (God created human beings pretty much in their present form at one time with the last 10,000 years or so).

The inquiry class had nine students in the category of evolution without God guiding the process, seven students in the category of evolution with God guiding the process, and four students believed that God created human beings in their present form at one time within the last 10,000 years or so. Beliefs were more evenly distributed in the inquiry class, as compared to the traditional class. Human beings created within the last 10,000 years had the lowest score in both classes, yet represents the largest percentage in the national surveys. Humans evolving without God in the process represented a much higher score in both classes (72% for the traditional class and 45% for inquiry class) than the national average (14%).

Darwinian Components in the cheetah response question

The inquiry class showed a larger net increase in the number of Darwinian components used in their cheetah responses, and they also had a greater total number of components used in their responses. Although the inquiry class had a larger student population (20 versus 18) they began with a lower number of Darwinian components represented in their pretests (14 versus 19). The net increase of components in the inquiry class was substantially larger from that of the traditional class. The inquiry class increased in their usage of Darwinian components by 32 from the pretest to the posttest, while the traditional class increased by 21 components.

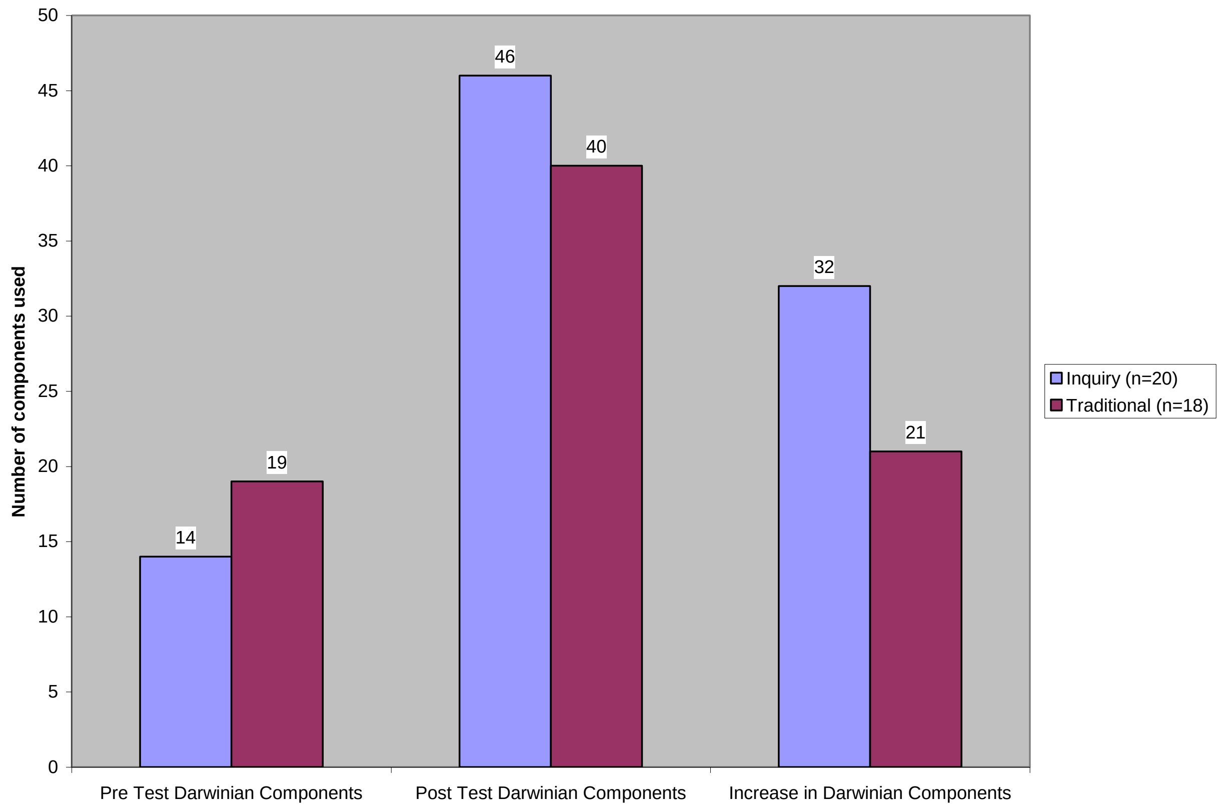

Figure 6: Total Darwinian components used in each class.

In addition to the inquiry class having a larger net increase and total number of components used, they also had more individuals using 3 or more components (10 compared with 6) in their cheetah responses on the posttests. This would represent a more robust scientific understanding of the concept. Only one student scored a 3 or 4 on the pretest in the inquiry class, while 3 students did so in the traditional class.

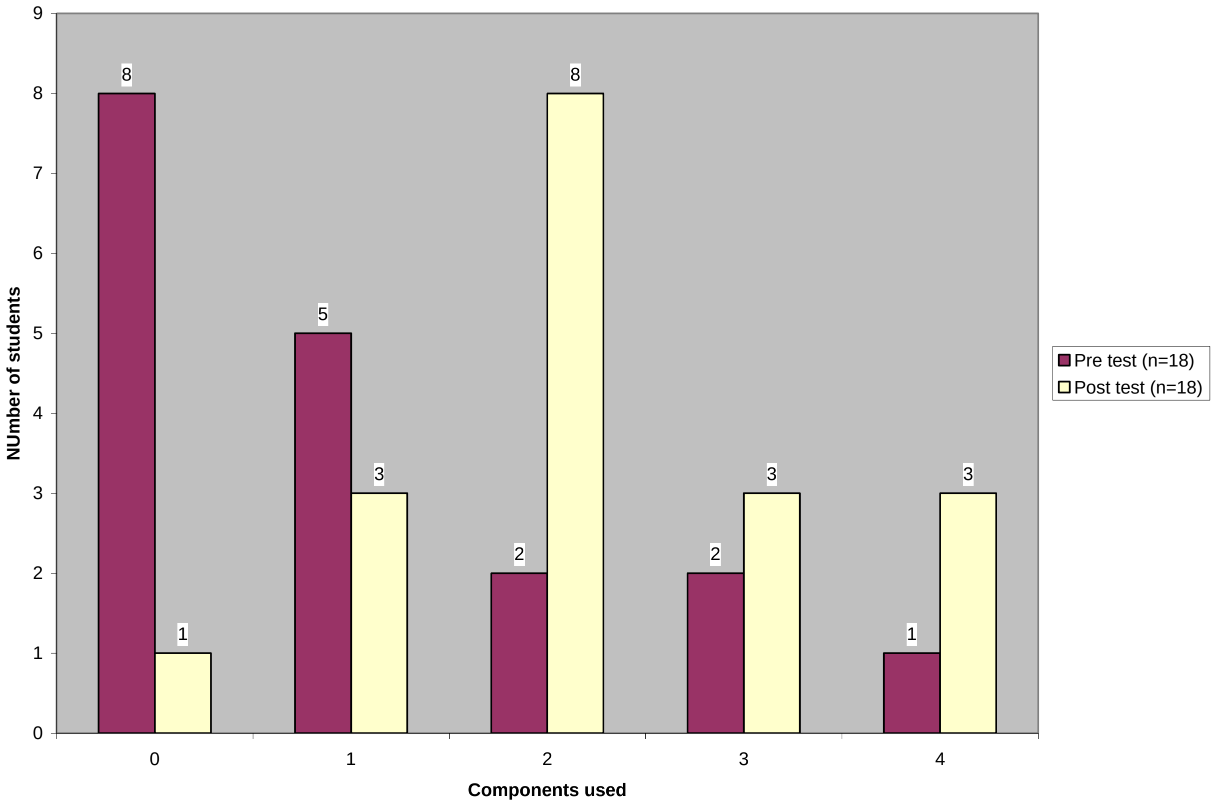

Figure 7: Darwinian component scores for the traditional class on the pre and post cheetah question

The majority of students in the traditional class used 2 components in their posttest. Fourteen students used two or more components on the posttest, compared to five on the pretest. Individuals using 1 or zero components dropped from 13 students to 4 students.

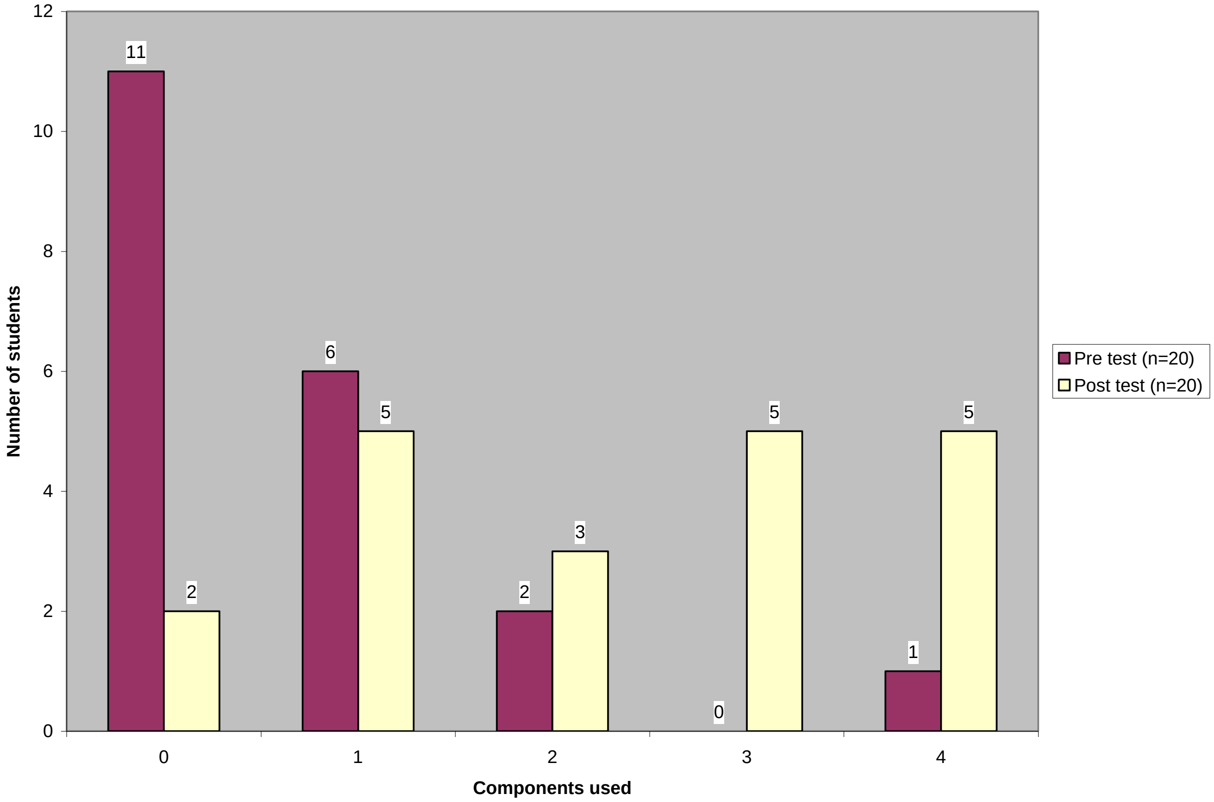

Figure 8: Darwinian component scores for the inquiry class on the pre and post cheetah question

Most of the students in the inquiry class used zero or one components on the pretest (17). This was larger than the traditional class, which had thirteen students using zero or one components.   Thirteen students in the inquiry used 2 or more components on the posttest, only three had done so on the posttest. Individuals using zero or one component dropped from seventeen students to seven students on the posttest.

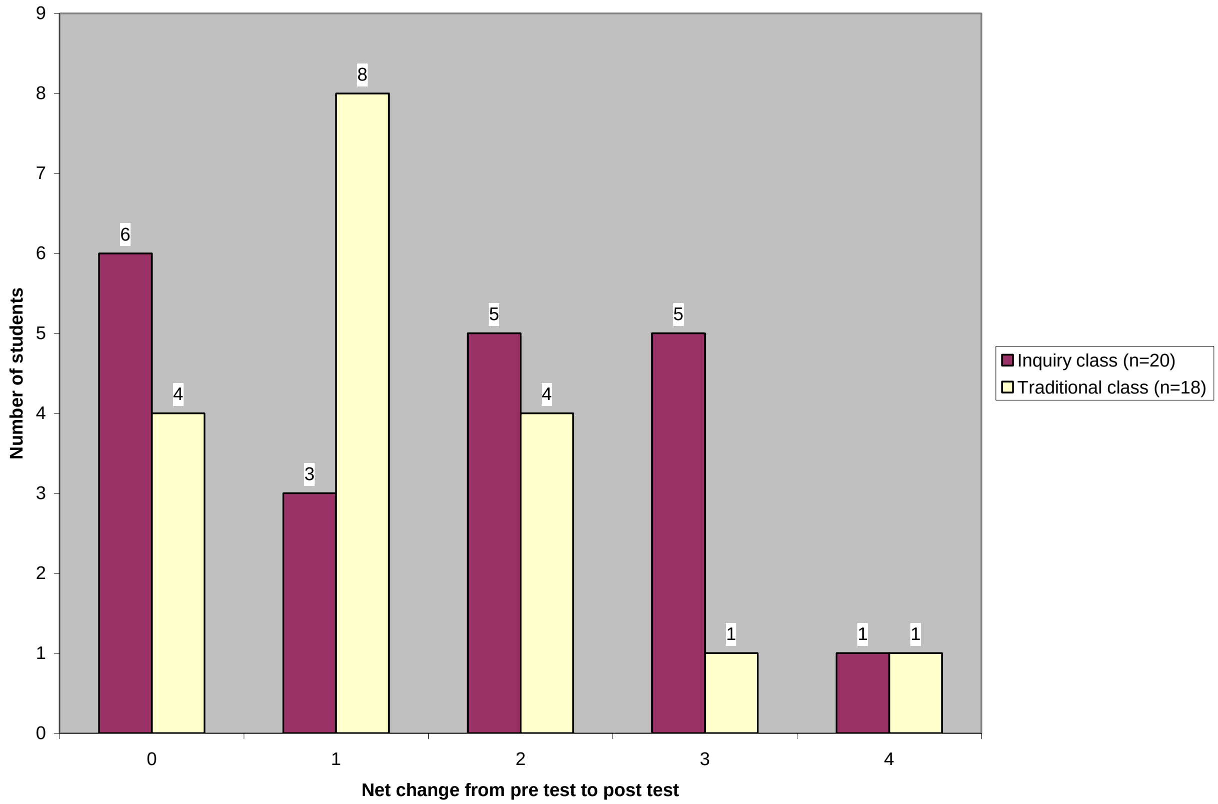

Figure 9: The net change in Darwinian components from pretest to posttest for each class

Six students in the inquiry class and 4 in the traditional class had no net change between the pretest and post. More students in the traditional class (eight) changed in one component, and the inquiry class had the largest net change in the use of two (5) and three (5) components. One student in each class had a net change of 4 components. This graph only represents the net change of components used from the pretest question to the posttest; students scoring a four and remaining a four would have no net change in their scores. For the inquiry class, three students used zero components on both tests, two used one component on each test, and one used four components on both tests. One student from the traditional class used two components on the tests, two students used three components, and one student used four components.

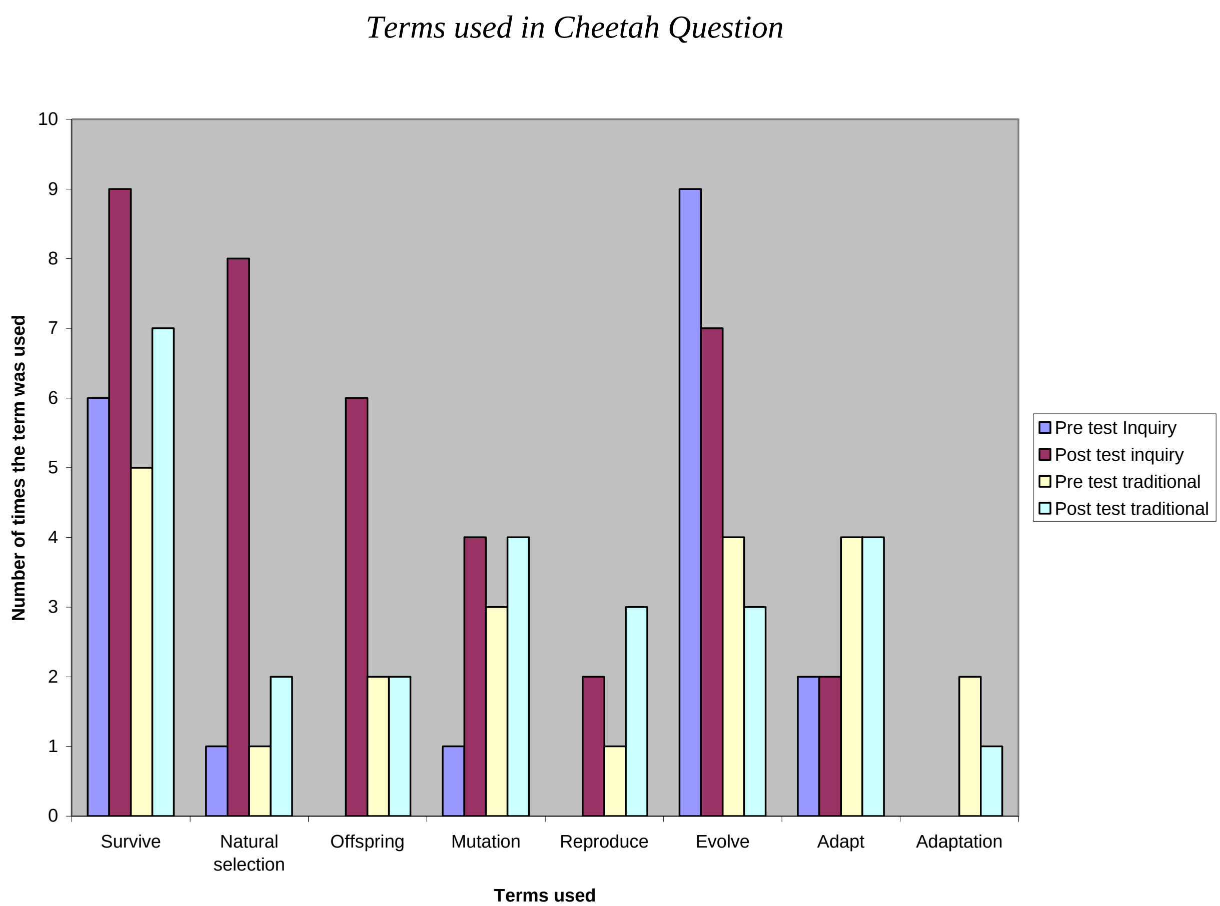

Figure 10: Terms used on the pre and posttest cheetah question for both classes

As shown in Figure (10) more inquiry students used the terms survive (9 versus 7), natural selection (8 versus 2), offspring (6 versus 2), mutation (4 versus 3), and evolve (7 versus 3) in their posttest responses. More students used the terms adapt and adaptation in the traditional class compared to the inquiry class. Use of adapt and adaptation in the response does not indicate an understanding of the processes of natural selection (Jensen et al., 2007). Organisms may be said to have "adapted" yet this does not reflect an accurate understanding of evolution. Accurate understanding terms in the scoring rubric from Jensen et al. (2007) were more often found in the inquiry class posttest responses (survive, offspring, mutation). These terms are more likely to be associated with accurate conceptions of natural selection since they are more accurate descriptors than terms like “adapt”. When the researcher shared the differences in results between the inquiry and the control class she was

> Instructor: I am going to be very honest that surprises me. I guess it is the control class I truly believe would have a better grasp of the term natural selection because I used it so often in class.
>
> Post Interview

Based on the instructor’s interpretation of her teaching, she used the phrase more often in the traditional class, which should have engendered a better understanding of the term. Videotapes of the inquiry class demonstrated that the instructor used the finch examples numerous times (five separate times during the first of two lectures) when talking about natural selection, but she did not do so in the traditional class. The ability of students to connect to an example that they were engaged with may have allowed them to gain a better understanding of the terms used when describing natural selection events.

Test results

Conceptual Inventory of Natural Selection

Before statistical analysis was completed on the C*onceptual Inventory of Natural Selection* scores, normality was established in both sections. Typically small samples have normal distributes. Figures 11 through 14 show histograms of CINS scores with the normal curve. All histograms show a fairly normal distribution in scores, therefore statistical testing could be completed on the populations.

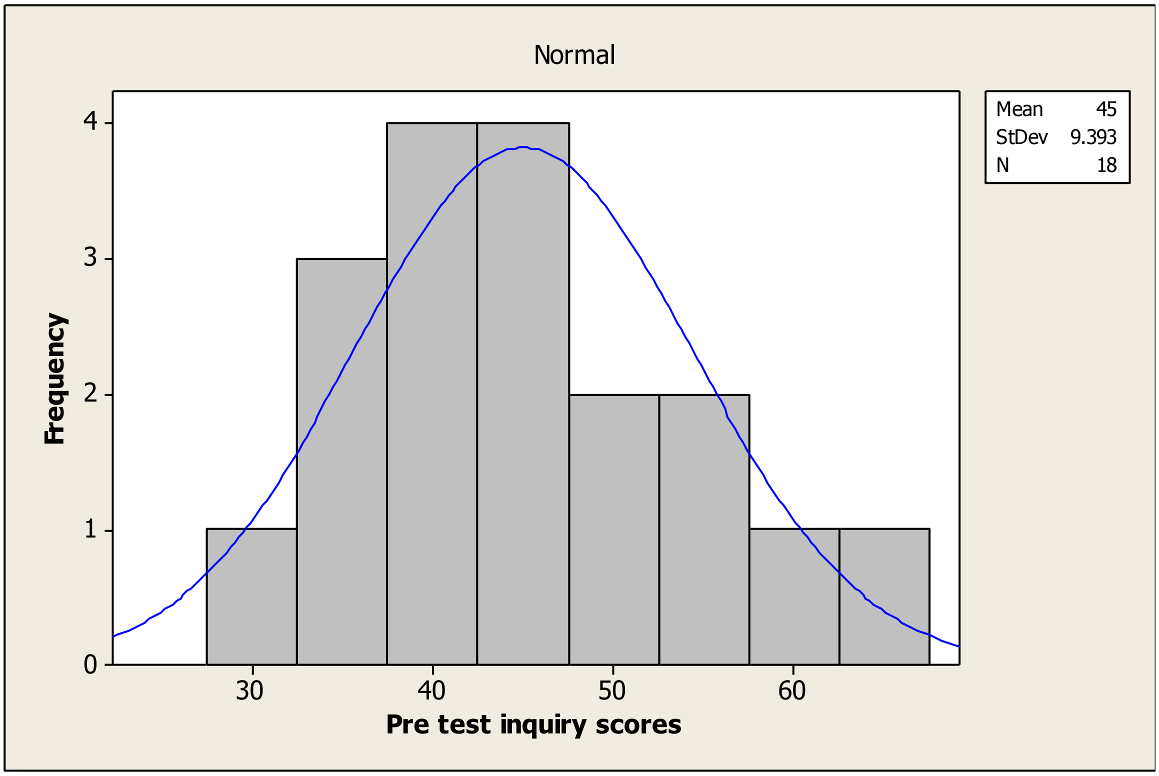

Figure 11: Histogram of pretest CINS scores for the inquiry class

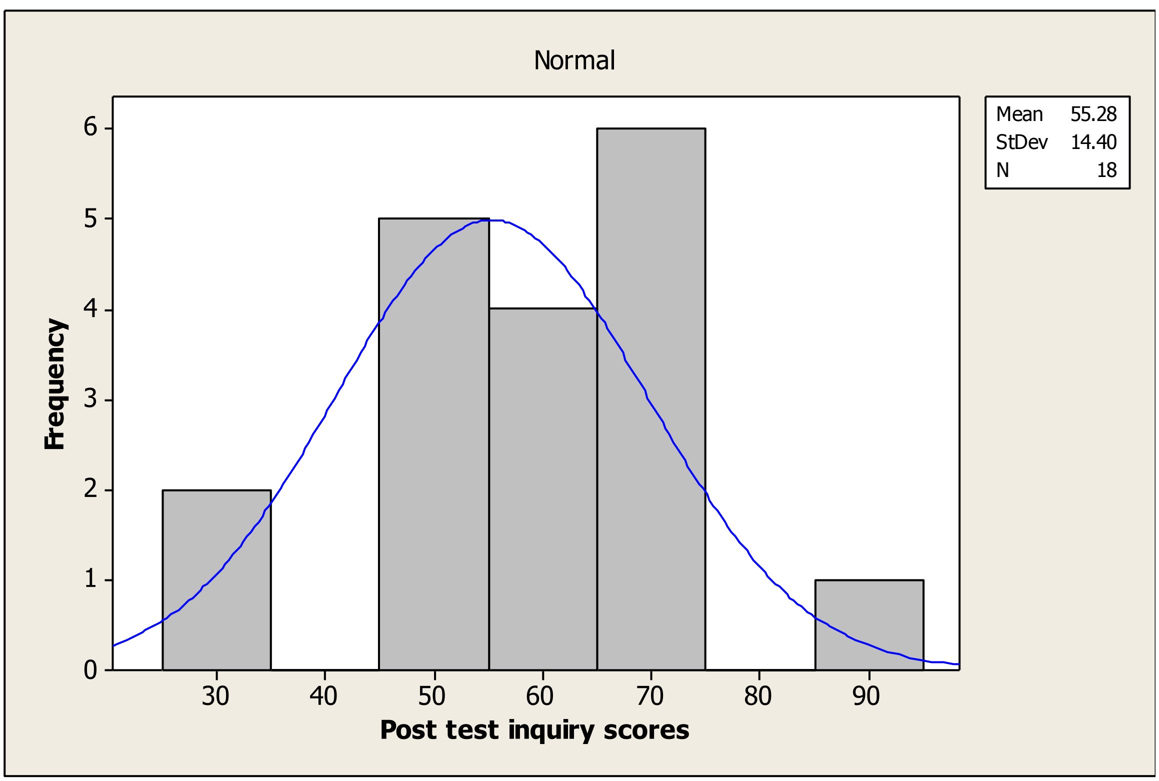

Figure 12: Histogram of posttest CINS scores for the inquiry class

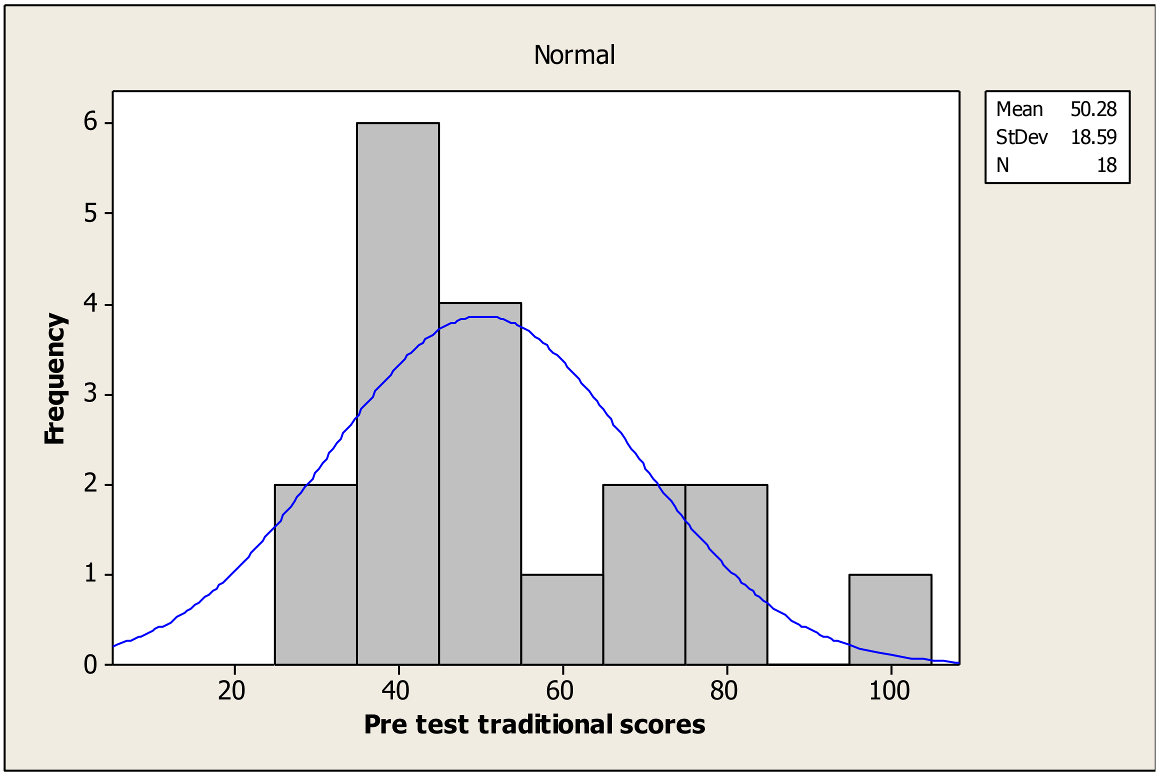

Figure 13: Histogram of pretest CINS scores for the traditional class

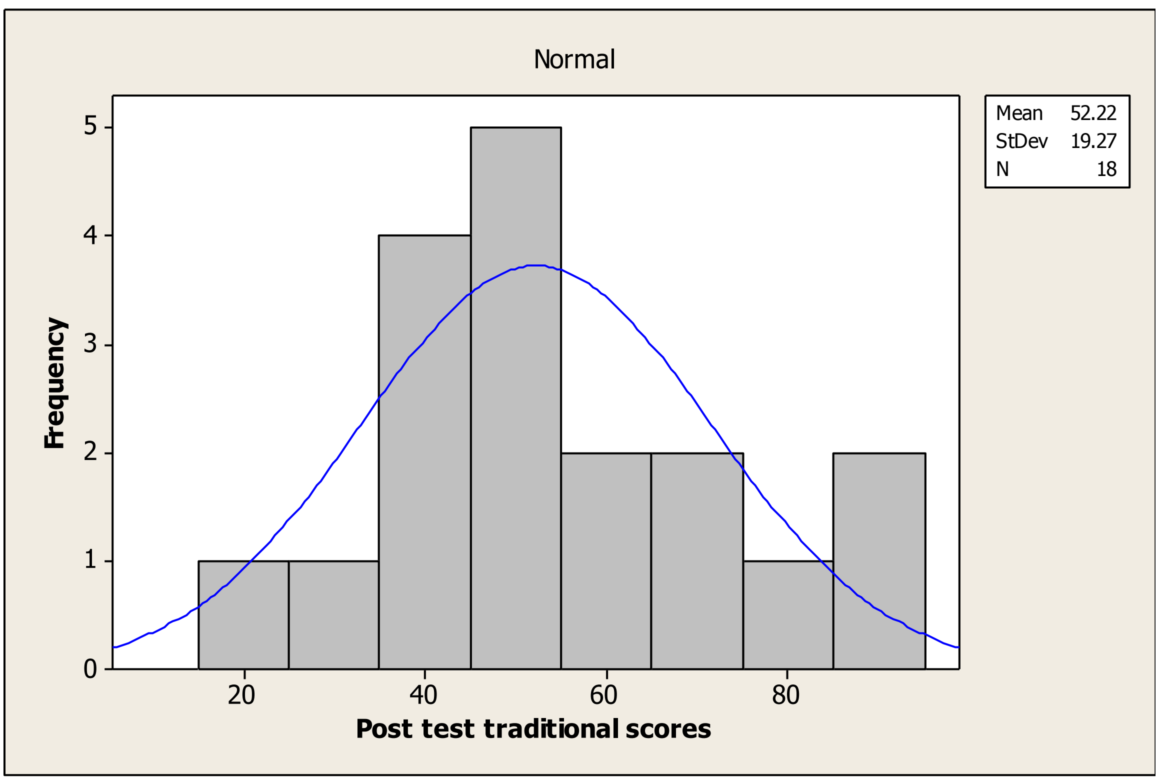

Figure 14: Histogram of posttest CINS scores for the traditional class

Eighteen students from each class were used in the comparison scores. Two students were excluded from the inquiry class – one student's pretest was missing and another's (Janet) only had three questions out of 20 answered. Mean scores for both classes are represented in Figure (15). The traditional classes' pretest mean was 50.28% on the C*onceptual Inventory of Natural Selection*, while the inquiry class had a mean of 45%. Posttest means for the two classes were 52.22% for the traditional class and 55.27% for the inquiry class. If the excluded scores from Janet's pre (0) and posttest (65) were included, the inquiry pretest mean would drop to 42.63% and the posttest would increase to 55.78%. Since Janet only completed three questions on the pretest, it was not considered to be indicative of her capability, and her scores were excluded from analysis. A two sample t test was conducted to determine if the differences in results were statistically significant between the two classes (a comparison of the pre and posttest means). Based on a two sample t test, the results were not statistically significant. In addition to a two sample t test, paired t tests were conducted on students' pre and posttest results. Based on the paired t tests, a T value of -3.27 and a p value of 0.005 was determined for the inquiry class. This value indicates the differences between pre and posttests results were statistically significant. Rejection of the null hypothesis, the difference between the mean of the pretest in the inquiry class and the mean of the posttest in the inquiry class is zero, occurred since the p value was below 0.05, the accepted alpha level. Paired t tests for the traditional class resulted in a t value of -0.69 and a p-value of 0.502, indicating that there was not a statistically significant difference between the pre and posttest results.

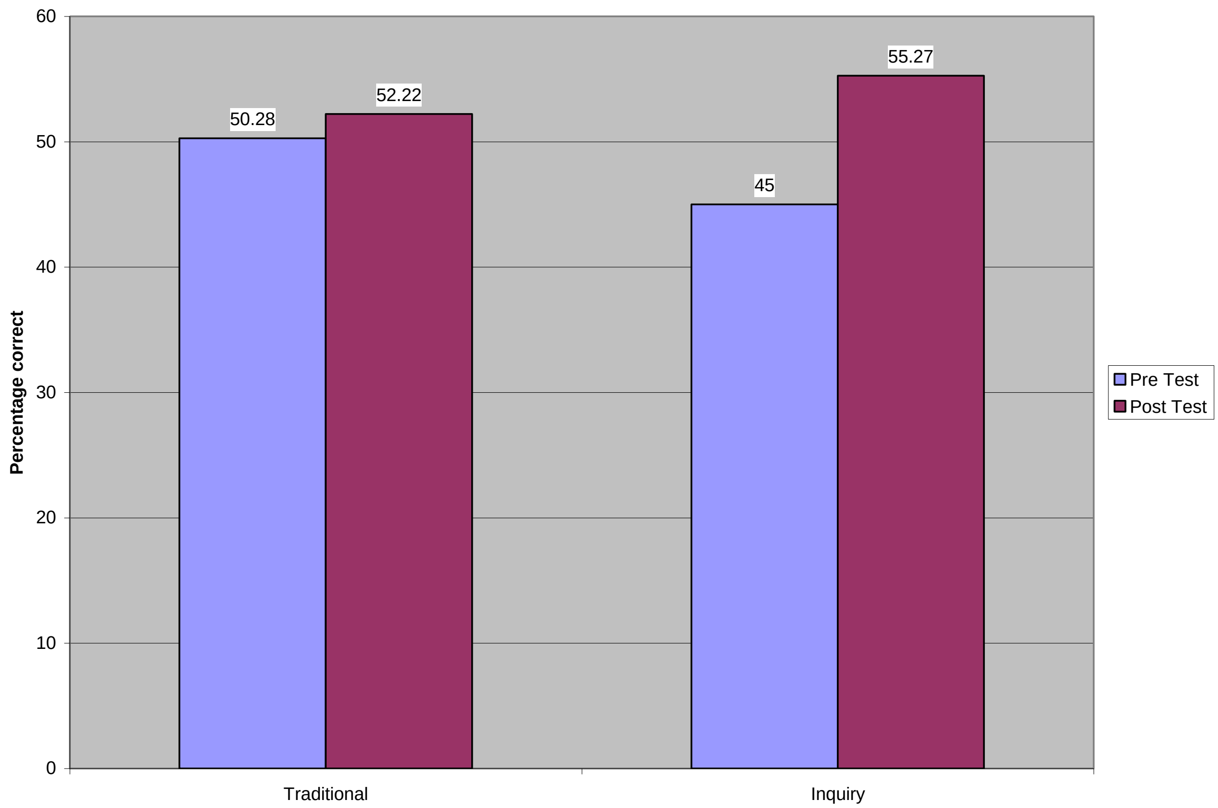

Figure 15: Comparison of pre and posttest CINS means for both classes

Table (10) shows the percentage of students in each class answering a question correctly on the CINS. On the pretest, the inquiry class scored higher on 10% of the questions (two questions – 6 and 17). Question 6 deals with concept of the origin of variation, while question 17 deals with the inheritance of variation. Less than 23% of the inquiry students answered question 6 correctly, while only 11.11% did so in the traditional class.   Results on question 17 were higher, with 55.6% of inquiry students answering correctly while 44.4% of traditional students did so. Three questions (7, 12, 19) had identical percentages of students answering the question correctly in both classes. The posttest results indicate a shift, with the inquiry students answering correctly at a higher rate on 55% (11 of 20) of the questions. The percentage of students answering correctly dropped on 5 questions in the inquiry class, while the traditional class dropped on three questions and stayed the same on six questions. On 13 of 20 questions 50% or more of the inquiry class answered correctly; in the traditional class it was 12 of 20.

Table 11: Percentage of students correctly answering each question on the pretest and posttest

Question	*Inquiry Pretest (n=18)*	*Traditional Pretest (n=18)*	*Inquiry Posttest (n=18)*	*Traditional Posttest (n=18)*
1	83.33%	88.89%	77.78%	66.67%
2	72.22%	77.78%	88.89%	77.78%
3	83.33%	88.89%	88.89%	88.89%
4	5.56%	16.67%	16.67%	22.22%
5	66.67%	83.33%	94.44%	83.33%
6	22.22%	11.11%	33.33%	16.67%
7	50.00%	50.00%	44.44%	50.00%
8	22.22%	27.78%	50.00%	27.78%
9	38.89%	61.11%	55.56%	61.11%
10	33.33%	44.44%	61.11%	55.56%
11	44.44%	66.67%	50.00%	44.44%
12	50.00%	50.00%	50.00%	50.00%
13	11.11%	16.67%	5.56%	22.22%
14	50.00%	61.11%	83.33%	66.67%
15	55.56%	61.11%	50.00%	61.11%
16	83.33%	94.44%	94.44%	88.89%
17	55.56%	44.44%	27.78%	55.56%
18	16.67%	22.22%	38.89%	38.89%
19	33.33%	33.33%	55.56%	38.89%
20	5.56%	16.67%	38.89%	33.33%

Table 12. Difficulty scores (% correct responses) for the CINS pre, post, and reported in Anderson (2002)

Question	*Pretest (n=36)*	*Posttest (n=36)*	*CINS Reported Difficulty (n=206)*
1	88.6%	72.2%	69.4%
2	75.0%	83.3%	61.2%
3	88.9%	88.9%	48.7%
4	13.9%	16.7%	18.2%
5	77.8%	86.1%	67.2%
6	13.9%	25.0%	14.5%
7	52.8%	44.4%	55.0%
8	27.8%	36.1%	41.4%
9	50.0%	55.6%	52.0%
10	38.9%	58.3%	55.5%
11	55.6%	47.2%	63.1%
12	47.2%	47.2%	48.7%
13	13.9%	11.1%	28.3%
14	55.6%	75.0%	51.5%
15	61.1%	55.6%	42.3%
16	91.7%	91.7%	80.6%
17	52.8%	41.7%	38.8%
18	22.2%	41.7%	39.1%
19	30.6%	47.2%	33.7%
20	11.1%	38.9%	22.3%

The pretest difficulty scores were compared to the reported CINS difficulty scores in Anderson et al. (2002). The reported CINS scores were identified as coming from a pretest, therefore difficulty scores are compared to the pretest and not the posttest. Compared to the reported results, participants in the study were higher on seven of the 20 questions. For the remaining thirteen questions, scores were within five percentage points for six of the questions. The other seven questions varied by no more than 16.9 percentage points. Anderson et al. (2002) indicated that questions 4, 6, and 20 appeared to be “particularly difficult for students” (p.965), which is matched by the performance of students in the current research study. In general, the performance of the research students approximately matched the performance of the reported difficulty scores. Questions with a reported difficulty greater than 50% were answered at a value above 50% (with the exception of question 10), while questions with a reported value below 50% were answered by less than 50% of the students (except for 3, 15, and 17).

CINS analysis

In addition to a comparison of the mean scores and difficulty ratings, an item analysis was completed on the multiple choice responses for the CINS. Each of the answer choices in the CINS explores a concept – the correct answer represents the scientific concept and the other three options represent common alternative conceptions (Anderson et al., 2002). The pre and posttest results were combined for the questions that addressed the same concepts (see Table 12) and are displayed in the following figures.

Table 13. Concepts and corresponding questions on the CINS

Concepts	**Questions**
Biotic Potential	1, 11
Stable Population	3, 12
Natural Resources	2, 14
Limited Survival	5, 15
Variation	9, 16
Variation Inherited	7, 17
Differential Survival	10, 18
Change in Population	4, 13
Origin of Variation	6, 19
Origin of species	8, 20

For each of the questions the scientific concept and the alternative concepts are reported in quotes. The answers selected and the material in quotes is not the actual wording of the response, only the concepts that Anderson et al. (2002) indicated are represented in the selections.

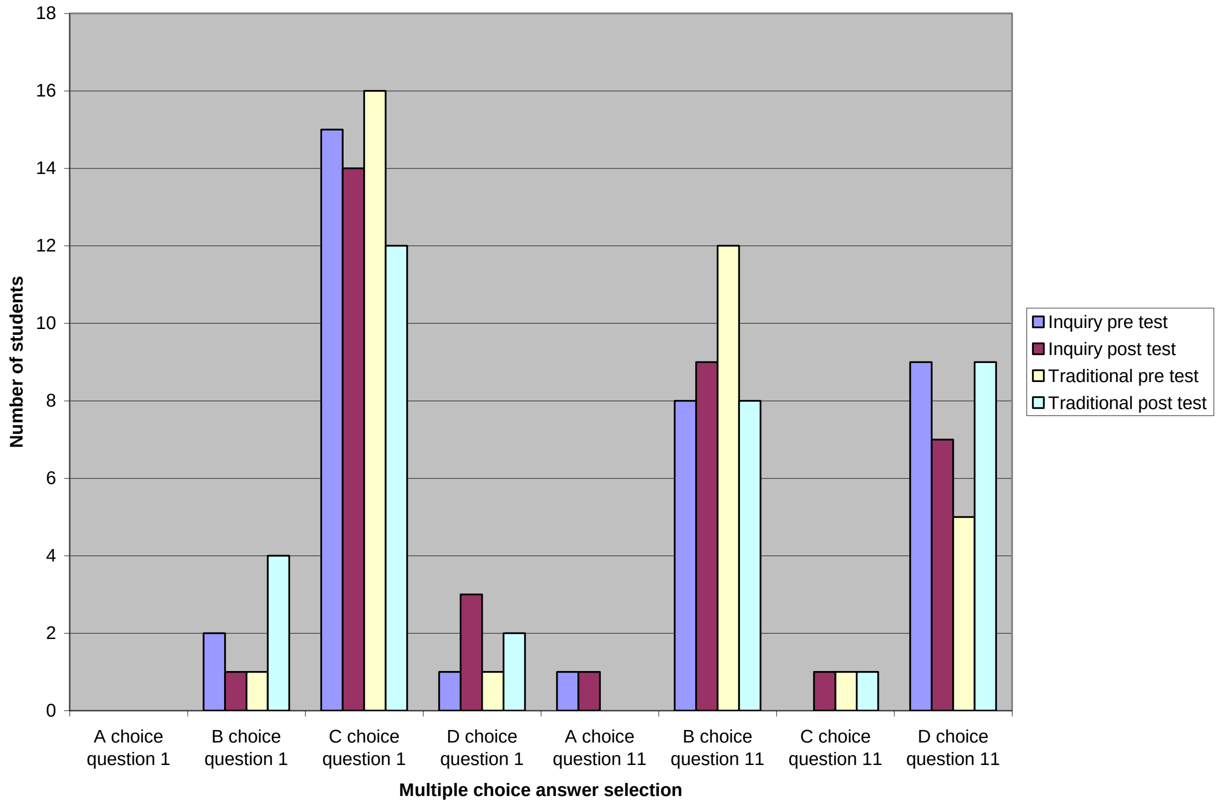

Figure 16: Number of students selecting each multiple choice option for questions 1 and 11 on the CINS.

Questions 1 and 11 on the CINS are geared at testing the concept of biotic potential. For question 1, the correct answer is choice C, the concept of "all species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully" (Anderson, 2002). Few students chose the alternatives of B and D which dealt with the alternative concept of "populations level off".

The correct choice for questions 11 was B, dealing with the concept "all species have such great potential fertility that their population size would increase exponentially if all individuals that are born would again reproduce successfully", while the most common alternative choice was selection D, "populations level off". This choice was selected by the traditional students on the posttest more often than the inquiry students (who chose B more often).

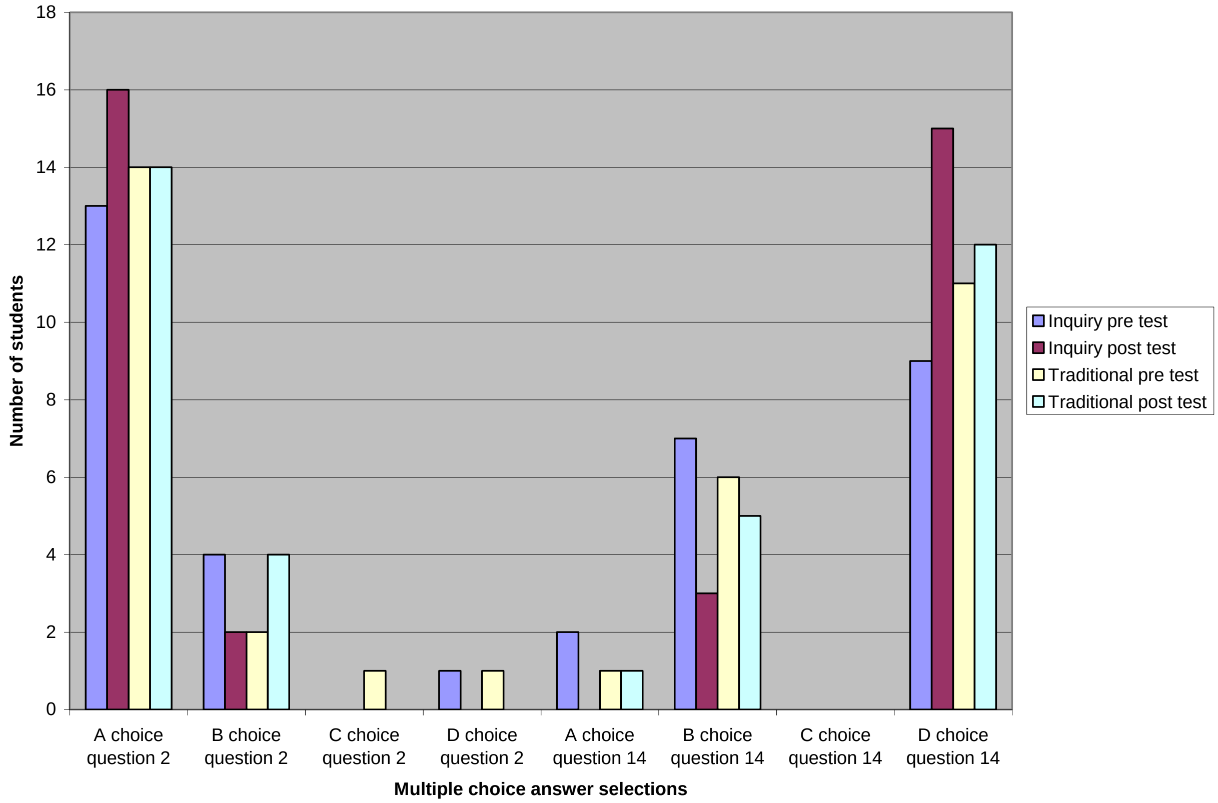

Figure 17: Number of students selecting each multiple choice option for questions 2 and 14 on the CINS.

Questions 2 and 14 assess the concept of natural resources. For question 2 the correct response is A, demonstrating the concept "natural resources are limited; nutrients, water, oxygen, etc. necessary for living organisms are limited in supply at any given time", with B the most common alternative selection "Organisms can always obtain what they need to survive." This alternative selection dropped in the inquiry class but increased in the posttest. Options C and D were only selected on the pretest in both classes.

The correct choice for question 14 is D, which deals with the concept "Natural resources are limited; nutrients, water, oxygen, etc. necessary for living organisms are limited in supply at any given time". The most common alternative selection was B, "organisms can always obtain what they need to survive." Question 14 had a larger number of students incorrect in their answer selection than 2. Both the inquiry class and the traditional class increase increased in the number of students selecting the correct response on question 14.

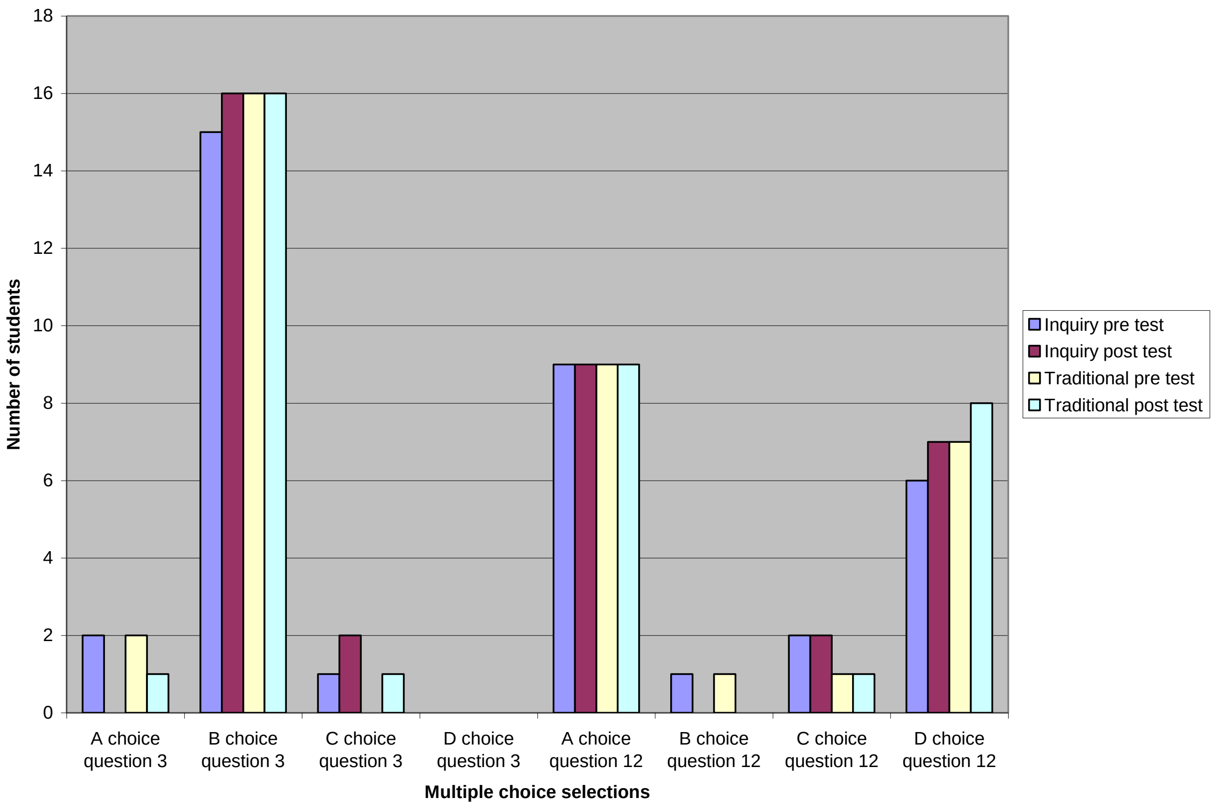

Figure 18: Number of students selecting each multiple choice option for questions 3 and 12 on the CINS.

Questions 3 and 12 investigate the concept of stable population. Question 3 had a high percentage of students answering the question correctly with selection B "Most populations are normally stable in size except for seasonal fluctuations." Two or fewer students chose the alternative concepts of A and C, with none selecting D. Question 12 had a split between choices

A and D, with A being the correct choice, “most populations are normally stable in size except for seasonal fluctuations”. D is the alternative conception that “populations always fluctuate wildly/randomly.” The selection of choice D increased in both classes on the posttest.

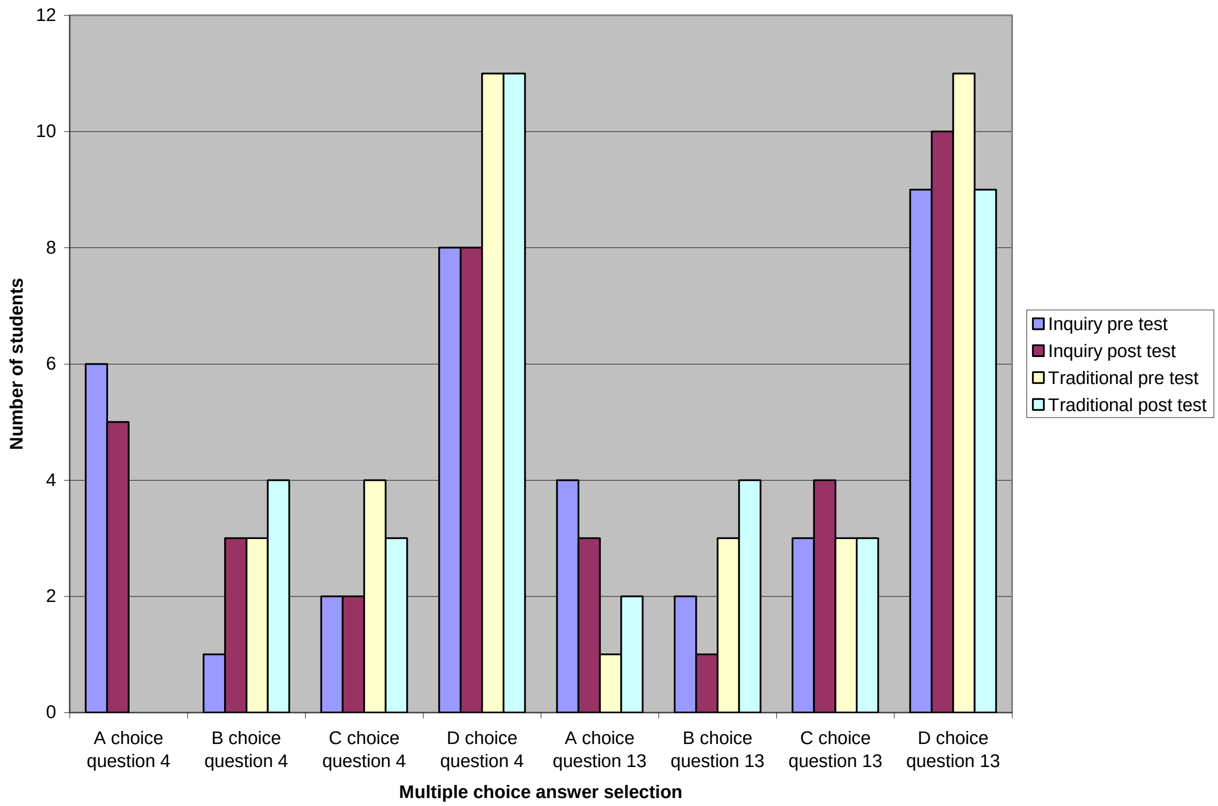

Figure 19: Number of students selecting each multiple choice option for questions 4 and 13 on the CINS.

Questions 4 and 13 examine the concept of changes in populations. The correct answer for question 4 was B, “The unequal ability of individuals to survive and reproduce will lead to gradual change in a population, with the proportion of individuals with favorable characteristics accumulating over the generations.” Students choosing correctly in the inquiry class increased from one student to three students, while the traditional class increased from three to four students. Only students in the inquiry class chose answer A “Changes in a population occur through a gradual change in all members of a population." The majority of students in both classes made choice D, "mutations occur to meet the needs of the population" their predominant selection.

For question 13 the correct selection was B, "the unequal ability of individuals to survive and reproduce will lead to gradual change in a population, with the proportion of individuals with favorable characteristics accumulating over the generations." Although variable in their responses, the most common incorrect choice, D, was the alternative conception that "mutations occur to meet the needs of the population." Both questions 4 and 13 were reported to have a high difficulty by Anderson (2002). Students in both classes were more likely to select the alternative concept that "mutations occur to meet the needs of the population".

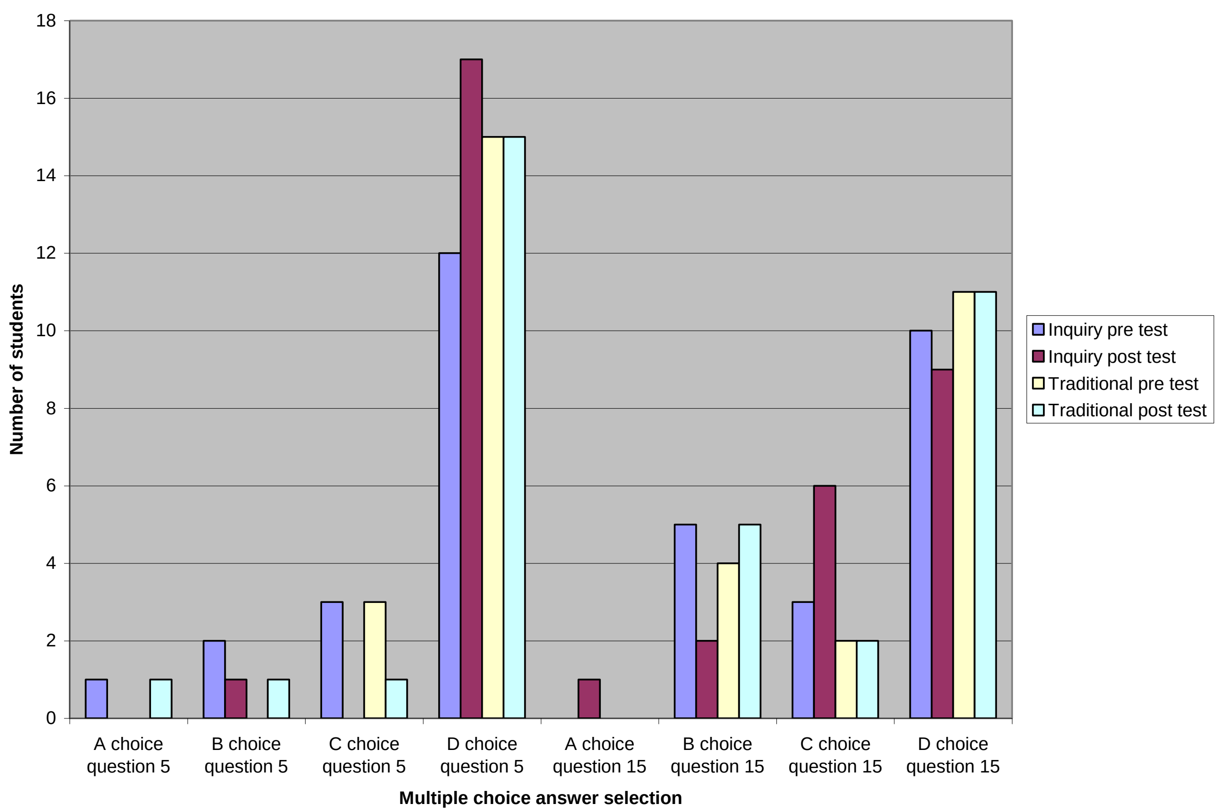

Figure 20: Number of students selecting each multiple choice option for questions 5 and 15 on the CINS.

Questions 5 and 15 assess the biological concept of limited survival. Both classes had a high selection rate of the correct response, D, "production of more individuals than the environment can support leads to a struggle for existence among individuals of a population, with only a fraction surviving each generation". Inquiry students choosing correctly increased from 12 to 17 on the posttest while the traditional class stayed the same (15 students). Question 15 had more variability in the selections – the correct choice of D was most often selected, but B "there is often physical fighting among one species (or among different species) and the strongest ones win", and C "mutations are adaptive responses to specific environmental agents were common alternative choices" were also chosen. Selection of choice B increased for the traditional class, while choice C increased for the inquiry class.

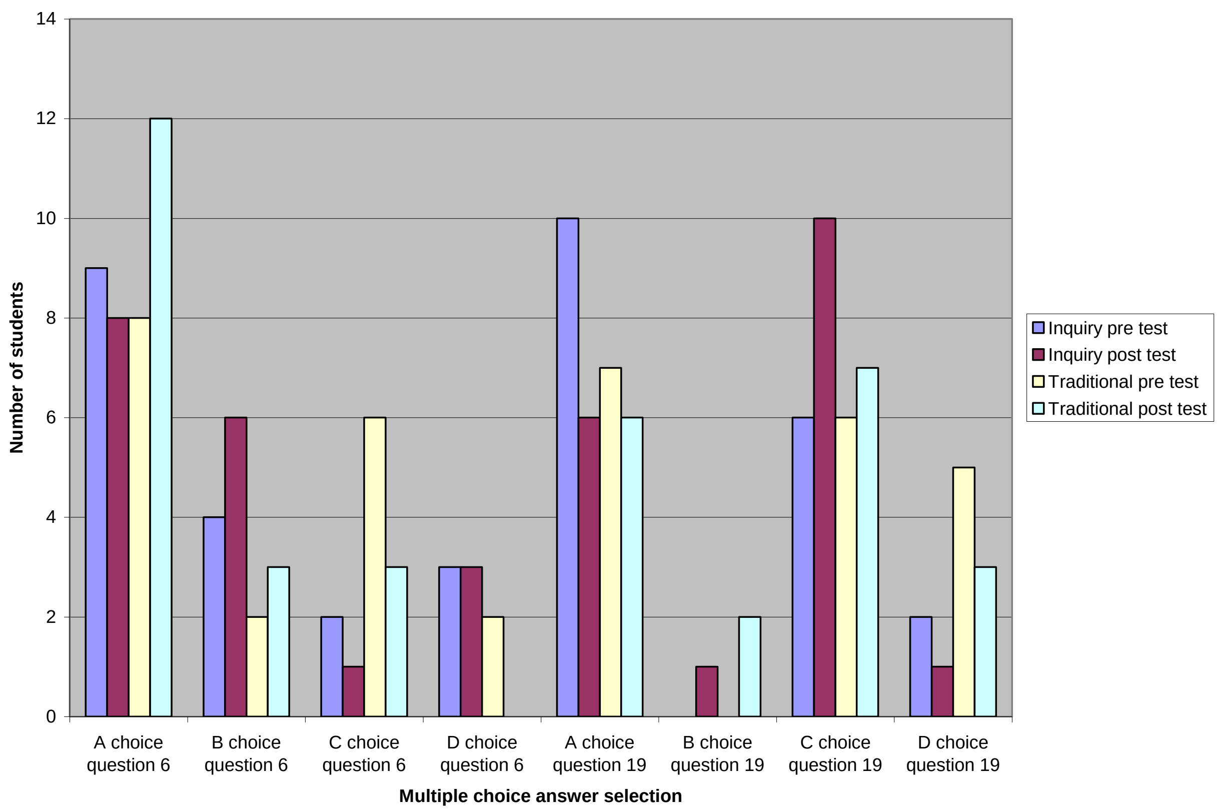

Figure 21: Number of students selecting each multiple choice option for questions 6 and 19 on the CINS.

Questions 6 and 19 address the concept of the origin of variation. The correct choice for question six is B, with A, "mutations are intentional: an organism tries, needs, or wants to change genetically", the alternative conception most often selected. The traditional class increased in this choice from pre to posttest, while the traditional class dropped slightly. Options C "mutations are adaptive responses to specific environmental agents" and D "Mutations are intentional: an organism tries, needs, or wants to change genetically" were also popular.

For question 19 the correct choice was C "random mutations and sexual reproduction produce variations; while many are harmful or of no consequence, a few are beneficial in some environments", while A was the most commonly selected alternative choice "mutations are intentional: an organism tries, needs, or wants to change genetically." The number of students accurately picking the correct answer increased in both classes. The traditional class also chose options B and D at a higher rate than the inquiry class.

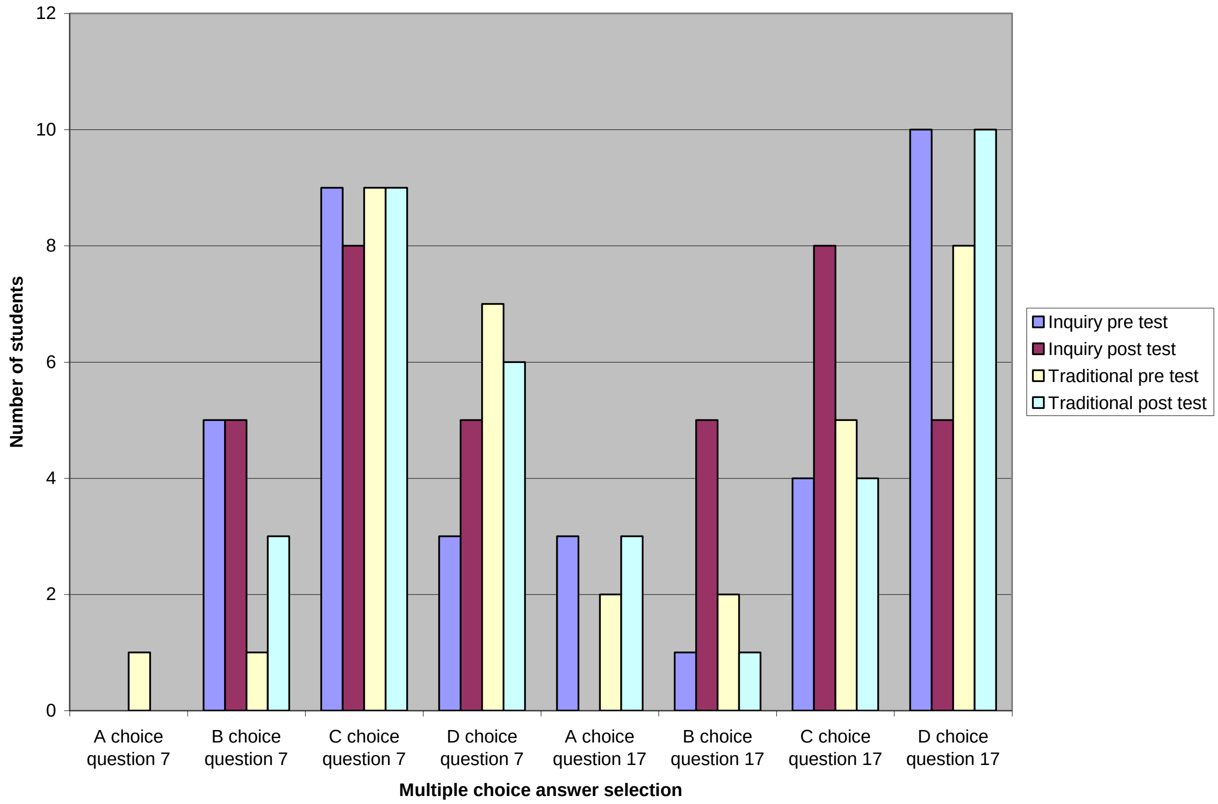

Figure 22: Number of students selecting each multiple choice option for questions 7 and 17 on the CINS.

Questions 7 and 17 examine that concept that variation is inherited. The correct choice for seven, letter C, assesses the concept "much variation is heritable". Choice B "when a trait (organ) is no longer beneficial for survival, the offspring will not inherit the trait" and D "traits that are positively influenced by the environment will be inherited by offspring" were popular alternative choices. Students selected choice B increased in the traditional class but stayed the same in the inquiry class. Choice D increased in the inquiry class but dropped in the traditional class.

The correct choice for 17 was D, with B and C common choices for the alternative concepts "when a trait (organ) is no longer beneficial for survival, the offspring will not inherit the trait" and "changes in a population occur through a gradual change in all members of a population”. The inquiry class was more likely to answer with the alternative than the correct response D. Selection of the correct choice increased in the traditional class but decreased in the inquiry class on the posttest.

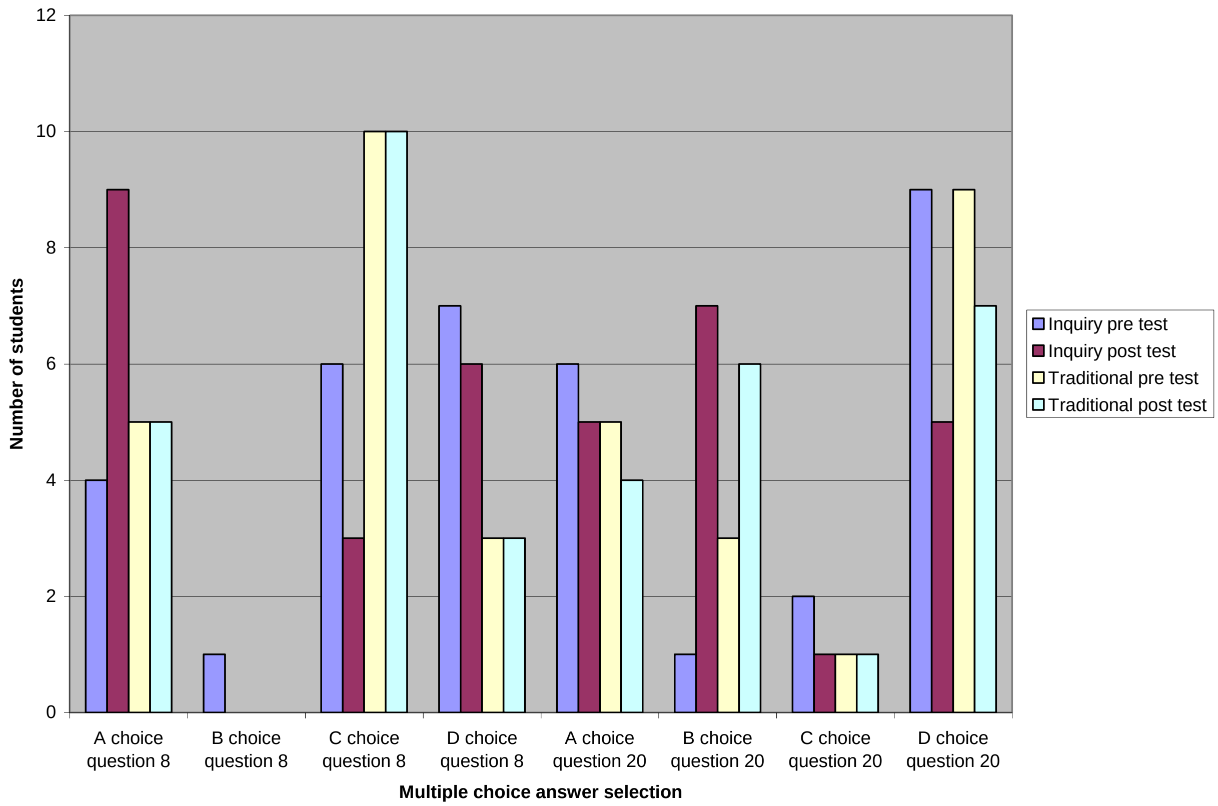

Figure 23: Number of students selecting each multiple choice option for questions 8 and 20 on the CINS.

Questions 8 and 20 explore the concept of the origin of species. The correct choice for 8, A, “An isolated population may change so much over time that it becomes a new species”, was more often selected by the inquiry class on the posttest. Choice C, “organisms can intentionally become new species over time (and organism tries, wants, or needs to become a new species)”, was most selected more often by the traditional class, followed by D, “organisms can intentionally become new species over time (and organism tries, wants, or needs to become a new species)". Choice D was also a common alternative selected by the inquiry class (second most selected on the posttest after the correct response).

Question 20's correct response was B, "an isolated population may change so much over time that it becomes a new species". A and D were the alternatives most often chosen after the correct answer; both dealt with the concept "Organisms can intentionally become new species over time (and organism tries, wants, or needs to become a new species)". Selection of choice B increased in both classes while all other selections decreased. The inquiry class had a larger jump from one student to seven students answering correctly, while the traditional class increased from three students to six students.

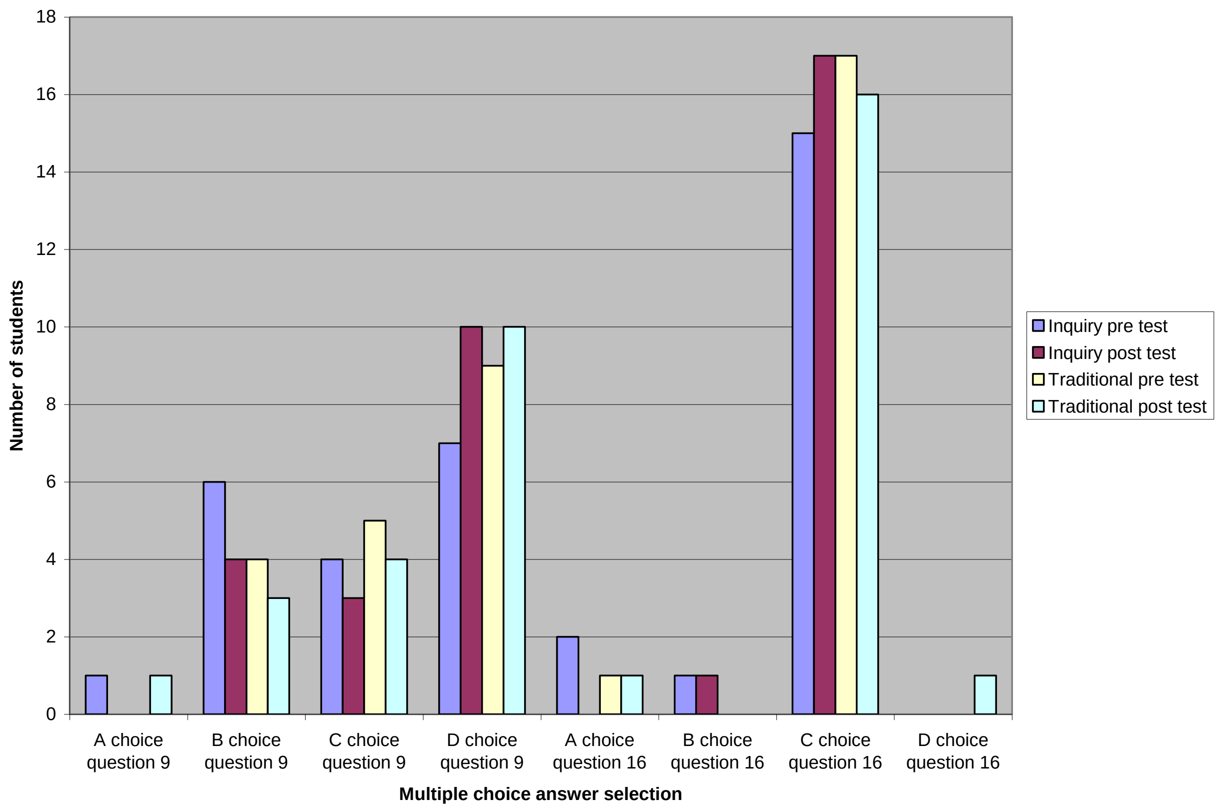

Figure 24: Number of students selecting each multiple choice option for questions 9 and 16 on the CINS.

Questions 9 and 16 assess the concept of variation. Question 9's correct response was answer D, representing the concept "individuals of a population vary extensively in their characteristics". Both classes increased in students answering correctly and incorrect selections dropped. However, the inquiry class and traditional class had a number of students picking choices B and C, which both represented the alternative concept "variations only affect outward appearance, don't influence survival".

Question sixteen was answered by a majority of students correctly with choice C "individuals of a population vary extensively in their characteristics". Less than two or less students chose answers A, B, and D. Those answering correctly in the inquiry class increased by two students while it dropped by one student in the traditional class.

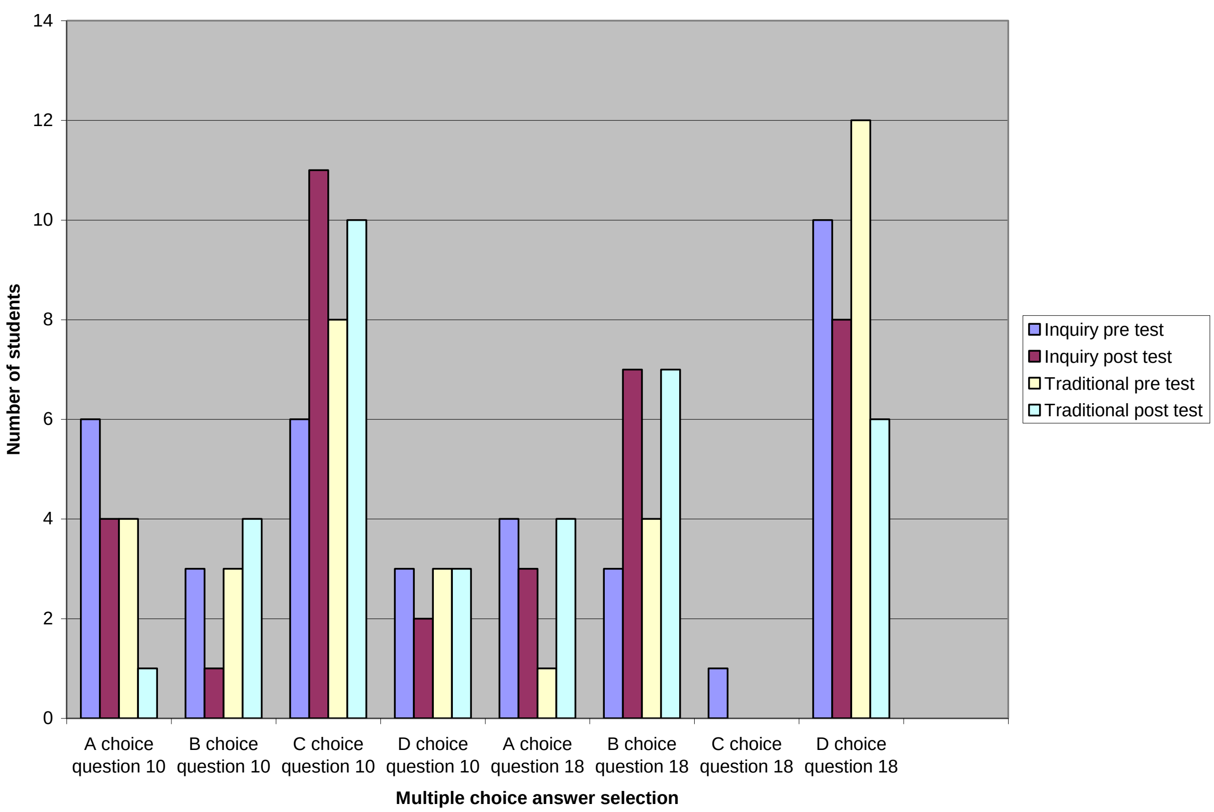

Figure 25: Number of students selecting each multiple choice option for questions 10 and 18 on the CINS.

Questions 10 and 18 look at differential survival. Question 10 had a bit of variability in the selection of the correct choice, C "survival in the struggle for existence is not random, but it depends in part on the hereditary constitution of the surviving individuals. Those individuals whose surviving characteristics fit them best to their environment are likely to leave more offspring than less fit individuals", and choice A, B and D. A and B tested the alternative conception that "Fitness is equated with strength, speed, intelligence or longevity"; while D explores the concept "organisms with many mates are biologically fit". Again both classes increased in the students choosing the right option, yet the traditional class increased in incorrectly selecting B. The inquiry class dropped in the each of the alternatives on the posttest.

For question 18 the correct option, B, was chosen less than the alternative choice D for all groups except the posttest traditional class. Both classes increased in the number of students correctly answering this question. Each of the alternative choices dealt with the concept that "fitness is equated with strength, speed, intelligence or longevity". The traditional class had an increase in students picking answer A from pretest to posttest while the inquiry class had less students choosing the wrong of choice A and D pre to post.

Summary of student responses on the CINS

There were a number of questions in which the inquiry class increased in their correct choices from pretest to posttest and dropped in each of their alternatives. At the same time the traditional class had an increase in students picking alternatives more often in these questions. In the case of questions 2, 6, 8, 10, 11, 16, and 18 the inquiry class increased in their correct choices and decreased in each of their alternative choices from the pretest to the posttest. Therefore students dropped in each of the categories where they had made an alternative conception choice.

In each of these questions the traditional students increased their selection of alternatives from the pretest to the posttest. In many cases the number of students answering correctly increased, but it was the number of alternatives that also increased. The instructional strategies may have been effective in addressing alternative conceptions held by students and decreased the likelihood that they would make those choices on the posttest. Questions 2, 6, and 8 dealt with the Galapagos finches, which the inquiry class had more experience with.

The traditional class alternative selections often reflected elements of the needs and wants of organisms. This was not as evident in the inquiry class and indicates that alternative conceptions were less likely due to the interventions used.

Exam Scores

The instructor gave 5 examinations in the course, each covering related topics. Exam means for each class are represented in Figure 26. Overall the total exam mean for the traditional class was higher (63.39%) compared to the inquiry class (61.69%). The highest mean score for both classes was exam 3, the evolution unit exam. As shown in Table 13, the maximum score was higher (103%) in the traditional class versus (92%) for the inquiry class. Minimum scores were fairly similar (52% traditional, 51% inquiry). The inquiry median was 72.5, while the traditional median was 76.5. The standard deviation was slightly lower in the inquiry class (11.96) as was the standard error of the mean (2.67). The inquiry class had a lower exam mean on every exam but the first exam. The exam mean spread between the two classes was largest for the evolution exam at 4 points, the other means varied between one and two points.

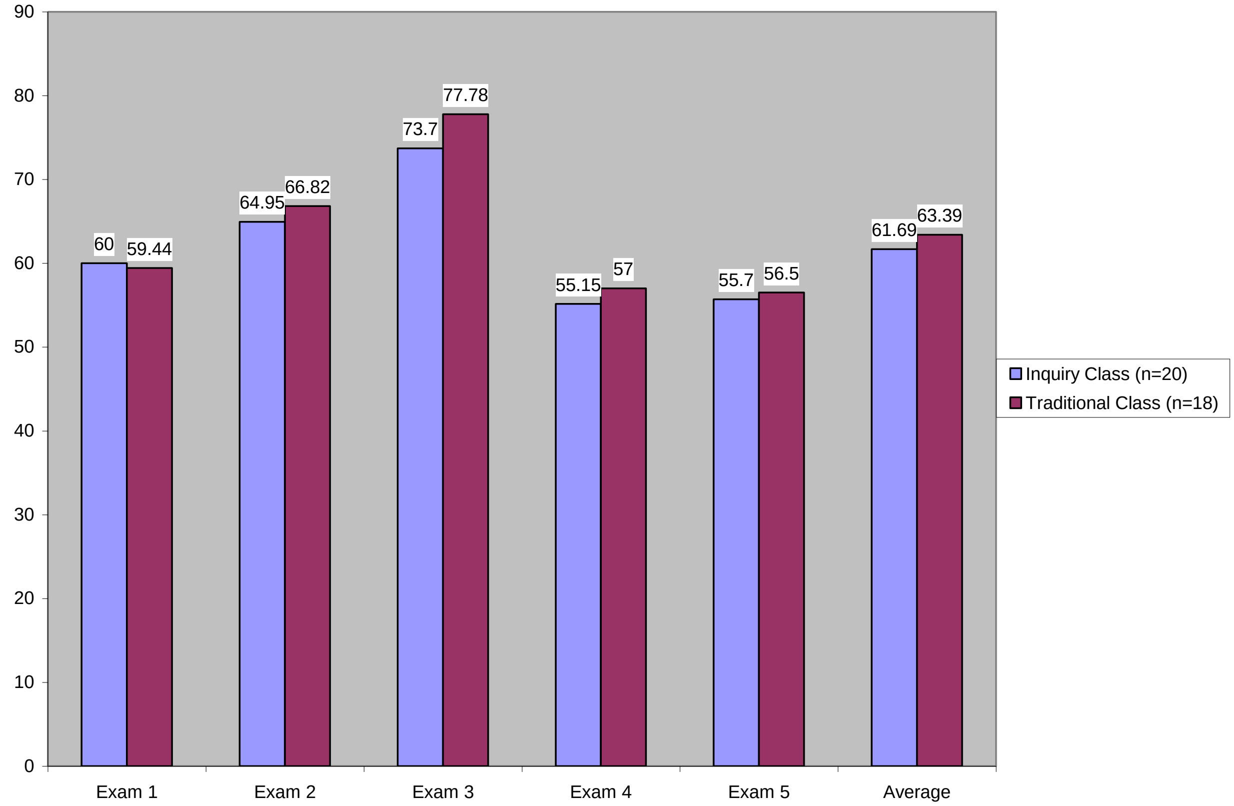

Figure 26: Instructor generated exam means for the traditional and inquiry class

Table 14. Descriptive statistics for the inquiry and traditional class evolution exam

Class	*Mean*	*SE Mean*	*StDev*	*Minimum*	*Q1*	*Median*	*Q3*	*Maximum*
Inquiry	73.70	2.67	11.96	52.00	64.25	72.50	84.25	92.00
Traditional	77.78	3.42	14.49	51.00	14.49	76.50	88.25	103.00

Histograms of the evolution exam scores are displayed in Figure 27 and 28. These values demonstrate normality of the data; therefore it is appropriate to do statistical comparisons between the two sets of data.

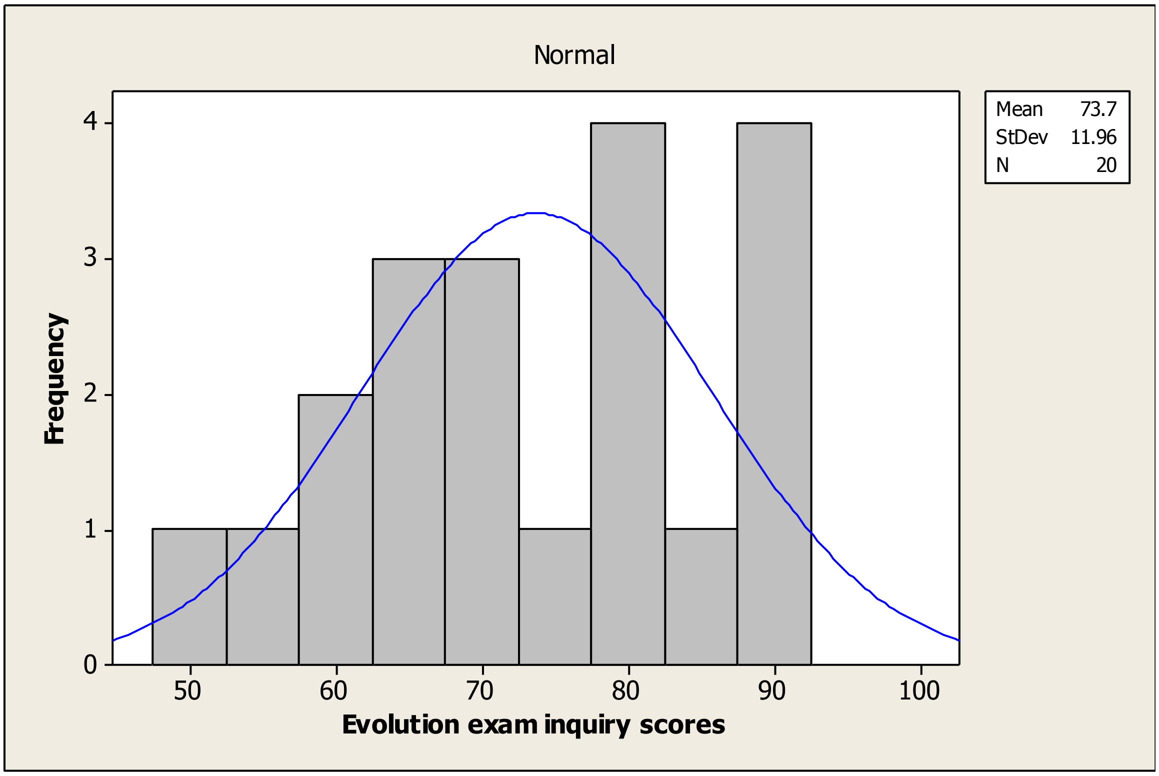

Figure 27: Histogram of instructor generated evolution scores for the inquiry class

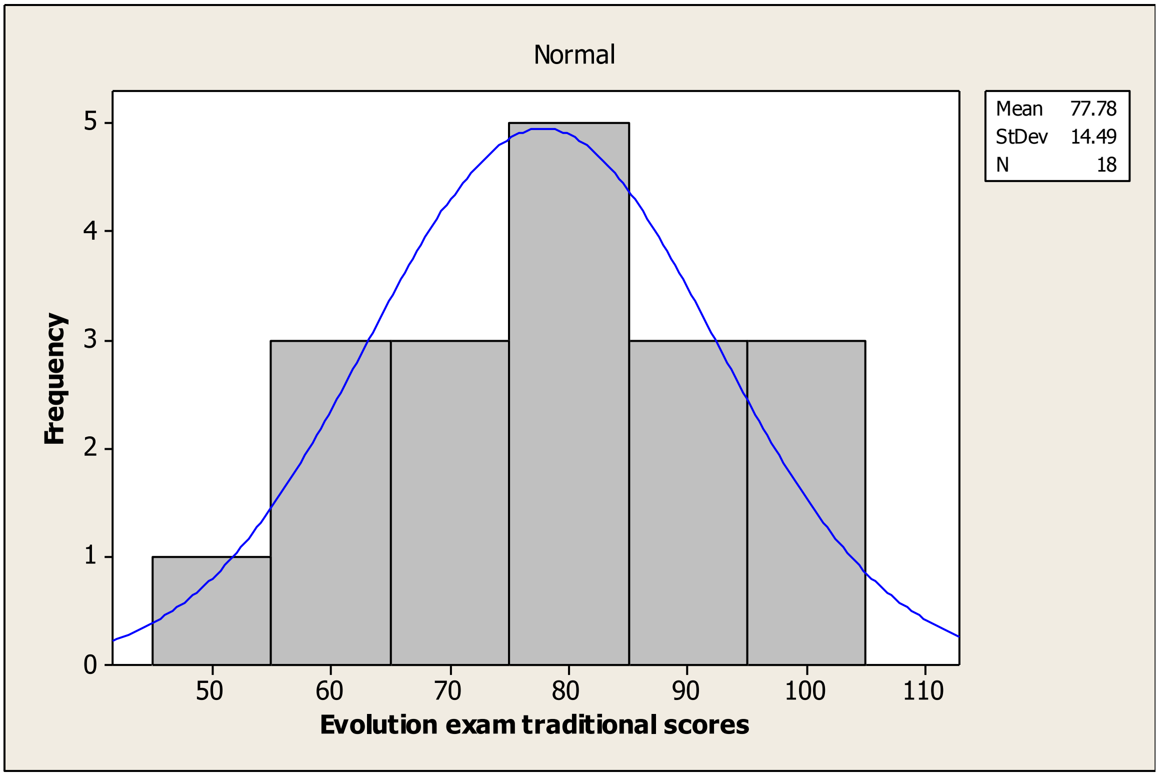

Figure 28: Histogram of instructor generated evolution scores for the traditional class

A two sample t test was conducted on the two classes to determine if their exam scores were significant in their differences. The null hypothesis is that the difference between the two groups is zero. This may also be stated as the difference between the mean of the inquiry class and the mean of the traditional class is zero. The alternative hypothesis is the difference between the observed mean of the inquiry class and the expected mean of the traditional class is not zero. The calculated T-value was 0.94, with a p value of 0.354 and 33 degrees of freedom. Since the p value was greater than 0.05, the null hypothesis is not rejected and the data indicates there is no statistical difference in the exam scores.

Student Interviews

The following are brief profiles of the students who were interviewed in December. The information is drawn from their responses on the demographic survey administered before the start of the course as well as their exam scores and Darwinian component scores for the cheetah question. Nine students participated from the inquiry class and two from the traditional class.

Mark was a Liberal Arts and Sciences: Math and Science major who was in his early twenties. His future career goal was elementary education. Although he stated that he had a biology class six years ago, he had recently completed Conservation of Natural Resources at the college. In high school he had taken earth science and living environment (biology). He rated his comfort level with evolution as a four on a scale from 1-5before the start of a class and his belief in evolution was a number 2, “Human beings have developed over millions of years without God in the process”. His evolution exam score was 70% on the instructor generated unit test. He saw an increase from 40 to 55 on the CINS but the number of Darwinian components remained the same from the pretest to the posttest (1 to 1).

Sharon, a Liberal Arts and Sciences: Math and Science major, was a nontraditional student who had previously taken BIOL 101 and Zoology at the college level. She planned on pursuing a career in radiation therapy. She identified her evolution comfort level at 1 (the lowest) and her belief in evolution at a one, “Human beings developed over millions of years but God guided the process”. She scored 82% on the instructor's evolution exam and saw a small increase from 45 to 55 on the CINS. Her Darwinian component score jumped from 0 to 4 on the posttest.

Helen, in her early 20s and majoring in liberal arts, had last taken biology in high school around 2002. She stated that her overall comfort level with biology was “difficult, not too comfortable" (pretest demographic survey, 2007). She had taken high school level science courses (biology and earth science) but not any college level science courses. Her comfort level with evolution was a three and her belief in evolution was a three, "God created human beings pretty much in their present form at one time within the last 10,000 years or so". She did well on the instructor exam, 79%, but her CINS dropped from 55 to 50. Her Darwinian component score increased from 0 to 3.

Bethany was an accounting major in her early 20s. She thought she had taken biology last in 2000 or 2001 in high school. She reported a one for her comfort level in evolution and her reported belief in evolution was selection three. Both her CINS and Darwinian scores increased from the pretest to the posttest - 35 to 45 and 0 to 3 respectively. She earned a 74% on the instructor's exam.

Alyssa had a future career goal of becoming an RN and was currently a nursing major. She had ninth-grade biology, earth science, chemistry, and anatomy physiology at the college level. Her comfort level with evolution was a five (the highest) and her evolution belief selection was choice one. She did very well on the instructor's test with a 90% score and saw her CINS increase from 50 to 85 on the posttest. She displayed a complete understanding of evolution/natural selection in the cheetah question and her score was consistent from the pretest (4) to the posttest (4).

Kim, a nontraditional student looking to become a therapist, completed biology over a decade ago in high school and had not completed any college level science courses. Her evolution comfort level was a three and her belief selection was one. Despite a low score on the instructor's exam (59%), her CINS increased from 55 to 70 and her Darwinian components went from 0 to 2.

Janet was another nontraditional student who last had a science course in the early nineteen eighties in high school. She wanted to teach mathematics in a junior high school after finishing her degree. She rated her comfort level with evolution at 3 and her belief was choice three. Janet's pretest CINS was excluded from consideration and analysis as she only completed three questions, but she scored a 65% on the posttest. Her instructor generated exam score was 81%, and Darwinian component scores increased from 0 to 2

Deborah, a biology and chemistry major in her early 20s, was interested in becoming a physician's assistant in the future. She previously completed college biology courses titled Health and History and Physiology of Aging at another institution. Her comfort level was a four with evolution and she selected choice 2 as representing her beliefs in evolution. She earned an 85% on the instructor's exam and both her CINS scores (40 to 55) and Darwinian components (1 to 4) increased from the pretest to the posttest.

Jill, a nontraditional student, had last taken biology in 10th grade in the late nineties. She was considering becoming a radiologist after her degree requirements were fulfilled. Her comfort level was a three in regard to evolution and she indicated in the demographic survey that biology "is very overwhelming" (Demographic survey, 2007). Her belief was choice two. Although she passed the instructors exam with 71%, her CINS dropped from 35 to 25 and her Darwinian components stayed at a zero for pretest and posttest.

Alex, in his early forties, last took a biology class two years ago; he had completed anatomy and physiology 1 and 2, nutrition, current issues in biology and microbiology already at the college. Alex was on health professions path and was looking to work as a physician's assistant or in medical radiography. He rated his comfort level with evolution at a 3 and his belief selection was number two. He received a 100% on the instructor generated exam. His

CINS scores improved from 35 to 55 and his Darwinian components were stable at 2 from the pretest to the posttest.

John was interested in becoming a chiropractor and last took a college science course, Human Biology, the prior semester. He was completing prerequisites in the hope of transferring to another institution. He rated his comfort level with evolution at a 3 and his belief selection was a two. He did very well on the evolution exam – scoring a 96%. His CINS scores increased from 50 to 65 and his Darwinian components went from 0 to 2.

The interview population ranged in age from the early twenties to the early forties and included four students interested in the medical field, three math and science majors, and four students in non science fields. Five students identified their beliefs in evolution as humans evolving over millions of years without God in the process, three students indicated that humans were created by God 10,000 years ago, and three believed humans had evolved over millions of years with God guiding the process. When asked in the interviews if their belief in evolution was reflected by their answers to this question, all the students indicated that was the case.

The researcher first asked the students what type of learning environment they preferred. The researcher wanted to see if there appeared to be a preference with students in having lectures, discussions, hands on activities, or some other format. Student responses to this question clearly show a major preference, a mixture of hands on activities and lectures (Table 15). Many of the students felt that these activities gave them the opportunity to make greater connections to the lecture based material. Some of the students also indicated that it depended on the type of material that they were covering.

Table 15. Student learning environment preferences

Student	***Code***	***Student Response***
Mark	Hands on/depends	It all depends on the class. Science class with the way that Joel has been teaching it, that's actually how I learn. So I like the power points and then – because I actually learned a lot more in biology this semester than I've ever learned in science.
Jill	Discussions/mix	Discussions, definitely, yeah.
Kim	Hands on	I have to have hands on to keep my attention.
Alissa	Hands on	Yeah, I definitely like hands-on because I'm going into nursing and stuff.
Alex	Hands on/mix	I think there should be a little bit of mix, lecture and hands-on.
Bethany	Discussion/hands on	Discussions. Hands on is easier to do it. It makes me remember it, like the diagram we did for the DNA, like I remember all the pieces to the DNA easier.
Helen	Hands on/depends	I like a lot of visual things like examples and comparing something technical to something, you know, that I could relate to it in real life. It helps me remember things and helps things register. It depends on the class. If it's a subject that I excel in, then lecture is fine, but if it's something that it's hard for me to understand like math or science, then I would be more like hands on or group activity type stuff.
Dawn	Hands on	I like hands-on stuff I think a little bit more. That way I can relate it to something else and understand it a little bit better.
Janet	Discussion/hands on	Discussion is always good. Hands on is always good. You need a lecture. I mean who doesn't prefer to just have a discussion and hands on? But you need to have a lecture. I'm a hands-on.
Sharon	Hands on/mix	I like taking a little bit more of the hands on stuff. I think that that works a lot better for me. I would rather do both. I would rather have a lecture and then do something hands on, I mean, because then it brings it all together.
John	Hands on/mix	Probably lecture and hands on

In addition to the learning environment the researcher wanted to determine students' views on various aspects of evolution and science. A common criticism of evolution is that it is "just a theory". This reflects an inaccurate view of theories in science and their standing in the scientific community. One of the main components of NOS is the understanding of theories and laws and the distinction between the two concepts in science (Lederman, 2002). Typically individuals incorrectly view laws as more certain or proven, while theories are not proven and once proven, lead to laws. This was reflected in the responses on the VNOS-C pretests. The researcher decided to ask students what their response would be if someone came up to them and said "evolution is just a theory." The intention was to discern if they had an accurate view of the standing of theory in science.

Table 16. Student reaction to phrase "evolution is just a theory"

Student	Code	Student Response
Mark	Theory accurate	It is a theory. That's all science – there is no really factual – well, there is facts, but theories can't really be proven because it's just a theory.
Jill	Theory accurate	It's not just a theory, I think. It's been tested, and it's not refuted by any science, I don't think. I mean I guess it is a theory, but – Well, people say a theory is just a thought, and evolution is not just a thought. It happened.
Kim	Theory accurate	Now that I know, I would say that a theory is based on a lot of actual data and it's believed to be true unless it's proven wrong eventually. A theory is pretty strong term in science.
Alissa	Theory accurate	Oh, wow. She taught us this one. That it's not just a theory. Theories have a ton of evidence to support them, and, I mean, I've said that before too, you know, it's just a theory, and it really is a lot more than what, like, the public makes it out to be.
Alex	Theory accurate	Now, from what I knew and what I've learned, evolution is a theory, but it's backed up by a lot of data and a lot of facts about it, and it's a very believable theory, and something, obviously, did happen.
Bethany	Theory inaccurate	It's your own opinion. Everyone's their own individual; they can do what they want to. Like I had her (a girl she works with)stop the conversation, like I interrupted and I just changed the whole conversation because she just – like someone else was, they were real religious, and she just tore them apart saying, "There is no God, there's none of this, there's none of that." I was like, "How do you know?" I was like, "You can't prove that." Like scientists have never proved that.
Helen	Theory accurate	Okay. Well, then you have to think of the definition of theory, which for some reason I can't think of the exact definition, but it can't be proven, but there is strong evidence to show that it is a very strong possibly that it happened. If there's evidence leading to it.
Dawn	Theory accurate	There is no such thing as just a theory. It's been proven – not proven, but there's a lot of data to support it, and until it's proven otherwise, you can't really say it's just a theory.

Janet	Theory inaccurate	Well, religion is just a theory. There's no – you can't argue it. If you sit down with someone that talks religious, you're not going to change their mind and he's not going to change a scientist's. There has to be an agreement that cells evolve.
Mark	Theory accurate	I would say that it's not just a theory. I would say that it's seen every day, that it's not just a fluke, and I think I would just follow the **evidence** and try to explain that. And I have.
John	Theory inaccurate	It's not a law. I would say everybody's entitled to their own thing. It's not worth killing each other over.

Eight students (7 from the inquiry class and one from the traditional class) described theories accurately when discussing their reaction to the phrase "evolution is just a theory". Five students accurately described the NOS aspect that theories are supported by data and evidence. The difference between definitions of a theory in their general sense and what they mean in science is thought to be a factor in individuals understanding of evolution. Jill, in response to the question, said "Well, people say a theory is just a thought, and evolution is not just a thought. It happened."

A lack of understanding of the scientific standing of evolution and religious beliefs are commonly cited as barriers in the understanding and acceptance of evolution (Allmon, 2011). The researcher tried to determine what students viewed as a block to acceptance of evolution. Acceptance of evolution differs between the American public and scientists in the United States (NSES, 2012). This difference may be a result of knowledge of science and evolution, as well as religious views. The researcher asked students the same basic question in their interviews, which compared scientists' acceptance of evolution and the American public's acceptance of evolution, their reactions are found in table (17).

> "Okay. So is it – now, evolution if you look at research – surveys and stuff – in the United States about 99 percent of scientists accept the process of evolution has occurred. And if you look at surveys of people in the United States, just a general public, we have a 40 percent, 45 percent accept evolution. Why do you think there's such a discrepancy?"

Table 17. Reactions to differences between scientists' and public's acceptance of evolution

Student	Code	Response
Mark	Religion/Beliefs	Well, because religion – creation, that's how people feel that we were made from God.
Jill	Religion/Beliefs	I don't think that they understand that evolution is not a belief… It goes back to the whole religion, creationism versus evolution. People have their religious beliefs, and they bring that into evolution, and they just don't believe that it could have ever happened because of their own religious beliefs.
Kim	Religion/Beliefs	They like the idea of scientific evidence. They may be going for religious belief because they tend to not support **it** for some reason
Alissa	Religion/Beliefs	Just because of all the different religion and different ideas, different cultures, everything like that. Everyone believes something different, and if they were raised to believe a certain way they might not be so easy to change their mind even if they have all the evidence in front of them.
Alex	Religion/Beliefs	But again, that's my opinion, and, you know, they might be a little too self righteous to understand that two things could happen, and faith can be important for somebody to survive, and I would never knock anybody about that, but also facts and data and information that is there, it can't be overlooked. And I guess to answer the question, I think some people are persuaded by the wrong things, and I think if somebody had time to educate everybody and they were open to the education, I think that the view would be there.
Bethany	Religion/Beliefs	Because – like my father's older, he's 55. So it's probably just the younger crowd who somewhat accept it or accepts it fully, as you know the fact of life or whatever. But like the older crowd, they were raised more Christian beliefs because what was it, back in the '70s everybody had at least a Bible in their living room on the table. And today I think the statistic's what, like maybe 2 percent of the country or something?
Helen	Education	Probably because scientists are more educated on it. I think that when people think of evolution they just think that we evolved from apes and then that's all they think. I don't think that they understand unless they are educated enough to know exactly what evolution is.
Dawn	Religion/Beliefs	Different beliefs I think some people are stubborn and will just stick to their beliefs.
Janet	Education	Because they don't know. I didn't know. I was like oh, gee, this evolution thing. My sister and I argue a lot about it all the time. I'm like when you're looking at the whole theory, then it's like okay, it's not just gorillas. It's why do we still have whales? What if everybody came from the water?
Sharon	Religion/Beliefs	I'll just take Christianity because that seems to be, since we're here, the huge thing where people don't want their children to go to public schools because they don't want them to learn about evolution.
John	Religion/Beliefs	Yeah, wholesome American. God fearin', in God we trust. I think it's all in how you're brought up.

Nine of the 11 students felt that religion and beliefs were the reason why there was a difference in scientists' views and the public's views about evolution. Two students thought that a difference in knowledge (scientists being educated or the public not knowing) could account for the separation between scientists' acceptance and the general public. Although this separation appears to be the results of beliefs, student responses to the next interview question appears to contradict this in a way.

To explore students' own views on the issue of religious beliefs and evolution, the researcher asked students if individuals could accept evolution and believe in God at the same time. The responses are shown in table (18) and reveal a consistent pattern.

Table 18. Student reaction to acceptance of both evolution and belief in God

Student	***Code***	***Response***
Mark	Accept evolution and believe	It just depends on how your belief in God is.
Jill	Can't accept evolution and believe evolution	I think you could accept both if you wanted to. I mean I guess if you have this belief that there's a God out there that created – well, I mean I don't know. I think if you're religious, you're going to believe that God created earth and all beings, and if you believe in evolution, that's just not the case. I think it's separate.
Kim	Accept evolution and believe	Yes. Definitely.
Alissa	Accept evolution and believe	Yeah. I don't know. Maybe they could think God put the earth here, and then everything evolved after that or I'm sure there's many ways they can put them together and stuff like that.
Alex	Accept evolution and believe	Well, I believe – yes. I mean, I can only speak for myself and my family in a sense, people that I know, but, yes, I believe evolution did happen, and I also have my own faith in a sense, and there's a happy medium. But a little of this might come with – I don't want to use the term education level, but it sometimes would happen, and it doesn't mean people who just go to church are not educated, but sometimes they tend to be maybe a little naive to some facts, but I do believe that there's a happy medium.
Bethany	Accept evolution and believe	It really depends on the person, because if they're very – like a born-again Christian, probably not, because then they won't even – like back in what the '20s or '30s when they did that thing down in Tennessee, the only reason why evolution won is because like the Christian man, he wouldn't even look at any of the material and he kept saying, "I don't believe it, I don't believe it." And stuff like that, and it – do you get what I mean? Like some people it just

		depends on what people want to believe or what they choose not to.
Helen	Accept evolution and believe	Yeah. Well, I do. I think it's possible.
Dawn	Accept evolution and believe	Yeah. It depends on which religion, though, I would assume. Scientologists would definitely think otherwise on things. I would, I'm sure. They probably think aliens were the reason why they did it or something.
Janet	Accept evolution and believe	I think I can. Because I know this is a very touchy subject, but no one knows. Because they don't know. I didn't know. I was like oh, gee, this evolution thing. My sister and I argue a lot about it all the time.
Sharon	Accept evolution and believe	So I think that you can have both. You can have a belief system based on God and you can have evolution. I mean they're two totally different things. One's science and one's a –
John	Accept evolution and believe	Yeah, to a certain point. A little of both worlds.

Ten of the 11 students thought an individual can accept evolution and believe in God. The student who did not explained that if one believed one or the other they would not be inclined to believe the other. She initially stated that one could accept evolution and believe in God before adding the either/or exclusion. Students specified acceptance often depends on the person and their beliefs. One could view these results as contradictory to the prior question, since the majority of students felt that the cause of the differences between the American public's views on evolution and scientists' views was due to religion. Students in this case felt that it depended on the individual and their own beliefs, as well as education.

The researcher also chose to explore students' perceptions of the inquiry-based activities, in particular the Galapagos Finch program due to its focus on natural selection. Students were asked what they thought of the activity and their responses are displayed in Table (19).

Table 19. Student reactions to the Galapagos Finch Program

Student	*Reaction to Finch program*
Mark	Yeah. It was different because, I mean, you don't really learn that way, usually it's just straight in the classroom learning about it, but we actually got to do the research and stuff. I mean, seriously, but that's the most stuff I remember from the class, that I looked up the finches and the evolution stuff.
Janet	Oh, that was tremendous. Well, the research part of it, it's just like with anything. You're doing a research project; you're going to know it inside and out. Putting it into the presentation, I thought that was good. In the beginning, I was like oh, what the hell is this? You know what I mean? But I'll tell you what. I can tell you a lot about those finches. So it did work.
Debra	I liked that.
Alissa	Yeah. I like some more hands-on.
Sharon	I liked it, one, because you could do it by yourself or with another partner so I think that you learned a lot more, plus it tied it all together. Like I never even knew that that took place, and I had a lot of different biology courses and I never really had done well in them.
Helen	Yeah, I think so. And that finch activity that we did, the evolution test was my highest test grade, and basically, I didn't really do well on the test, but because we worked so long with the finch activity, it really helped me to understand evolution a lot and I did really good on the test because of it.
Bethany	I actually liked that for some reason. I don't know; like I came in and I spent a lot more time on it than most people. Remember, I had trouble? And I came in for like three or four hours, and I didn't know I spent that time, and I just went through it all and just did it. I don't know – I like activities like that. I'm more hands-on like than my brother. That's the only test I passed.
Jill	I actually liked it. It was pretty decent. I think I learned a lot from that lab.
Kim	I felt like that was one of the areas that I – I mean I didn't excel in the class at all, but I felt that was one of the ones I retained better as we had to do so much hands on research ourselves.
	Yeah. I thought that it was pretty neat.

All nine students liked and valued the Galapagos Finch activity and three of the students referred to their test scores (Mark, Helen, Bethany) as evidence that the activity helped. Eight students felt they learned a lot or retained more information as a result of the finch activity. Students were also shown the other activities completed in the traditional class, and they were asked their preference of learning environments. Some students found the exercise difficult since they had not done both, but the majority of students felt that they would prefer to do the Galapagos Finch program over the lab simulating bird beaks. For instance, Bethany thought that the finch activity was valuable since it dealt with actual data.

> Bethany: That one just seems like – well, there's – like we got information from the Galapagos Islands that was real actual information. We're just basically guessing on it. Like we had more aware of what the beaks could actually do compared to what tools could do. It depends on someone's strength; it doesn't depend on what a tool can do, or whatever. And it's just a certain individual; it's not a bird, so you're not really coming up with the exact data –
>
> Yeah, you use real data, and that was actual data. That wouldn't really – I don't know. That just seems dumb to me – sorry.
>
> (Post interview, Lines 150-156 and 166,167, 12/08/07)

Student case: Bethany

Bethany was a very interesting case since she was clear about her own beliefs and her views on evolution. Bethany was an accounting major in her early 20s. Her scores on both evolution assessments had increased from the pretest to the posttest, and she scored a 74% on the instructor's exam. The evolution exam was the only instructor provided exam that she passed during the semester. The researcher had gotten to know her a little better since she had spent a longer period of time on the Galapagos Finch program than other students in the computer lab. She appeared to be hard working and was often focused on the tasks provided to her. The researcher also became more aware of her due to her response on the cheetah question. Bethany indicated in her response she did not believe humans evolved. The researcher was interested in exploring the interplay between her beliefs and the interventions used. Despite her religious views she demonstrated a robust understanding of the theory of natural selection on the cheetah question post results; her answer score went from zero on the pretest to three on the posttest.

> I believe in animals evolving and changing their -organisms and cells and mutations but not as drastic as humans once being apes
>
> Pretest

> If the cheetahs could only run 20 miles per. At first there(sic) prey probably ran slower or maybe only the faster cheetahs survived by catching prey and the offspring of cheetahs inherited the speed instead of other qualities of there ancestors.
>
> Posttest

Beliefs are commonly cited as a possible cause for a hurdle in acceptance and understanding of evolution. However, Bethany did not appear to have issues with understanding the scientific concept of evolution and natural selection. She described her views on religion and her religious upbringing at length in her interview. Her interview was the longest of the eleven, lasting 61 minutes. The researcher first asked her to confirm her Gallup poll response during the interview.

> Researcher: And we asked which of the following statements comes closest to your views on the origin and development of human beings? And you picked three, God created human beings pretty much in their present form at one time within the last 10,000 years or so.
>
> Interviewee: 10,000 years – I'd say it was more than that. If you actually read the Bible there's parts and times where, you know, stuff has happened – but I don't know; like that's what I believe, and it's like hard to know and all that.
>
> Researcher: So would this still pretty much describe what you feel?
>
> Interviewee: Yeah.
>
> (Lines 360-373, 12/08/07)

Bethany came from a deeply religious family and she often mentioned her father and his views on evolution during the interview. She felt the way an individual was raised definitely influenced their outlook. She identifies herself as having creationist views during the interview, yet it doesn't appear to block her understanding of evolution, as this sequence describes.

> Interviewee: It's somebody's beliefs that's gonna tear someone up, like in how they were raised and stuff. Like I still have – I can understand the concept of evolution, but I don't believe it to be all factual of what scientists believe, because I'm more creationist compared to anything. Same with my father, but my father, he'll look at evolution and he won't even look at it.
>
> Researcher: So you can understand the concepts.
>
> Interviewee: Yeah.
>
> Researcher: And can you kind of see that organisms, species can change over time?
>
> Interviewee: Yeah.
>
> (Lines 227-241, 12/08/07)

Since she described herself as having more creationist views, the researcher decided to ask her whether she subscribed to a literal interpretation of the bible. Young earth creationists are predominantly literalists when referring to the Bible. Bethany confirms this in her interview response.

> Researcher: I don't recall; it's been a while. And kind of on that note, do you take a literal interpretation of the Bible?
>
> Interviewee: Yes.
>
> Researcher: You do. It's literal as the book.
>
> Interviewee: Yep; that's how I was raised.
>
> Researcher: Okay.

Interviewee: I'll raise my daughter the same.

(Lines 486-497, 12/08/07)

Thus Bethany's upbringing has not only influenced her it has also influenced her daughter as well. Her father appears to have had a strong influence on her religious beliefs and she mentions him six times in the interview. The first time he is mentioned Bethany responds to a question asked by the researcher about how individuals presented with the same information can come up with different ideas. Bethany states "because they think differently on a certain subject, like if you give my father evolution he'd tear it apart" (Bethany, 12/07). She implies that her father may accept evolution on a microevolutionary level, but not on macroevolution scale (one species into another).

> Interviewee: I don't know; that's how I was raised. But my father, he, I mean he won't like listen to anything evolution. He would just be like so angry. He's like, "Yeah, everything changes everything," you know, that's how he starts it, like when I talk to him about stuff trying to study or stuff, and –
>
> Researcher: So he accepts change in organisms?
>
> Interviewee: Yeah, but he doesn't think that's considered evolution.
>
> (Lines 545-553, 12/08/07)

A little later Bethany in the interview briefly talks about her father's views on speciation and change in science "he thinks a lion and a tiger and a species – he doesn't really know about the huge difference, because – I don't know. My father's very smart for his age, but like the way science is he says it changes constantly" (Bethany, Lines 562-565, 12/07). While her father is certainly a strong influence on her, Bethany is able to articulate an understanding of evolution throughout the research study and in the interview.

In addition to her upbringing, Bethany brought up how she felt when she had been presented with evolution in high school and her reaction to it. To her the concept had been forced on her and she got angry at the situation. She indicates that it may have had something to do with her mental development, in that when individuals are younger they "can't think as straightforward as it probably is now when you're older" (Bethany, Lines 1072-1074, 12/07). The researcher mentioned that he felt that individuals could have beliefs and understand evolution. This elicited a response from Bethany that included references to her school experiences.

> Researcher: And I try to – I want people to kinda – I personally don't think you have to sacrifice what you believe in terms of religion to actually understand evolution. I think you can have both of those at the same time.
>
> Interviewee: You say that, but I remember like in high school like they kinda pushed it out there saying we came from apes. You know, like they kinda just pushed it right out there, so when I heard evolution I just really didn't care, it just pushed the kids away. I was taught previous, and when you're younger your mind can't think as straightforward as it probably is now when you're older, and you usually – like I got angry with it. I just did what they wanted me to do just to get it done, but this one was more interesting because it wasn't like just pushing it on you saying hey, this is all you can believe. This is it, how it's done.
>
> (Lines 1065-1078, 12/08/07)

Later in the interview the researcher asks if evolution should be taught in schools and Bethany said "I think people should have a choice." (Bethany, 12/08/07). The researcher asks if individuals should have a choice in science classes and she brings up her own educational experiences again.

> Interviewee: Like I'd say in college it should be more mandatory than it is in high school, because like when I was in high school – I was probably 12 at the time, and I got very distraught with it. And like if my – I'd say like when you're that young, because your parents

> still have custody of you and everything at the time that it's up to your parents. It shouldn't be up to, you know, the school to make the decisions. It should be on your beliefs, on how you're raised. I think they should have two different schools you know, so one is that state and one is the other.
>
> (Lines 506-514, 12/08/07)

Bethany makes the connection to one's upbringing as well as the aspect of who decides what an individual is exposed to. She reiterates the conflict and discomfort that evolution created for her. Based on her views, it appears that she would advocate for separate classes where evolution is and is not taught.

Regardless of these views, the format of the evolution instructional sequence definitely appeared to help in Bethany's progression towards a greater understanding and acceptance of evolution – both based on her test results and her interview responses. As opposed to making it a choice between competing belief sets, the program allowed her to explore how evolution operated. She also seemed to be more willing to consider the origins of humans and the general process of evolution and natural selection as it related to the origins of humans.

> It's not like that. It's just showing that changes occur, and you know different species or within a group of the same animals that were split or something. Not because apes were getting credit. I learned to like that book; we all can read from it.
>
> (Lines 1080-1083, 12/08/07)

Since the main goal of the research study was to determine if inquiry-based techniques were more effective in helping students the researcher asked her if she understood the concepts. Bethany incorporated the finches into her explanation as well as information about changes that occur in humans.

> Researcher: Do you feel after having done this you have a better idea about how the process of natural selection occurs in a population?

Interviewee: Yeah. Like the beaks, or like humans like she was saying if I have – if you were moving to a new area you have the sickle cell on you, but you might not have sickle cell itself, but you carry the gene to have it. There's someone – I don't know if the person's died yet or not. I think there's a person out in Africa who was immune to AIDS. She was a prostitute, and she'd give it to everybody, but she couldn't die from it.

(Lines 1031-1041, 12/08/07)

Finally the researcher attempted to establish whether or not Bethany was open to the theory of evolution. One can note that Bethany modified the phrasing so that she was answering whether or not things change. Despite this, it does not appear to be a strong indication of her dissatisfaction with evolution but rather a clarification of the definition of the terminology.

Researcher: So do you think you're a little more open to evolutionary ideas now than you were before you started with it?

Interviewee: You mean everything changes?

Researcher: Changes, or just –

Interviewee: Sure.

(Lines 924 -931, 12/08/07)

Student case: Mark

Mark originally participated in the inquiry-based activities and returned to the college to complete more course work after his first degree. The researcher stumbled across Mark at the college after four years had passed since the study. Mark agreed to be interviewed to see whether or not the inquiry-based activities had an impact on his understanding of evolution after the long time frame. In November 2011 Mark was interviewed concerning the Biol 103 course he had taken. The researcher started the interview by asking Mark what he remembered from taking the class.

> Researcher: Do you remember anything from Biol 103?
>
> Mark: I remember going to the computer lab a lot. For the bird thing.
>
> Researcher: So you do remember that. Do you remember other stuff from the class?
>
> Mark: No that's about it, that really popped out in my mind.
>
> Researcher: Do you remember what the point of that thing was?
>
> Mark: Wasn't it like different ways to learn …I remember we had to research the birds. But you did lecture in the other class I know that.
>
> Researcher: Do think in general that was a decent activity?
>
> Mark: I prefer learning that way because I hate lecture. This was how long ago that I did that class and I actually remembered some of that stuff. And I'm not a science person. I took what I had to for science and that is pretty much the only thing that I remember in taking any of her classes.
>
> (Lines 1-20, 11/9/2011)

It is clearly evident the learning strategies had an impact on Mark, since this and the nature of science activities were the only things he remembered from the course. In fact, the very first thing he mentions is the birds and the program they worked on. Mark had not taken science since a spring semester section of Biol 104 in 2008. Biol 104 is the second course in the sequence introductory biology sequence at Cayuga Community College. Biol 104 does not deal with evolutionary principles and they are rarely discussed in class. When Mark was asked to define evolution, he used the birds, their beaks, and the environment to briefly explain the process. Mark self identifies as someone who is not a "science person." Mark only ended up with a C in the course; therefore it is important to stress these teaching strategies had a positive impact on a student who may not have been as strong as other individuals.

Summary of interviews

Based on the interviews a number of interesting patterns emerged. Despite the three month lag time, many of the students in the inquiry class remembered the cube and tracks activities they participated in at the start of the semester. All of the students preferred learning environments that included hands-on activities. Students were able to accurately describe theories in the majority of cases and articulated that theories are "it" in science. They easily tackled the often phrased rebuttal to evolution "it's just a theory" by stating that is what science is– just theories. A number of students demonstrated an understanding of the role data and evidence play in supporting theories. While the majority of students felt individuals can accept evolution and believe in God, they thought the main cause for the differences in acceptance between various groups to be a result of religious beliefs. Students thought the decision to accept evolution often depends on the individual and how their beliefs are. Students overwhelmingly supported the Galapagos Finch activity and often attributed their understanding of evolution to participation in the program. Students were more likely to choose the inquiry-based activities over the activities conducted in the traditional class. Finally, the inquiry-based activities appear to have translated into long term impacts on student learning, as Mark demonstrates.

Instructor interviews

In addition to completing pre and post interviews, the researcher asked the instructor to write down her thoughts about each of the activities and the overall opinion of the instructional process. While the focus of the study was student learning the instructor's ability and willingness to teach through inquiry-based activities is an important facet of the shift to inquiry-based instruction.

Instructor's views on science

Discussing and conveying components of NOS was an essential part of the research study, as it may impact an individual's understanding of evolution. The instructor obviously knew a great deal about science, but had not heard it referred to as "nature of science." She briefly discusses this in her pre interview.

> Researcher: Had you heard about the nature of science?
>
> Instructor: Previous to this? I never knew it was called that. I knew things about it but I never knew it was called that. I teach my students that science the information that we identify is tentative. I taught aspects of it but I never called the Nature of science. I do compare it to other disciplines and I just never have called it the nature of science.
>
> (Pre interview, Lines 22-26, 8/04/07)

Many of the main components of NOS were not directly taught by the instructor prior to the research study. The instructor's own views of science appeared to change as a result of the study which she addressed in her post write up.

> I now have a better understanding of the nature of science, and a better understanding of how to relay that to my students. I have refocused my attention to quality versus quantity.
>
> (Post write up, Lines 78-80, 01/12/07)
>
> I think that was an important point for students to understand – that there is a subjective component to science and that interpretation is literally "in the eye of the beholder".
>
> (Post write up, Lines 39-40, 01/12/07)

She was more focused view on the subjective component of science, one of the main aspects of NOS.

Instructor understanding and views of inquiry

The ultimate aim of this research study is to investigate the effectiveness of inquiry-based instruction as a more effective method in helping students understand evolutionary concepts than traditional, lecture based approaches. To elicit a change in instruction, evidence has to be presented that will cause a shift in an individual. One of the challenges of the study was the instructor's limited use of inquiry-based activities and her understanding of inquiry. The instructor initially had described her understanding of inquiry as limited in the pre interview

> Researcher: How would you describe your understanding of inquiry before today?
>
> Instructor: Like on a scale from one to ten?
>
> Researcher: Yes
>
> Instructor: I would say I was a two, maybe a three.
>
> (Pre interview, Lines 1-4, 8/04/07)

The research study appeared to change her understanding of inquiry in a positive manner, as demonstrated by her post interview response.

> Researcher: Do you feel you understand inquiry better?
>
> Instructor: Yes. On a scale from one to ten I am at least a five or six now…. I'll say seven.
>
> (Post Interview, Lines 160-161, 12/20/07)

It appears that the instructor shifted to a better understanding of inquiry-based on the hypothetical scale she introduced (from 2 or 3 to a 7). This understanding of inquiry may translate into more willingness to try new activities in the course.

Although the instructor described her instructional style as “traditional and efficient”, she demonstrated interest in slightly modifying her instructional style in the future. She was clear, however, in not wanting to try anything new the next semester.

> Researcher: Would you be open to doing more inquiry-based activities?
>
> Instructor: Yeah - I would be open to it. I think it exposes my weakness though. I would need to introduce it slowly into my repertoire of lectures because it exposes weaknesses that I have that reflect on students' learning. I mean I can safely say not one student learned how to write a paper because it was not something - I didn't spend enough prepping for.
>
> Researcher: So you would work it in slowly if you do?
>
> Instructor: Yeah - I am not going to trying anything new next semester but I might incorporate the things we used, but I am not going to try anything new.
> (Post interview, Lines 162-169, 12/20/07)

It is interesting to note that she did not want to expose her “weaknesses” since that could “reflect on students’ learning.” Clearly the willingness to implement inquiry-based instruction was dependent on whether it fit into her comfort zone.

The instructor clearly continued to feel apprehension about teaching through inquiry and was only willing to continue with activities that she considered worthwhile and effective. She felt that one’s instructional style and teaching ability had a significant amount to do with the success of the inquiry-based activities. The instructor felt her own teaching style did not match that of the openness of an inquiry-based classroom. She described a number of hurdles that she faced while engaging students in inquiry-based activities.

> Instructor: You have to have control over the whole class, who's talking off to the side. You have a lot of little things going on at once. Plus you have to try to get them to say answers - like with that footprint thing. You always have one or two students shouting them out. I feel like you really have to be somewhat experienced to really have good control over getting everyone to be engaged. If that is not your strong feature of teaching then half the class is going to be excluded. Especially the one's who are really quiet - I mean they will still get something from just listening. Even when we broke up into groups, people just sat there and looked at the boxes, it's like lab; it is very difficult to get them engaged in the activities.
>
> (Post interview, Lines 69-77, 12/20/07)

Instructor apprehension

As previously stated, the instructor had not completed any education course work and had not previously heard of the nature of science (NOS). She was not familiar with the terminology, as indicated by her pre interview. The instructor also wrote about her concerns in her post write up:

> I was very nervous about some of activities and topics I had to cover. Some of the topics I had not previously covered in my introductory biology courses and I felt as though I would not be able to field questions students may have. For example, I tell students that biology is based on data obtained from observations and inferences; however I do not devote time to activities that specifically address these tenets.
>
> (Post write up, Lines 2-6, 01/12/07)

The instructor expressed concern about her ability to guide students through the activities and her ability to emphasize the point of the activities.

> One of the major reservations I had with the footprint activity was that I did not feel as though I would be able to guide the students through it so that they would understand the purpose of the activity. I was not sure that I could confidently emphasize the point of the activity throughout each step so as to achieve the learning outcomes. I am someone who likes/needs a certain level of preparation. I felt this was especially important for the footprint activity because this was the

> first “inquiry-based” activity that the students had (and also because there are variations of the activity that may have had a greater impact on student learning outcomes).
>
> (Post write up, Lines 9-17, 01/12/07)

A common theme that emerged in her post interview was the apprehension that she felt over teaching through inquiry and about the nature of science.

> Researcher: What were your thoughts on the activities?
>
> Instructor: I was very nervous; I don't know if students got what they should have out of them because I didn't feel very prepared.
>
> I mean, some things you didn't need to prepare for - but when you are brand new going into it. I really liked some of them - like the box activity I will probably always use. I thought that was a great idea even if the students didn't get it. I think the point is well taken - sometimes you just never know. Science, information is not always known. I liked some of them and others of them - it was a lot of stress.
>
> (Post interview, Lines 1-7, 12/20/07)

Her apprehension and nervousness over teaching in a different style was not the only concern that she expressed about the instructional sequence. She brought up an often mentioned concern about inquiry instruction - the perceived amount of time that had to be devoted to inquiry instruction:

> Instructor: As much as people who are such advocates and proponents of inquiry-based education it takes probably double if not at least two thirds more.
>
> (Post interview, Lines 37-38, 12/20/07)
>
> Instructor: We dedicated a lot of time to it - precious time that I could have been in class going over terminology.
>
> Researcher: So going back to the inquiry thing - why did it take more time?

> Instructor: I had to prep, I had to be ready to field questions, and I wasn't. I mean it just seems really stressful. It is difficult to engage students.
>
> (Post interview, lines 94-95; Lines 68-70, 12/20/07)

Instructors at many levels often do not teach through inquiry due to comfort level with the topic and the perceived time commitment (Trautman et al., 2004). The instructor repeatedly cited time as a hurdle in implementing inquiry-based instruction and she commented on this in her post write up:

> The amount of preparation work was obviously more than a traditional lecture, but the rewards were greater – and of course I can find a balance that suits my outcomes and available time commitment.
>
> (Post write up, Lines 83-86, 01/12/07)

The instructor also identified time as an issue when students were learning about the terminology used in discussing evolution and natural selection. The inquiry-based class had a lower exam mean (73.7) than the traditional class (77.8).

> Researcher: Do you think that doing that unit was worth if your exam scores were about three points lower?
>
> Instructor: I do, I know why they were lower, but yes I do.
>
> Researcher: Why were they lower?
>
> Instructor: They were lower because there was so much specific terminology that they only had one day to learn. I mean you could understand the process of it but if you've never heard the terms artificial selection or convergent evolution or analagous structures - they didn't have nearly as much time to learn as the other class did. So I do I just, you need to take more time, instructors who say equal time it's not true. As much as people who are such advocates and proponents of inquiry-based education it takes probably double if not at least two thirds more.
>
> (Post Interview, Lines 29-37, 12/20/07)

Despite her nervousness and concerns about time and specific terminology covered, the instructor found the activities to be worthwhile for her students and herself.

> I enjoyed incorporating new activities into my classes. I feel as though students benefited from my inclusion of various teaching styles. Equally important, I feel like I benefited from this experience. I now have a better understanding of the nature of science, and a better understanding of how to relay that to my students.
> (Post write up, Lines 76-79, 01/12/07)

While she indicated a number of issues with the instructional process (preparation time, time of the activities, lack of familiarity with the material, and lack of coverage of the terminology) she had a number of positive impressions of her students and the activities as a result of the research.

Thoughts on the use of the inquiry-based activities and their role in instruction

Finch activity response

The instructor was asked about the effectiveness of the instructional activities that she used. When discussing the Galapagos finch software program she mentioned a number of other qualities of students besides an understanding of evolutionary processes.

> Researcher: So you saw some benefits for your students?
>
> Instructor: Yes
>
> Researcher: Such as?
>
> Instructor: I think they learned how to analyze data. I could see other qualities that they had versus just memorizing for tests; I could see where their other strengths were. Analyzing data, following directions, presenting on it.
> (Post interview, Lines 22-27, 12/20/07)

Before the research study the instructor's major grades had only been five tests distributed equally throughout the semester. The inquiry-based activities afforded her the formatively assess other characteristics of her students. In particular, she described how students who were not as academically strong became equivalent to "A" students during the presentations.

> Overall I was impressed by the students' response. Many of them quickly delved into the activity, even though they had never analyzed scientific data before. Students whom I previously did not feel were very strong academically (or who performed poorly on tests) were asking questions, taking notes, and giving presentations that were on par with "A" students. Although many students came up with the same conclusions, not everyone's was exactly the same, even though they were looking at exactly the same data.
>
> (Post write up, Lines 33-39, 01/12/07)

Essential components of inquiry include the ability to analyze data and communicate those findings to an audience of other members of the scientific community (NRC, 1996; 2000). Based on her own perceptions of her students, the inquiry-based activities appeared to be effective in conveying important aspects of NOS to students.

Goldfish activity response

Of all the new activities used in the course the instructor appeared to be most emphatic about her appreciation for the goldfish activity. This is surprising since it was an open inquiry activity that one would have expected would have to have elicited a great deal of apprehension in the instructor.

> Researcher: How did you like the goldfish activity?
>
> Instructor: I loved that activity. Even though they had the worst results on that. Had I spent time - I know what I am going to do next time for that activity. Everybody is going to have a journal article to summarize, then they are going to have a fake journal article that they have to write where they put sentences where they go in the right headings. So they know how to write an article. I thought that was great, because yet again no only did that class - did both classes do that?
>
> Researcher: Just the inquiry class.
>
> Instructor: Not only did they get to analyze data, present a presentation on it, but then I get to see that they can come up with an experiment on their own. I would

> do that right in the beginning of the semester. I think it also teaches them the scientific method - I know you guys say there is no scientific method - it teaches them how to collect data. I mean after they did that finch activity they should certainly know that everything is data - everything is. I think that was a great idea, especially since in my class I never have them do an actual journal paper and they should. It's important to know what goes into an introduction and the materials and methods – that's important to know.
>
> (Post Interview, Lines 118-131, 12/20/07)

Her positive views of this activity were also conveyed in her post write up. From her response it is clear that participation in the inquiry-based activities had an impact on her views on teaching and learning about science.

> I do not require formal laboratory reports, nor do I require students to design their own experiments. I always wanted to incorporate a component that involves these activities in my courses. I thought this lab was a great way to introduce students to experimental design and scientific writing.
>
> I will definitely use that activity again – probably in the beginning of the semester so that it coincides with the scientific method and the nature of science topics.
>
> (Post write up, Lines 57-60, 66-68, 01/12/07)

<u>Instructor perceptions of students' understanding of science</u>

The instructor served as a valuable data source for her views on her students' understanding of various concepts in the course. This allowed the researcher to triangulate the data collected through assessments, videotapes, and interviews of students and the instructor. The instructor felt the inquiry-based class had a better grasp of scientific processes than the traditional class. With both of the activities used in the inquiry-based class (Galapagos Finch program and Goldfish activity) she felt that students were in involved in more scientific processes and gained various skills.

When discussing the finch activity:

> I think they learned how to analyze data. I could see other qualities that they had versus just memorizing for tests; I could see where their other strengths were. Analyzing data, following directions, presenting on it.

> I have no doubt in my mind that conceptually they understand how to analyze data better, they understand the nature of science better, they even understand the process of evolution better - I'm sure.

When discussing the goldfish activity:

> I think this activity clearly presented the role of a scientist in developing a hypothesis, designing an experiment (some students were very creative), utilizing appropriate controls (some students need help with this and many did not understand the importance of a comparison data set), collecting data (many students took poor notes and were not able to adequately substantiate their conclusions because they had very little data), and report writing.
>
> (Post write up, Lines 68-73, 01/12/07)

Instructor perceptions of students' understanding of evolution

The instructor and the researcher discussed the differences that existed between the two classes.

> I have no doubt in my mind that conceptually they understand how to analyze data better, they understand the nature of science better, they even understand the process of evolution better - I'm sure.

>
> (Post Interview, Lines 45-47, 12/20/07)

Later in her post interview she again brings up student understanding of evolution.

> Researcher: You say precious time, but the CINS showed a larger increase and higher test average than the control group.
>
> Instructor: What did I say about conceptually - there is no doubt in my mind that they understand the process of evolution better than that class. I have no doubt.
>
> (Post Interview, Lines 98-99, 12/20/07)

Instructor perceptions of students

Recognition of student inquiry abilities can often go unnoticed in classes that depend solely on exams or exams and "cookbook" style laboratories. The instructor had previously focused on exams as her major method of assessing students, which is not uncommon in undergraduate higher education settings. During the second day of the Galapagos Finch project the instructor made some comments about her students approximately 40 minutes into the class that are relevant to this issue.

> Instructor: You know, I am so glad I did this project.
>
> Researcher: Why?
>
> Instructor: You see the two girls working together in the third row? They are not doing well in the course, mainly because of their tests. But you have to see the presentation they are making – they are doing a great job. They are analyzing the data and generating graphs and pulling in all kinds of information. I wouldn't have been able to see those abilities if I was just using my tests.
>
> Field notes (October, 2007)

Without participation in this study, the instructor would have been unable to form these views about her students. Before the study she previously had assessed students using only exams. In the post interview the instructor also talked about the qualities of students that she was able to see that she had not been privy to in the past

> Researcher: Do you think the inquiry-based stuff helped your low achieving students?
>
> Instructor: Absolutely yes.
>
> Researcher: Why?
>
> Instructor: They might not be, I hate to say good test takers, because I don't believe there is such a thing. I was certainly able to see some of their strengths come out, like creativity as far as designing experiments for the goldfish. The way

> they analyzed the data, and they presented, some were very good public speakers, and again not that it's always science related they excelled in some aspects where their grades didn't show it on exams and students always request more things to earn points from. So in addition to just traditional labs they had the presentation the paper to write, an experiment to put together, so I do. I don't know what the overall averages were I would imagine that group would be higher.
>
> Post Interview

Implementation of different instructional techniques in future classes

One could argue that changing an instructor's practice is more important than a small group of students in a research study, due to the residual impact of the instructor. The goal of the study was not to change the instructor's teaching practices but rather to examine the impact of instructional practices on students' understanding of evolution. The researcher was pleased to discover that the instructor was considering modifying her future instruction after she submitted her post write up.

> I have refocused my attention to quality versus quantity. I want them to understand and retain, not memorize and regurgitate, and I think that nontraditional teaching approaches are imperative for this. I now have the mindset that 'letting them figure it out for themselves in 10 minutes' leads to better understanding than me 'telling them how it is in one in 1 minute'.
>
> (Post write up, Lines 79-83, 01/12/07)

In fact, the instructor did incorporate nature of science activities into her instruction as well as the goldfish activity into her laboratory sessions. A copy of her syllabus from fall 2011 (the most recent time she taught the course) demonstrates that she has continued to use inquiry-based activities in her instruction. One major difference from the study was that she taught the topic of evolution immediately after NOS (see Appendix H for syllabus). In the research study there was approximately one month between NOS and evolution. When asked why she made the change in a recent interview she described the impact of evolutionary theory on other topics in biology.

> It is such a unifying concept in biology that I feel it is important that students understand how differences arise in organisms as well providing them with a foundation of knowledge of how differences accumulate between and within species. It is very difficult to teach the rest of the concepts if students don't understand that we (organisms) are all related.
>
> June 9, 2011

She was also asked about the extent to which she used inquiry-based activities and if she continued to talk about the components of NOS. She did not, however, continue to use the Galapagos Finch software program or the island activity that was used in the traditional class.

> I still use the box activity, I talk about the NOS at the beginning of the course, and I do the goldfish activity as well. I don't do the finch activities because I feel that they require too much time, despite the fact that students appeared to score the same on tests. I constantly feel pressure to make sure I am covering material in my syllabus and in the master syllabus.
>
> June 9, 2011

The first PowerPoint that she presents in class includes coverage of the components of NOS (see Appendix C) and her syllabus (Appendix H). When she teaches about evolutionary concepts she also discusses the differences between theories and laws (Appendix H). Prior to the study, the instructor had not specifically covered NOS. As a result of the study she has incorporated these activities into her instructional sequence and had an open inquiry lab at the start of her laboratory instruction.

CHAPTER 5

DISCUSSION

The central question of this research study will be explored by focusing on the sub-questions, which contribute to an understanding of the main research question.

The research questions were:

> What is the effect of using inquiry-based instruction versus a traditional approach in teaching about evolutionary theory on student understanding of evolutionary concepts?

a. How was the inquiry carried out (what was the nature of the instruction)?
b. What is the influence on students' views of nature of science?
c. What is the influence on students' understandings of evolutionary concepts?

a. How was the inquiry carried out (what was the nature of the instruction)?

Implementation of the inquiry-based activities involved a negotiation between the researcher and instructor to make sure the needs of both individuals were met. The researcher wanted to incorporate as many inquiry activities as possible, while the instructor wanted to make sure that the appropriate content was covered. The researcher met with the instructor with a basic plan for the instructional sequence, but he gave the instructor numerous options in selecting the actual activities. This interaction was extremely important to the implementation of the instructional sequence since the instructor had a partial stake in its development. Using policy documents, current research literature, preliminary research findings and his prior teaching experience, the researcher designed an instructional approach that he felt would increase student understanding of evolution. One of the more influential pieces of support was the 1998 National Academy of Sciences publication, *Teaching about evolution and the nature of science.* This publication provided examples of lessons that could be used to integrate nature of science with evolution through inquiry-based activities. Tricky Tracks and the cube activity were both recommended in this document and included in the research study. *Inquiry and the national science education standards* (NRC, 2000) also provided major recommendations in designing the instructional unit, especially in the focus on the instructor and the students. Finally, the preliminary study that the researcher had been involved with (Crawford, Humphrey, and Vaccaro, 2007) also influenced the design of the instructional sequence. Instead of starting with lectures on nature of science and evolution, the researcher took a learner centered approach that elicited student ideas and preconceptions about the topics they were covering (Bransford, Brown, and Cocking, 1999).

A fundamental component of this study was the focus on the instructional process as a mechanism to elicit understanding of evolution. Although the two classes covered the same content material, the inquiry class had a number of differences from the traditional class. One of the most significant differences (besides the inquiry versus traditional approach) was the explicit discussion of nature of science right before the beginning of evolution. This decision was made based on the researcher's assumption that an understanding of NOS influences an understanding of evolution. This view is supported by research demonstrating a link between understanding NOS and understanding evolution (Rutledge and Warden, 2000; Akyol et al., 2012).

As previously mentioned, the inquiry class learned about nature of science using both lecture notes and inquiry-based activities. These two activities, the cube activity and Tricky Tracks!, were used to directly address students' views of nature of science in the inquiry class. All of the students interviewed from the inquiry class thought the activities conveyed aspects of science to them. Additionally all of the interviewed inquiry students felt that lecture alone would not have been sufficient to help them learn as much about science. Mark summed it up well by saying “I would’ve been lost because science is definitely not one of my big subjects” (Post interview). During the interviews students were more likely to remember the cube activity and believed this was a better representation of the work scientists do (discovering the unknown using observations and evidence) than a simple lecture. Although the two activities took place the very first day of class, the majority of students remembered these activities very well. Blanchard, Southerland, Osborne, Sampson, Annetta, and Granger (2010) found that students with teachers who had stronger implementation of inquiry performed better on a number of measures and had better long term retention of the material. During her interview Jill stated “I guess now looking back, I did remember that – what is was supposed to be about” (Post interview). In lecture-based courses, students rarely have the opportunity to engage in activities of this nature in a classroom setting. Helen, one student who remembered the cube activity, said:

> I’m not a science person so if someone was just standing up there talking about stuff that I just – just talking without giving examples, it just would’ve went in one ear and out the other.
>
> Post Interview

This strongly correlates with many of the students’ identified preferences for learning environments that included hands-on activities. Eight of the 9 inquiry students interviewed indicated a learning environment preference for hands-on activities to help reinforce topics they learned through lecture. The learning environment of the classroom allowed the inquiry students to interact in a manner that was not available in the traditional class. Keys and Kennedy (1999) and Crawford (1999; 2000) have described the roles of students in inquiry-based classrooms and how it varies from that of a traditional classroom. Students are not only engaged in hands-on activities, they are engaged in an active process of generating meaning from their experiences. Inquiry activities provide students with an opportunity to gain ownership over their learning

(Crawford, 1999; 2000). Inquiry is not just participation in an activity that is hands-on, it also involves opportunities to examine and interpret data.

The nature of the inquiry instruction provided students with opportunities to influence their cognitive development and they were also interacting in a social context that influenced their views of the activity. Janet mentioned some of the discussions she had with one of her colleagues in the class concerning the cube activity.

> Janet: That was something that it was because that kid – he's really smart; he seems really smart – he's like this is what's gotta be on the bottom. I'm like no because I already said okay, I already looked at them. Were there different colors also?
>
> Researcher: Yeah, there were different shades and patterns.
>
> Janet: I was like it's got to be. I was thoroughly convinced that it was going to be, like, either a gray, but then it was like either white or whatever, and he was like no because – I thought I was interacting.
>
> Post interview

Janet's own cognitive development would not have followed the same pattern had she been working alone or with another individual. Not only does the individual's own view impact learning, it is also a product of the context. The inquiry class context focused on using evidence and data to support claims made in class, which falls in line with national recommendations for science education (NRC, 1996; 2000). The traditional class did not have this focus on evidence and data as they were engaged in confirmation laboratory activities. Von Secker and Lissitz (1999) discovered that instruction that emphasized laboratory inquiry was associated with greater student achievement. Inquiry students had numerous opportunities to work in pairs and small groups unlike the traditional students. As a result, they were exposed to different ideas and viewpoints that influenced their own views on the subject matter. The quality of the interactions was also greater in the inquiry class. Rather than simply writing down answers in a laboratory manual, students had to have discussions about the data and they had to negotiate with each other to decide on their experiments. Reiser, Berland, and Kenyon, (2012) stress the importance of this "If we expect students to learn that the scientific community builds knowledge by constructing explanations and arguments, then they must experience using these practices to address questions they have identified" (p.35). Turpin and Cage (2004) and Cuevas et al. (2005) both have reported statistically significant changes in inquiry students towards a better understanding of inquiry and experiment abilities.

In addition to the use of the inquiry-based techniques to teach about nature of science the instruction in the inquiry class diverged from the traditional class when the evolution unit was started. One of the most significant differences (besides the inquiry versus traditional approach) was the explicit discussion of nature of science right before the beginning of evolution. This view is supported by research demonstrating a link between understanding NOS and understanding evolution (Rutledge and Warden, 2000; Akyol et al., 2012). Assessment of the impact of this approach actually took place through the interviews. The researcher found that all of the interviewed inquiry students thought that the discussion about nature of science right before the beginning of the evolution unit helped them understand evolution better. One rationale for this might be the increased understanding of what a theory means in science. Research has shown that individuals do not understand the scientific standing of evolution and this integration of nature of science with evolution appeared to alleviate this issue (Abd-El-Khalick, 2001; Irez, 2006; Moore, Froehle, Kiernan, & Greenwald, 2006; People for the American Way Foundation, 2000)

The evolution instructional process in the inquiry class also varied from that of the traditional class. The students did not go over anything about evolution before they started the

Galapagos finch activity. The researcher wanted students to construct their own meaning and interpret the data without any influence of the evolution lecture content. When asked if the sequence of the unit was appropriate all of the inquiry students thought that it was the right sequence or process. All of the inquiry students had positive views of the Galapagos finch activity and three students cited it as a reason for their improved grades in the evolution unit. Too often in classrooms we are not engaging students in activities that they feel directly attribute to their understanding and success in a classroom.

The goldfish activity provided students with the opportunity to develop their own questions to investigate, their own experiments, and their own determination of what counted as data. Fogleman, Mcneill, and Krajcik (2011) discovered students who completed investigations on their own had greater learning gains compared to students who watched a teacher give a demonstration on the same topic. The goldfish activity situated students deeply in the mechanics of scientific experimentation and can be classified as an open inquiry activity. Sadeh and Zion (2009) found that students engaged in open inquiry had a better understanding of scientific concepts than those individuals who participated in guided inquiry. In the interviews, inquiry students later mentioned a lack of connection to evolution, but they felt they understood science better after the lab. Many students came to realize that science was not only driven by experimentation, but also observations. However, all was not fine with the process. During the lab some students were frustrated because they could not think of experiments to conduct. Student frustration is a common issue with open inquiry activities (Anderson, 2002; Trautmann, Makinster, & Avery, 2004, Wenning, 2005). Some students wanted to engage in continuous monitoring of the fish over a few weeks to collect more accurate data. A three hour lab block did not appear to be sufficient to walk students through inquiry processes and have them design and carry out experiments. The instructor planned on modifying the laboratories in the future to better suit the needs of her students.

According to the inquiry students the instructional sequence was effective and helped them to understand both science and evolution better. This is a component of the research study that would have been overlooked if the researcher had omitted interviews.

Implications for science educators

The instructional sequence for this research study has not previously been discussed in the research literature. Although studies have investigated inquiry-based instruction for nature of science and evolution, no one has taken an integrated approach to both topics using inquiry-based instruction. This approach has been recommended by a number of investigators but it has not been carried out (Smith, 2010). Students identified the instructional sequence as one of the reasons for their success in the course. The students in the inquiry class spent less time in lectures yet performed better on the post assessments for both evolution and nature of science. The instructional sequence started with inquiry-based activities in evolution, rather than a lecture. This allowed students to immerse themselves in the data and they were able to draw conclusions on their own. Based on this study instructors should explicitly discuss nature of science in the classroom as a standalone unit as well as with evolution. Using more inquiry – based activities also is suggested during evolution, especially where students examine and interpret data.

Impact of the instructional unit on the instructor

Although instructional interventions and their impact on student understanding of scientific concepts was the focus of this study, it is also important to recognize that the instructor changed as a result of the research intervention. At the beginning of the study the instructor identified herself as a traditional instructor. The instructor used these methods because she believed that they were the most effective and she was comfortable with them. She was firmly entrenched in a particular teaching style that appeared to work for her and her students. It cannot be stressed enough that this was an instructor who was not using inquiry-based methods, did not really know about them, and viewed them with apprehension. When she was first interviewed it was the second time she had ever discussed what inquiry was. She considered herself a novice and she indicated a great deal of apprehension when talking about changing her instructional technique as she was not familiar with inquiry-based activities. She had described herself as a traditional, effective teacher and there appeared to be little incentive for to change her instructional style. However, she expressed dissatisfaction with the laboratory portion of her course and felt that inquiry-based activities could be helpful. This dissatisfaction may have provided an opportunity for the researcher to help with a shift, however slightly, in the instructor's teaching style.

After the research study she integrated nature of science and inquiry-based activities into her course and has continued to do so. This is quite a departure from many other research studies that found teachers did not incorporate NOS into their lessons after interventions (Abd-El-Khalick et al., 1998; Akerson et al., 2010; Lederman, 1999; 2006; Waters-Adams, 2006). This appears to stem from her exposure and experience with inquiry-based activities. The instructor had described herself as a traditional teacher and research has found that this does not mean an individual will not implement inquiry into their classroom (Mellado, 1997; Trumbull et al., 2006). The selection of the activities in her current course has continued to come down to something she expressed at the beginning of this study, that of time management. While she did not integrate the Galapagos Finches activity into her instructional sequence, she did add the nature of science activities and the goldfish lab activity. As of the fall 2011 semester she has continued to use inquiry-based activities in her courses, but she has been selective about which activities she has used. This holds with the pattern witnessed by Roehrig and Luft (2004) who demonstrated a steep decline in the number of teachers attempting at least one inquiry-based activity after participation in an inquiry-focused teacher education program. Alkaher and Dolan (2011) identified a similar trend with college instructors. Unlike these studies, however, the instructor has continued to implement the majority of the activities used in the initial research study. Employing supportive frameworks alone may not be sufficient to cause a shift in the instructional practice of individuals. In her investigation of prospective teachers Crawford (2007) discovered that their enthusiasm for implementing inquiry-based lessons waned over time. Their mentor's openness to inquiry did not play a significant role in whether or not they attempted inquiry lessons. In the case of this research, the instructor was able to see the direct impact of the interventions on her students through reported results. It is clear that she would not have changed her instruction if she had not participated in this study since she had very little reason to do so. Despite her teaching and education experience she was uncomfortable with inquiry-based activities as it did not fit with her strengths. This is a common theme in the science education research literature related to changes in instructional practice, that of leaping into the "unknown" (Trautmann, Makinster, & Avery, 2004).

This instructor had the advantage of having the researcher present during the laboratories and there was a constant discussion that went on between the two individuals. Without the support structure it is highly unlikely the instructor would have continued to use these activities if it was her first time trying them. The researcher was able to go over the inquiry-based activities with the instructor and had prior knowledge of how they worked in a classroom. Crawford (2007) identified not knowing how to try inquiry in the classroom as a major factor as to why new teachers did not implement inquiry-based lessons. Sadly this is something faced on a daily basis by instructors at all levels in science education. It is probably more acute at the two-year and four-year level since these instructors most likely have not completed coursework in inquiry-based instruction. There are a number of reasons why instructors do not implement inquiry-based activities despite the national push for these techniques (Anderson, 2002; Barrow, 2006). This study reinforced the fact that instructors need support and assistance in overcoming real and perceived hurdles in implementing inquiry-based instructional techniques. Despite the positive outcomes of this research study, the instructor still was not inclined to implement the activities into her instructional practice. The greatest hurdle in this case actually appeared to be that of time. The instructor often discussed this during the research study and in her post interviews. According to her, the inquiry activities took “precious time” that she could be using to go over terminology. This sentiment is identified amongst teachers employing inquiry-based instruction (Anderson, 2002; Barrow, 2006, Trautman et al., 2004, Wenning, 2005). The instructor identified preparation time for the activities as a reason for a lack of implementation and is another issue found in the literature (Songer, Lee, & Kam, 2002). Anderson (2002), Wenning (2005), and Barrow (2006) have identified common “dilemmas” confronting individuals looking to enact inquiry instruction. The instructor’s barriers would fall into the category of technical barriers, where time problems, preparation issues, and teaching ability all reside. Despite providing her with the evidence and data supporting inquiry-based approaches, she continued to be resistant to the idea of inquiry-based instruction. She was clearly swayed by the research study in her views on the experimental classes understanding of evolution as she repeatedly referenced their conceptual understanding of evolution. Again, her lack of implementing the strategies stemmed from time and also comfort with the activities. At the primary and secondary education level here in the United States teachers are able to train with experienced teachers during their student teaching experiences. In some cases this provides students with an opportunity to try inquiry-based activities (Crawford, 2007). However, most college instructors are not able to do so and until inquiry-based activities are consistently demonstrated to be more effective than traditional techniques it is going to remain so.

An ancillary benefit of the study was the instructor's perception of her students. Prior to the study, the instructor had relied heavily on exams for her in class assessments. Engaging the inquiry class in a PowerPoint presentation allowed her to see many of her students in a different light. During sessions in the computer the instructor told the researcher she was glad she had participated since it allowed her to see the strengths of her students outside of a lecture-based environment. In addition to the direct benefits to student understanding the study also allowed the researcher to see students in a different light, in particular students who did not do well on exams. Although Tretter and Jones (2003) did not find a benefit of inquiry instruction they did find a positive outcome of more student involvement. The instructor was impressed by her students' interactions with each and learned about the benefits of the

Implications for science educators

The major implication for science educators is that an instructor who was clearly entrenched in traditional teaching methods can effectively implement inquiry-based strategies in their classroom. This change in teaching methods can be fairly permanent given the right support and conditions. The most powerful rationale for the instructor's change was her ability to witness her students performing better in the units where, particularly for students who were not effective test takers. Participation in professional development experiences does not allow instructors to witness the positive impacts of their implementation of inquiry-based activities This instructor did not participate in professional development yet her a fairly large shift in her instructional style occurred. The positive attitude of her students and their performance on assessments both supported this change in the instructor. This instructor had a great deal of apprehension about using the strategies but was also dissatisfied with some of the laboratory experiences her students had. Having a supportive mentor present who had also tried inquiry-based techniques appeared to be vital to the change in the instructor. Science educators should make every attempt to place student teachers with mentors who are open to and experienced with inquiry. Researchers have identified a regression that occurs after interventions that was not experienced in this study (Alkaher & Dolan, 2011; Crawford, 2007; Roehrig & Luft, 2004). The close interaction between the researcher and the instructor, as well as the ability to witness the performance of her students, both alleviate this regression.

b. What is the influence on students' views of nature of science?

Various models of epistemological development exist which are useful in framing the impact of this research study on students' views of knowledge. At the lowest levels of epistemological development knowledge is viewed as being certain and not subject to failure or change (Hofer, 2001). Students' view all knowledge as being capable of discovery as long as the proper process is used. These views are contradictory to the development of scientific knowledge. Accurate views of nature of science comprehend that science is tentative, cannot be proven, is uncertain, and the answers may not be found. Science, because of its perceived objectivity, appears to be able to give certain results that are proven beyond a doubt. Students, and much of the American public, fail to understand that science is filled with subjectivity and is a construction of humans. According to Sandoval (2003), individuals with sophisticated epistemological viewpoints understand that scientitific knowledge varies in certainty. Elby and Hammer (2001), on the other hand, have challenged this view of labeling a sophisticated epistemologies based on an individual's perception of science as tentative. However, Elby and Hammer do not rule out tentativeness of science but point out that using tentativeness to evaluate epistemologies as sophisticated is not fully correct. A general understanding of the support that evolution has in the scientific community may impact acceptance of evolution.

Students' epistemological understandings were discerned by examining their views of the nature of science questionnaire as well as their interview responses. Cho, Lankford and Wescott (2011) recently demonstrated that epistemological beliefs are related to beliefs of nature of science. Their results suggested that less mature epistemological beliefs are reflected as less mature beliefs of nature of science. Since only 11 of 38 participants were interviewed the challenge exists to show that the study had an impact on an individual's epistemology of science. Additionally not all of the students' responses were collected in the views of nature of science questionnaires. The study had a total population of 38 students yet only 30 students' questionnaires were used. Despite this, some trends can be recognized from the data. For instance, the number of students holding accurate conceptions of the nature of science in the inquiry class was higher for all the reported categories. In particular, the inquiry class saw a large posttest gain in both the social and cultural embeddedness of NOS and that science is a product of human imagination and creativity. This may be a shift from the basic levels of epistemological development where knowledge is certain to a view where knowledge is uncertain and contextual.

The concept of a theory in science is also an important piece of knowledge that may impact understanding of evolution (Abd-El-Khalick, 2001; Irez, 2006). No inquiry students thought/stated that theories needed to be proven and laws were proven on the posttest. A high number of students from the traditional class initially had the perception that laws are facts or are certain. This view persisted into the posttest at a high rate. Only two students (11.76%) from the inquiry class thought that laws were facts/certain on the posttest. The instructor made numerous references to the differences between theories and laws in science in both classes. In fact, the instructor discussed these differences more often in the traditional class than in the inquiry class. Dagher and BouJaoude (1997) found students often indicated evolution was only a theory and not a law. A significant difference involved the connections the instructor made between NOS and evolution as well as the instructional activities the students participated in. The inquiry-based students were able to participate in actual investigations that dealt with evidence and supporting claims. The immersion in the data allowed students to form more accurate conceptions of NOS. Students in the traditional class did not have the opportunity to explore an actual scientific data set and they also did not learn how to evaluate what counted as data. The inquiry-based class learned to consider what "counted" as data when they designed their goldfish experiments and collected observations. All of the inquiry student responses to the question "If the instructor just lectured on science would you have learned as much?" indicated they would not have learned as much about the topic if the instructor had just lectured on it.

When discussing evolution, Allchin (2011) recommends that instructors not focus on the distinction between theories and laws in science but rather on the support and evidence for it. Unfortunately, this does not adequately address a clear issue with evolutionary theory: its perceived status in the scientific community. In this research study, 9 of the 11 participants were able to accurately describe what a theory was in science when discussing evolution. This is significantly different from many studies, which often find that students continue to have an inaccurate view of the status of hypotheses, theories, and laws in science (Rutledge and Mitchell, 2002).

Confronting them with the phrase "it's just a theory" elicited responses that demonstrated their understanding of the difference between theories and laws. This would not have been the case if the instructor had simply provided the students with evidence for evolution (which she did). The instructor gave students a cognitive framework that they could use to address this issue. If the components/aspects of NOS had not been taught explicitly to these students they would not have been able to address this issue head on. Based on this study's results, Allchin's recommendations are not entirely appropriate for the discussion concerning evolution.

The inquiry class increased in the number of individuals believing that scientists use their imagination and creativity throughout the processes of science while the traditional class dropped. The traditional class did not have the opportunity to design actual experiments – thus their views of the imaginative components of science were distorted by the confirmation laboratory activities they partook in. Without a challenge to their cognitive framework, students in the traditional class would be less likely to change in their perceptions of science.

Despite their participation in experiments, an interesting trend was identified in regards to students who stated experiments were "proving scientific ideas" – it dropped from 35.3% to 17.6% in the inquiry class but increased from 23.1% to 38.5% in the traditional class. This appears to be a function of the types of experiments and situations the inquiry class encountered. The traditional class was engaged in laboratory activities that were verification in nature – they were predominantly focused on confirming an already known concept. The inquiry class, on the other hand, often examined data sets or developed their own experiments to test hypotheses they came up with. Instead of verifying a known concept, they dealt with exploring previously unknown items.

Based on the views of the nature of science questionnaires, the inquiry students appeared to have more developed epistemological views of science. This may be directly attributed to the instructional sequence used. For instance, the activities in the first class session were aimed at helping students understand that scientist cannot always find the answers and that individuals have different views and ideas. The Galapagos finch presentations demonstrated individuals could develop different arguments based on the same data set. Students were required to support their hypotheses and justify their positions using data. The goldfish activity allowed the students to immerse themselves in the development of scientific processes to answer their own questions. The instructor in both of the cases did not tell students how to approach the problem, and although seen as an authority figure, did not have all the answers. The traditional class did not have these opportunities, which were more suited in allowing students to confront their views on knowledge and how knowledge comes into being. College students engaged in designing experiments and supporting their positions have previously indicated these actions impact their views of the certainty of scientific knowledge (Wenk, 2000). However, since epistemological belief surveys were not administered to both classes it is extremely difficult to determine where students stand in their development. Additionally, the sample sizes were different for both classes, with three missing responses from the inquiry class and five missing from the traditional class. These samples were missing from the posttests of the classes, and certainly impact the reported percentages.

Students interviewed from the inquiry class held fairly positive attitudes towards the inquiry interventions and they also appeared to be more positive in general towards science. Chang and Mao (1999) found students' attitudes toward science improved when using inquiry methods comparing to a control that was non-inquiry.

The inquiry class demonstrated a more robust understanding of NOS following instruction. For instance, they scored higher on all of the views of the nature science questionnaire components on the posttest. Individuals in the inquiry class were much less likely to consider scientific knowledge to be certain, and they were more open to the subjective and social/cultural embeddedness of NOS. This appears to stem from the types of experiences that the inquiry class participated in. Liu et al. (2011) identified a link between individuals who had tentative beliefs about knowledge and their ability to consider multiple aspects of an issue. The NOS activities used at the start of the semester directly addressed the subjective aspect of science – both the cube activity and the Tricky Tracks! activity. Each of the six groups that formed during the cube activity brainstormed a different answer for the bottom on the cube. Students offered a range of explanations for the footprint activity. The inquiry class analyzed data and developed explanations from that data – many of which were different. Each of the student groups brainstormed and developed different experiments when examining goldfish behavior. The inquiry students were deeply involved in assessing data and evidence, as well as providing justification for the claims that they made. Students in the traditional class did not have these challenges to their epistemic frameworks regarding scientific knowledge. By not engaging the traditional students in processes that mirrored scientific inquiry in the “real world” a less accurate understanding of science resulted. Bransford, Brown, and Cocking (1999), Duschl (2007), and Kittleson (2011) all recommend engaging students in experiences that are similar to how science is conducted to achieve change in individuals.

As described in the research methods, the instructor spent a portion of her class reviewing aspects of NOS before starting the unit on evolution. To discern whether the explicit connections helped students understand about evolution and natural selection the researcher used student interview responses. Students were asked if they thought talking about NOS before the unit had helped in understanding about evolution. Those students who responded to the question all agreed that the coverage of the aspects of science before discussing evolution helped them understand the topic better. Rutledge and Warden (2000) found a positive relationship between understanding of NOS and evolution amongst teachers they surveyed. While not identical to this study in the use of acceptance, rather than understanding, other research studies have demonstrated a link between the two constructs (evolution and NOS). It is important to stress that many of these studies have examined *acceptance*, and not understanding, of evolution in relationship with NOS. Acceptance is not equivalent to understanding nor is understanding equivalent to acceptance. These research studies do provide some support for connections between evolution and NOS. Johnson and Peeples (1987) found a significant relationship between acceptance of evolution and understanding of science amongst biology majors and nonmajors at a range of institutions. This supports both the explicit discussion of the nature of science with evolution but also a focus on nature of science itself. Cavallo and McCall (2008) examined beliefs about evolution and NOS and found a positive relationship between the two. According to the researchers, individuals who viewed science as more tentative were more likely to have a belief in evolution; the more fixed it was the less likely they espoused a belief in evolution. Unlike the present study they did not find a change in students' beliefs in NOS or evolution from start to finish. This supports the application of inquiry-based approaches to help students.   Lombrozo, Thanukos, and Weisberg (2008) discovered a significant correlation between understanding of NOS and acceptance of evolution. They specifically identified aspects of science themes related to an understanding of theories in science; students with more complex views of theories were more accepting of evolution and vice versus. Studies of teachers also demonstrate a relationship between NOS and acceptance of evolution (Aguillard, 1999; Rutledge & Warden 2000; Rutledge & Mitchell, 2002; Scharmann & Harris, 1992). While teachers were not the population for this research study, it helps shed light on the interplay that exists between understanding about science and acceptance of evolution.

The results are not entirely consistent regarding a relationship between evolutionary theory and nature of science as Cho, Lankford and Wescott (2011) more recently demonstrate. Their study results showed that students' beliefs in NOS did not explain conceptual change in evolution. Despite these findings, the majority of studies investigating NOS and evolution have found some relationship between the two.

A more complete understanding of NOS also may allow students to challenge it better, as other research has indicated (Akerson & Buzzelli, 2007a). Since NOS involves a tentative aspect, individuals use this as a way to target evolutionary theory. The inaccurate perception of science as the pursuit of truth and not subject to change makes learning about the tentativeness of theories an opening to disregard or reduce the standing of evolutionary theory. When students are taught that scientific knowledge is tentative and subject to change this contradicts their currently held view about science. Science being viewed as tentative could elicit a response from students that borders on “why bother” if the information is going to change. Evolution is commonly referred to as a “just a theory” and is viewed as having less of a standing than other theories in the scientific community (Irez, 2006). By shifting students’ understanding of science from absolute truth to tentativeness, researchers may weaken the standing that evolutionary theory has with students.

Fortunately in this study there appeared to be a positive relationship between understanding NOS and evolution. The inquiry class had a greater understanding of NOS and evolution on the post test and demonstrated a larger increase from the pretests to the posttests than the traditional class.

Implications for science educators

The inquiry-based methods in this class gave students an improved understanding of science and evolution when compared to the traditional class. This contributes to the larger body of research by Lederman that supports the use of inquiry-based methods to teach about NOS as well as the explicit instruction in NOS as a standalone unit (Lederman, 2006). The research study supports the integration of NOS and evolution as well, which students in this study identified as helping them to understand about evolution. Despite numerous recommendations instruction in NOS with evolution still does not appear to be taking place. To improve students’ understanding of evolution we should be integrating NOS with evolution in science classes.

c. What is the influence on students’ understanding of evolutionary concepts?

The major focus of this research study was to discern if inquiry-based instructional strategies were more effective at helping students understand evolution than traditional lecture-based activities and laboratories. Although the two classes spent almost equal amounts of time on the topic of evolution, the traditional class was engaged more often in lectures and activities on the topic and terms of evolution. The traditional class had six lectures (80 minutes each, except for the first lecture of 60 minutes) covering evolution related topics, while the inquiry class only had two lectures (80 minutes each). During the evolution unit the traditional class spent 183 minutes (3.05 hours) on laboratory activities while the inquiry class spent 192 minutes (3.2 hours). Some of the time that the inquiry class would have been in lecture was actually devoted to the Galapagos finch program.

While the inquiry class was designing experiments to investigate fish behavior, the traditional class completed a lab on evolutionary concepts from their lab manual. As students in the inquiry class used evidence and justified their scientific claims, the traditional class sat in lecture going over the process of natural selection and evolution. The traditional class spent six class sessions/lectures on evolution and the inquiry class only spent two lectures on the same material. Despite an obvious discrepancy in direct exposure to evolution concepts in lecture, the inquiry class had higher means on the posttests for the *Conceptual Inventory of Natural Selection* and the cheetah question from Bishop and Anderson (1990). The inquiry class had a mean increase of two correct answers from the pretest to the posttest, while the traditional class remained static. The traditional class appeared to start with a better grasp of evolution as shown in their CINS and Darwinian component scores. Despite this better initial starting point, the inquiry class ended up with higher posttest scores on both measures.

The inquiry class did not perform as well as the traditional class on the instructor generated evolution exam, but this may be explained by a number of factors. The instructor spent additional time in the traditional class reviewing evolution before the exam, which may have accounted for the higher instructor exam mean in the traditional class. The traditional class was also exposed to more terminology during the laboratory sessions on evolution. The two labs completed by the traditional students included a large amount of reading and answering questions based on evolution topics. This is not the case with the inquiry class, since they instead focused on examining data and evidence, as well as designing experiments.

Although the traditional class was exposed to more evolution terminology in laboratory sessions, this was not reflected in the accurate use of terms in their open responses to the cheetah question. The traditional class was more likely to use the terms adapt and adaption on the post test and the inquiry class was more likely to use survive, natural selection, and offspring. While adapt and adaptation are accurate terms used in relationship to evolution, they do not reflect an accurate understanding on their own (Jensen et al., 2007). The inquiry class had a large increase in the use of natural selection, offspring, and mutation. The only term that was accurate and used more often in the traditional class was reproduce (3 students versus two students). These findings are in line with other research studies that have found instructional treatments to be effective in changing students' understanding of evolution (Crawford et al., 2007; Settlage, 1994). These results may be explained by considering the activities that took place in each classroom settings. Since the inquiry class focused on an example of survival in a species, it makes sense that they would use terms like offspring, natural selection, and survive more often than the traditional class. However, the traditional class also was engaged in a laboratory exercise on the survival of birds based on food sources and traits. It is evident that the inquiry-based activities, with their focus on evidence and data, helped to shift the students' understanding to a more accurate level.

If the two instructional techniques (inquiry and traditional) were assumed to be equally effective, and the amount of time was kept essentially equal for the total unit and the laboratory, the assumption would be the scores on the posttests would be equivalent. Since the lecture material was identical in both classes, as well as the instructor, the most likely conclusion is that the instructional processes resulted in the differences in scores. Other studies, dealing with a range of scientific concepts, have found inquiry-based approaches to be more effective in helping students learn a variety of scientific topics (Lee et al., 2010; Lyons, 2006; Mao & Chang, 1998; McCrathy, 2005; Ruhf, 2006; Thacker, Kim, & Trefz, & Lea, 1994; Tretter & Jones, 2003; Wilson et al., 2010). Despite the increasing number of studies that have dealt with learning about evolution, few have dealt with inquiry-based approaches ((Demastes, Settlage, and Good (1995b), Jensen and Finley (1996), Passmore and Stewart (2002), Beardsley (2004), Crawford et al. (2005), Robbins and Roy (2007), Nehm and Reilly (2007), Heitz, Cheetham, Capes, and Jeanne (2010)). Some studies have investigated different curricular approaches, such as when Jensen and Finley (1996) compared a historically rich curriculum with paired problem-solving to a traditional curriculum using traditional techniques. The experimental curriculum increased the students' use of Dawinian conceptions and decreased their use of alternative explanations. Non-traditional curricular approaches may translate into a deeper understanding of various concepts.

The use of multiple sources of data, including pre-and posttests of different types, instructor exams, and interviews allowed the researcher to more strongly support this conclusion. In the post interviews students were able to describe, in fairly accurate detail and citing information from activities, the processes of natural selection. The recent interview with Mark demonstrates the persistence of the inquiry-based activities in helping students to understand difficult science concepts. Despite the passage of four years, Mark still remembered the inquiry-based activity dealing with the finches. It is important to remember that the evolution unit only lasted a total of three weeks and occurred in the first one third of the semester. During his interview he indicated he was "not a science person" but he still remembered the activity and he used examples from the finches to explain the process of natural selection. Mark was able to accurately describe how natural selection worked and integrated information from the inquiry-based activities into his explanation. When asked if he remembered anything else from the course, Mark was unable to do so. This is a powerful example to support the impact of a three-week unit inquiry-based unit on long term retention of information. The researcher is currently unaware of any evolution studies that have followed up with participants after such a long time frame (four years) to see what impact those studies have had on students. Blanchard et al. (2010) found that students with teachers who had stronger implementation of inquiry performed better on a number of measures and had better long term retention of the material. Mark's recollection of evolutionary processes supports these findings as well.

. As a self-professed non-science person, Mark did not have a predisposition to understanding evolutionary theory or retaining that information. Mark had only taken one science course since then, which was Biol 104, the second half of the biology sequence he started with during the research study. This course does not deal with evolutionary theory and is primarily focused on anatomy, physiology, and genetics. He last took a science course in the spring semester of 2008, still three and half years from the time of the second interview. Since he remembered only one topic, which was covered fairly early in the course (mid October out of a fall semester that ended in mid December), it lends strong evidence to the notion that the inquiry-based instructional techniques assisted Mark in his learning. Bransford, Brown, and Cocking (1999) point out that students need to have their initial understanding engaged to grasp new concepts and they may learn material for a test but revert to preconceptions once they leave the classroom. This is clearly not the case with Mark since he still held onto his understanding of the various science topics years later.

Mark had initially discussed the role of the inquiry-based activities in his first interview in 2007:

> Mark: Yeah. It was different because, I mean, you don't really learn that way, usually it's just straight in the classroom learning about it, but we actually got to do the research and stuff. I mean, seriously, but that's the most stuff I remember from the class, that I looked up the finches and the evolution stuff.

Mark continued to cite the inquiry-based activities as a role in his ability to recall the topics in his interview in 2011.

It also is encouraging to note that in addition to their performance on the posttest in the experimental class, members who were interviewed also were consistent in their praise of the inquiry-based activities. Each of the students described how they liked the activity and a number of them felt that it helped them understand evolution much better than if they had simply participated in lectures. Some students also indicated that using various activities might also help individuals accept evolution or change their views on evolution.

One of the disheartening parts of the study was the performance of students on the *Conceptual Inventory of Natural Selection*. Posttest results had means in the low to mid 50s, which does not indicate a robust understanding of the concepts tested. Nehm and Schonfeld (2008) also found low CINS scores with a different population of students, second semester biology majors'. In their sample population of 100 students, they had a mean of 62.9%, with a SD=19.9 (Nehm and Schonfeld, 2008). Anderson et al. (2002) reported low pretest means for two sections of a nonmajors' biology course used in creating the CINS: section A (n=110, mean=41%) and section B (n=96, mean=52%). While the CINS results are low for this study, they do not appear to be unexpected in light of other studies. Very few students earned passing scores on the CINS: four students from the traditional class and two from the inquiry class scored above a 70% on the CINS. A partial explanation for these low scores could be explained by the fact that the posttest was administered at the end of November, one month after the evolution unit. Posttest means therefore may have been significantly higher if they had been administered at the end of the unit. This was not carried out since the researcher wanted to avoid testing influences from exposure to the pretest and the short time to the posttest (approximately 3 weeks). The lag time between administration of the pretest and posttest allowed the instructor and the researcher to examine retention of the material. Both classes had an increase in their posttest means, which one would expect from exposure to the information. The inquiry class results were statistically significant, supporting the idea that the inquiry-based techniques were more effective than the traditional approach in assisting students with their understanding of evolution and natural selection. Although one would have hoped for passing posttest means 70% or higher, the fact that the scores increased and did not decrease is important to recognize. The majority of students in both classes increased their scores on the posttest. Thirteen students from the inquiry class increased their scores from the pretest and posttest; 12 did so in the traditional class. The *Conceptual Inventory of Natural Selection* scores also may not be indicative of the ability level of students. Alex, a nontraditional student in the control class, earned an A in the course and had exam grades that ranged from 85 to 107 (100% on the evolution exam). His scores on the *Conceptual Inventory of Natural Selection* increased from a 35 on the pretest to a 55 on the posttest, yet these values were not passing and do not demonstrate a robust understanding of natural selection. This is counter to his interview responses which were highly detailed, scientifically accurate, and cognizant of a number of elements of natural selection.

The *Conceptual Inventory of Natural Selection* also demonstrated some other support for the inquiry-based approach. There were a number of questions in which the inquiry class increased in their correct choices from pretest to posttest and dropped in each of their alternatives. At the same time the traditional class had an increase in students picking alternatives more often in these questions. In the case of questions 2, 6, 8, 10, 11, 16, and 18 the inquiry class increased in their correct choices and decreased in each of their alternative choices from the pretest to the posttest. Therefore, students dropped in each of the categories where they had made an alternative conception choice. In each of these questions the traditional students increased their selection of alternative conceptions from the pretest to the posttest. Other instructional strategies have shown to be effective in dropping the number of misconceptions used by students (Nehm & Reilly, 2007; Zuzovsky, 1994). The overall effectiveness of the inquiry approach stems from the exploration of the data. Students from the inquiry class identified the role of the inquiry activities in helping them to understand about the various evolution topics.

The traditional class alternative selections often reflected elements of the needs and wants of organisms. This was not as evident in the inquiry class and indicates that alternative conceptions were less likely due to the interventions used. The Galapagos Finch program dealt specifically with the topic of species change. Students explored a data set and learned that organisms do not suddenly develop needed structures but instead die or already have the variation to survive. The traditional class did not have the benefit of immersing themselves in the data and evidence; therefore their alternative conceptions or misconceptions about need continued to persist and actually grew.

As previously indicated, the inquiry-based class demonstrated a more robust understanding of evolution than the traditional class after the intervention. Misconceptions, while not a focus of this study, increased in the traditional class on the CINS. Besides these misconceptions, there may have been other issues at play that could have impacted students' understanding of evolution. One of the common themes that it is identified with student hurdles related to understanding evolution is the conflict, either real or perceived, between religion and evolution (Dagher and BouJaoude, 1997). The results in this study provide evidence to both support and refute this idea.

Relationship between religious beliefs and understanding of evolution

Allmon (2011) identifies five major causes for the non-acceptance of evolution: inadequate understanding of the evidence, inadequate understanding of science, religion, psychological factors, and political and social factors. Researchers have predominantly, but not exclusively, focused on religion as a significant reason for non-acceptance. Students from both the inquiry-based class and the traditional class were asked a question from the Gallup organization that was used to assess their beliefs in evolution. It was interesting to note that students from both classes showed more openness in believing humans were a result of evolution than in the national polls. Seventy two percent of the traditional class selected the option that humans evolved without God in the process while 45% of the inquiry class did so. This is significantly higher than the 14% recorded from the Gallup poll, which has remained fairly constant over the past 30 years (Newport, 2007). The Gallup organization and reporters describe these choices as beliefs and views, “Forty-six percent of Americans believe in the creationist view that God created humans in their present form at one time within the last 10,000 years” (Newport, 2012). The researcher confirmed the beliefs of students during the interviews. The current results do not support the idea that religious beliefs are a significant impact on understanding evolution or achievement in the course. For instance, McKeachie, Lin, and Strayer (2002) found a progression in mean final grades from creationists to evolutionists in seventy five students in a community college introductory biology course. The authors indicated that a disproportionate number of students who did not pass or failed to take the posttest did not believe in evolution. Based on the Gallup question responses of both of the classes, one would assume that the traditional class would have higher posttest results and a better understanding of the concepts in the study. The current study runs contrary to McKeachie, Lin, and Strayer (2002), as the results for the *Conceptual Inventory of Natural Selection* were higher for the inquiry class. The inquiry class had a statistically significant increase from their pretest to their posttest. Additionally, the inquiry class used more Darwinian components in their posttest than the traditional class and had a higher net increase in those components. One would expect the opposite to be true since the traditional class appeared to express a higher incidence in belief in evolution and less creationist viewpoints. However, Ingram and Nelson (2006) have shown that acceptance of evolution is not related to achievement in a course. The reported results within the present study did not demonstrate an impact of religious beliefs on understanding of evolutionary theory. Individuals who were more likely to choose evolution without God in the process were not more likely to do better on the post assessments than individuals who answered that God played a role in human evolution. In fact, the students in both classes who selected the choice

"*Human beings have developed over millions of years from less advanced forms of life, but God guided this process"* scored higher (57.5%) than the students who selected the choice "*Human beings have developed over millions of years from less advanced forms of life, but God had* no part *in this process"* (53.68%). The group of students who chose *God created human beings pretty much in their present form at one time within the last 10,000 years or so* performed the worst of the three groups (46.25%) but it only included four students. Although as a whole the traditional class expressed greater numbers of students believing in evolution, they did not perform better than the inquiry class on the evolution assessments. This appears to be consistent with other studies that have found understanding of evolution and acceptance of evolution are not related (Bishop & Anderson, 1990; Sinatra et al., 2003). However, researchers have focused on understanding of evolution as a mechanism to elicit acceptance (Shtulman & Calabi, 2008). Shtulman and Calabi (2008) found that there was a correlation between the accuracy of one's understanding of evolution and the strength of their acceptance.

Student interviews revealed an interesting dichotomy when it came to their views on the impact of beliefs on acceptance of evolution and the differences between the public and scientists' acceptance of evolution. Ten of the eleven individuals interviewed stated that one could accept evolution and believe in God. However, when asked to explain the difference in the acceptance of the theory of evolution between scientists and the American public, nine of the eleven interviewees indicated it was a result of religious beliefs. The other two students indicated it was education related. Although the students overwhelmingly felt that individuals could accept evolution and believe in God, they pegged the difference in acceptance rates of evolution on religious beliefs. Lombrozo, Thanukos, and Weisberg (2008) discovered a significant negative relationship between religiosity and evolution acceptance. The students in this study did not display this negative relationship and they indicated individuals could find a place for both in their lives.

A majority of students (9 of 11) were asked about beliefs and how beliefs could be changed. The researcher was interested in whether or not students felt that: 1. Beliefs could change and 2. What would be necessary to change them? This was specifically tied to evolution and what tools might be effective in changing an individual's views on evolution. Six of the 9 students felt that an individual's beliefs were not going to change even if they were presented with science content in different ways; these students described beliefs as being "stuck" and "stubborn". This is a consistent view that is held by many researchers and research studies (Pajares, 1992). Students very commonly talked about the "open mindedness" of individuals as having a role in their acceptance of evolutionary theory. Regardless of how the material was presented students did not feel individuals would accept evolution if they were not open minded. Sinatra et al. (2003) also identified open mindedness as a component in the acceptance of evolution, particularly of human evolution.

The most striking finding that developed out of this research study had to do with Bethany. The inquiry-based activities appeared to have a profound effect on Bethany's understanding of evolution. Bethany initially indicated in her cheetah question response that she did not believe in evolution of humans.

> I believe in animals evolving and changing their –organisms and cells and mutations but not as drastic as humans once being apes.

Although she had young earth creationist views, it did not prevent her from believing in change in organisms. If Bethany had been in the traditional class it is entirely possible that she would not have had the same understanding of evolution. The instructional sequence and the method of presentation of the material in the course were identified by Bethany as a reason for her understanding. Bethany compared and contrasted her prior experiences with evolution in a K-12 setting with her current experience during the post interview.

> Bethany: You say that, but I remember like in high school like they kinda pushed it out there saying we came from apes. You know, like they kinda just pushed it right out there, so when I heard evolution I just really didn't care, it just pushed the kids away. I was taught previous, and when you're younger your mind can't think as straightforward as it probably is now when you're older, and you usually – like I got angry with it. I just did what they wanted me to do just to get it done, but this one was more interesting because it wasn't like just pushing it on you saying hey, this is all you can believe. This is it, how it's done.
>
> Post interview

Bethany clearly had an issue with the initial exploration of the concepts of evolution in a school setting. The feeling of conflict, negative consequences, and disturbance felt by Bethany is commonly discussed in the research literature (Brem et al., 2003, Dagher & BouJaoude, 1997; Griffith & Brem, 2004). By presenting evolution as a collection of facts to be learned, regardless of the standard of acceptance in the scientific community, Bethany was in her own words "pushed away" and "got angry with it." Her experience in school ran counter to what she had learned at home and at a young age. Duschl (2007) and Evans (2001) both indicate that children develop creationist explanations for the development of species at an early age. According to Duschl (2007), "such beliefs may reflect the formation of an explicit theory based on their initial essentialist bias—that is, their initial tendency to believe that things have a true underlying nature" (p. 100). When students arrive in science classrooms they already have deeply ingrained views, beliefs, and misconceptions about evolution (Beardsley, 2004; Bishop & Anderson, 1990; Bizzo, 1994; Brumby, 1984; Demastes et al., 1995b; Moore et al., 2006; Settlage, 1994).

Unfortunately students are presented with evolutionary information that is hard to grasp in a lecture based format – they are not able to examine and contemplate the information on their own terms. Williams (2009) notes that one of the reasons for difficulty with evolution is that it is counterintuitive. Simply presenting the information to students, without the opportunity for analysis of data, does not support an understanding of a complex topic. Bethany brought up the manner in which the evolution information was presented as a reason for her ability to grasp the information and see that organisms have evolved. The inquiry-based activities dealt with actual scientific data and were not simulations like the traditional class had engaged in. This allowed students to explore the mechanisms of natural selection and they were able to address the mechanisms in a manner that may not have been as dogmatic as one perceives lectures or teacher presentations to be. Schrader's (2004) discussion of intellectual safety, moral atmosphere and epistemology in college classrooms provides a framework to consider Bethany's response. The inquiry-based instructional practices created a classroom environment that allowed students to negotiate through their own views on evolution and science, without feeling a great deal of pressure or stress from the instructor. In fact, the instructor's course surveys often mentioned the comfortable classroom environment she created. Learning and teaching about evolution is associated with stress and negative consequences by both teachers and learners (Brem et al., 2003, Dagher & BouJaoude, 1997; Griffith & Brem, 2004). Allowing students to investigate data on their own and draw their own conclusions alleviated the problem of an all or nothing choice with evolution. The environment of the classroom appeared to better suit the cognitive stretch that is necessary when moving to new epistemological positions.

Winslow et al. (2011) recently described a study dealing with a population similar to Bethany that can shed some light on her views on evolution and her changing view into that of acceptance of evolution. Most of the study participants, like Bethany, had been raised to believe in young earth creationism. Bethany described anxiety with her father, similar to the anxiety participants felt from their parents about accepting evolution. Like many of the participants Bethany's father had a strong belief in creationism. Bethany did not describe the pressure from her father concerning evolution, unlike some of the participants. Participants in the study did not observe evolution as having negative implications for them, an outlook Bethany shared as well. Dagher and BouJaoude (1997) and Brem et al. (2003) have both reported that individuals ascribe negative connotations to evolutionary theory. Another critical component of Bethany's shift to an acceptance of evolutionary theory was her open mindedness. Sinatra et al. (2003) also identified open mindedness as a component in the acceptance of evolution, particularly of human evolution. Finally, the presence of evidence for evolution was an important element in the participants and Bethany's acceptance of evolution. Bethany discussed the previous way in which she had been presented evolution and contrasted that with her experience in the current study. Instead of having it forced on her, she felt she was allowed to explore the data and come up with the answer on her own. Interestingly a participant in the Winslow et al. (2011) study reported a similar experience in school as Bethany – they both completed assignments because they had to but were not receptive to evolutionary theory. Although Bethany started out as an individual who did not believe in evolution, she shifted to accept that it was occurring. At the same time she did not abandon her faith, nor was this visible in the Winslow et al. (2011) study.

Implications of Bethany being a creationist

The Winslow et al. (2011) study as well as this study both offer an approach for assisting individuals who have religious convictions against evolution. Both of the studies demonstrate that a focus on evidence in evolution and teaching approaches can lead to acceptance of evolution. Does providing students with more evidence lead to acceptance of evolution? It depends on the approach that is used to show that evidence. In the current study Bethany had the opportunity to explore evidence on her own without the instructor's influence. Winslow et al. (2011) demonstrates how important evidence can be in helping students come to accept evolution. Ten of the 15 participants in this study mentioned the importance of evidence in making a determination as to whether they could accept evolution. Although researchers continue to explore the role of religious beliefs in educational settings, it may be more appropriate to focus on the instructional practice and the role of evidence in science.

Major findings of the study

What is the effect of using inquiry-based instruction versus a traditional approach in teaching about evolutionary theory on student understanding of evolutionary concepts?

The message that can be gleaned from this study is that an inquiry-based approach can successfully help learners understand the concepts of evolution, even if students spend less time in lecture (when compared to a traditional class). This statement is supported by the results on the *Conceptual Inventory of Natural Selection*, the use of Darwinian components on the Bishop and Anderson (1990) question, and interviews. Each of these results favored the inquiry-based approach over the traditional strategies. In addition to the quantitative data, student interviews allowed the researcher to examine students' understanding of evolution as well as their perception of the instructional approach. Each of the students interviewed was able to articulate an understanding of the mechanisms of natural selection and evolution, even though approximately two months had passed since the evolution unit was completed. The inquiry-based activities also helped students retain information for longer periods of time (Blanchard et al., 2010).

Three of the students interviewed in the inquiry-based class directly cited the activities as a reason for their improved performance and understanding of the evolution topics. All of the students in the inquiry class had positive views of the inquiry-based activities. The inquiry activities alleviated barriers to understanding of evolution (such as in the case of Bethany). Expressed belief in evolution did not appear to negatively impact understanding of evolution (the inquiry class was less likely to believe in evolution but performed better on posttest assessments). Finally, the integration of NOS and evolution promoted student understanding of evolution, as identified by students. Students believed that discussing NOS with evolution helped them understand the topics better.

In what ways does this study inform the science education community? This study suggests a short duration inquiry-based instructional unit can facilitate students' understanding and retention of science and evolutionary concepts better than traditional teaching techniques. The inquiry instructional techniques helped increase students' understanding of evolution while also decreases their misconceptions. Unfortunately, research studies dealing with teaching evolution have continued to focus on whether or not students accept evolution and do not focus on how instructors can best teach the topics. The inquiry-based activities employed in this study provided opportunities for students to explore data sets and develop explanations for those data sets – without being told what the exact answer was (aligned with the New Framework, NRC, 2012). The study has shown that a short instructional unit can also have an impact on an instructor's views and pedagogy. Evolutionary discussions are often described as being dogmatic on both sides. In particular, individuals who are not evolution acceptors critique the dogmatic nature in which evolution is presented. Those of us who are aware of the standing of evolution in the scientific community understand how weak of an argument it is, however, students often are inquisitive of other ideas and concepts that exist relating to evolutionary theory. The appearance of "dogma" may be removed or lessened by allowing students to explore data sets on their own to arrive at an understanding of evolutionary processes. While this may not be the case in every instance, it does provide students with a process of engaging their existing epistemic frameworks without having them shut down in the face of pressure. Bethany is an illustrative case of this issue – having been presented with "dogma" she initially is angry and shuts down. When she is again engaged in evolution in a different manner she is more receptive of it due to the manner in which is presented. Teachers are constantly faced with this issue when discussing evolutionary theory; while it may not be a solution in every instance, this research study does provide evidence for using an approach that is effective with a variety of students – especially those individuals identifying themselves as "creationist" as Bethany did.

Future directions

As previously mentioned, science education researchers investigating evolution education have commonly identified instruction in nature of science as method to increase student understanding of evolution (Scharman & Harris, 1992). This was one of the considerations in designing the research study and the instructional sequence used in the course. A future direction of this study would be to add more classes so that one could examine the impact of implicit and explicit approaches to teaching NOS. A more detailed analysis of the relationship between beliefs, understanding, and acceptance would also be necessary to see what impact the inquiry-based approaches had on each of these components. An examination of the impact of the amount of evidence presented to students, and the relative impact it had on their views of evolution, would also help inform the research community. Finally, it would be important to determine the impact of varied amounts of inquiry-based activities on individuals understanding, acceptance, and belief in evolution.

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Appendix A

Name: Email address:

1. Are you a part time or full time student?

2. What is your age? (Do not provide if you don't feel comfortable - this helps me in relation to previous science classes and knowing what high school biology Regents you took)

3. What is your current major?

4. What are your future career goals?

5. When was the last time you took a biology class?

6. What high school or home schooled science classes have you taken (list all courses - if you remember dates, please provide them)?

7. Have you taken any college level biology classes? If yes, which ones?

8. Have you taken other college level science classes? If yes, which ones?

9. How would you describe your overall comfort level with/understanding of biology?

Please describe your comfort level/understanding of the following topics by circling the number that most appropriately describes it.

1- Not at all comfortable I don't understand this topic well or Have not received instruction in it	3 – Somewhat comfortable	5- extremely comfortable, I understand the topic completely, I probably could instruct other students

Microscopes and their use	1	2	3	4	5
Biological molecules/chemistry	1	2	3	4	5
Cell Structure and function	1	2	3	4	5
Classification/systematics	1	2	3	4	5
Evolution	1	2	3	4	5
DNA, RNA, and genetics	1	2	3	4	5
Mitosis and Meiosis	1	2	3	4	5
Photosynthesis	1	2	3	4	5
Cellular Respiration	1	2	3	4	5

Appendix B

Date	Lecture Topic	Textbook	Lab Dates	Labs
Th Aug 30	Properties of Life, Nature of Science, Scientific Method	Ch 1		
	Molecular Basis of Life	Ch 2	Sep 4 & 6	Scientific Method, Lab 2 - Metric System & Microscope
	Biological Molecules	Ch 3	Sep 11 & 13	Lab 3 – Chemical Composition of Cells
	Cell Structure & Function	Ch 4 & 5	Sep 18 & 20	Lab 4 – Cell Structure & Function
T Sep 25	EXAM 1		Sep 25 & 27	Lab 6 - Enzymes
	Cellular Energetics	Ch 6		
	Photosynthesis	Ch 7		
	Cellular Respiration	Ch 8	Oct 2 & 4	Lab 8 – Photosynthesis
T Oct 9	EXAM 2		Oct 9 & 11	Evolution Lab
	Evolution	Ch 14	Oct 16 & 18	Evolution Lab
	Origin of Species	Ch 16	Oct 23 & 25	Evolution Lab
	Origin of Life	Ch 17		
	Systematics	Ch 18		
T Oct 30	EXAM 3		Oct 30 & Nov 1	Parts of Lab 22, Handout - DNA Project
	DNA	Ch 9 & 10	Nov 6 & 8	Finish DNA Projects, DNA Movie
	Mitosis & Meiosis	Ch 11	Nov 13 & 15	Lab 5 - Mitosis and Meiosis
T Nov 20	EXAM 4			
Th Nov 22	No Class Happy Thanksgiving!		Nov 20 & 22	No Lab Happy Thanksgiving!
	Survey of Kingdoms	Ch 19, 20 & 21	Nov 27 & 29	Parts of Labs 9, 10, 26, 27 Organization of Plants
Dec 11	Last Day of Class		Dec 4 & 6	Review
TBA	Final Exam			

Appendix C

Notes

Nature of science notes:

What are some the elements of the Nature of Science that we should know?

Tentative (subject to change)
Empirically based (based on and/or derived from observations of the natural world)
Subjective (theory-laden)
The product of **human imagination,** inference, and **creativity**
Socially and culturally embedded
Distinction between **observations and inferences**
Relationship between **scientific theories and laws**

Below are the evolution notes covered in both the inquiry class and the traditional class. Blue indicates slides with pictures that don't show up in the typed notes, but were presented to the class. The traditional class sequence of notes was:

Traditional class Class 1 – 10/09/07

Theory of Evolution

- Definition: Change in gene frequency over time
- How it occurs:
- More offspring are produced than can survive
- Competition for survival
- Populations show variations for almost all traits
    - -Variations in DNA arise by mutations
    - -DNA is responsible for morphology, physiology, behavior
- Certain variations are beneficial and increase chances of survival
  →more likely to survive →more likely to reproduce →pass on beneficial genes

Theory of Evolution

- If traits are **heritable** their frequency increases
- This is **Natural Selection** = differential success in survival and reproduction
  - in other words, *nature* selects the survivor
  - *survival of the fittest – the most unfit individuals (for a particular environment) do not survive*

Theory of Evolution

- Results in more favorable traits being disproportionately represented in the next generation
- If enough variation accumulates a new species may evolve (termed macroevolution – this is like a collection of microevolution events)

- Traits are only beneficial depending on circumstances
- Populations evolve, NOT individuals

Slides - Pictures of frogs with dark and light coloration and how that was influenced by genes.
A picture of bacterial resistance to antibiotics and how it could develop, with the question "did this population evolve."
Showed peppered moths and the possibility of change in the population as a result of industrial revolution. (three slides – one showed bird preference on light and dark areas).
Various slides of animal adaptations: (9 slides total). Slides with pictures of frogs blending into rocks, an orchid mantis, and monarch/viceroys, a frog blending into leaves, katydid mimicking a leaf, bird-dropping bell moth, plant that looks like rocks, eyespots on moths and caterpillar.

Discussion shifted to the question "can genes determine behavior?" Instructor described cuckoo behaviors and coevolution in three slides – first had a picture of an adult cuckoo with the question, one showed a baby cuckoo pushing eggs out of a nest and another showed a warbler feeding a fledgling cuckoo.
Coevolution – joint evolution of 2 or more species because of interactions

Evidence of Evolution
1. Biogeography - distribution of species
2. Fossil record
   - progression from primitive to modern forms
3. Comparative anatomy
   - anatomical similarities in related organisms
4. Molecular biology
   - DNA, proteins
5. Comparative embryology
   - similar embryonic stages

Slides – comparison of squirrels on different continents, picture of various fossils (amber, dinosaurs, hominids, footprints, shells), picture of sequence of fossils in strata, picture of transitional forms in a whale, picture of horse phylogenetic tree.

Traditional Class 2- 10/11/07
Reviewed prior topics, went into a bit more detail on

Terms
Homologous Structures – same structures in related organisms even though they have a different function
Slide - picture comparing whale, cat, bat, and gorilla; another showing evidence of ancestry and the different functions of the structures (flying, swimming, running, grasping).

Vestigial Structures – had purpose in ancestor but no apparent function today.

Slide – picture showing structures in amphibians, whales, and snakes.

Convergent evolution – analogous structure in unrelated organisms due to similar environmental pressures.

Slide – first slide compared dragonfly wing to bird wing, second compared various wings of organisms, third compared marsupials placental mammals, fourth showed similarities in molecular data (amino acids) amongst organisms, fifth showed similarities in DNA with the cytochrome C oxidase gene, sixth through ninth showed a comparison of embryos.

Artificial selection – we breed plants and animals to produce desired features

Slide – comparison of wolves and various dogs. Comparison of pigeon varieties.
Sexual Selection - Favors certain traits or behavior
- may only be advantage during reproduction
- mostly dictated by females

Slide – demonstrates comparison of male traits (lion, pheasant, bird, elk).
Three slides on guppy spots and the influence of predators/sexual selection.

NS does not *necessarily* produce well-adapted species
Evolution by NS selects for organisms that are best adapted to a particular environment, not the best in an absolute sense.
Two slides showing giraffes and how they are well adapted to eating but not drinking.

Traditional Class 3 – 10/16/07

- Charles Darwin, born 1809 in England
- 1820's – drops out of medical school, studies to be a clergyman
- Back then, science was "natural theology" – dedicated to determining "Creator's" plan
- 1830's - Darwin sails around the world including the Galapagos Islands
    - he collects different finch species

Slide – map of Darwin's voyage.

- Darwin is influenced by 2 ideas:
- Charles Lyell's *Principles of Geology* – earth is old
- Thomas Malthus' *Principles of Populations* – pop size is limited by resources
- 1838 - Darwin comes up with his theory of evolution by NS but does not go public
- 1858 - Wallace independently comes up with same idea and sends his paper to Darwin
- Both men present their theories
- 1859 – Darwin's book is published
- 1865 – Mendel publishes inheritance papers

Evolution Debate

- "Theory"

- Scientists do not debate about *whether* evolution occurs, only about *how* it occurs
- Gaps in fossil record
    - science *predicts* gaps – many organisms do not fossilize
- Do some scientists reject Darwinism?
    - only modification to Darwinism → evolution can occur <u>rapidly</u>
- Evolution is NOT a belief system, it is a scientific concept
    - Can't teach evolution AND religion - they are not based on the same principles

Slides – two slides comparing science and religion as it relates to evolution and natural phenomenon.

Traditional Class 4 – 10/18/07

ORIGIN OF SPECIES

2 slides showing linnaenan classification system.

What is a species?

- Biological Species Concept:
  <u>interbreeding natural population</u> whose offspring are <u>fertile</u> and <u>genetically isolated</u> from other species

Daughter species evolves from parent species
Anagenesis – parent species disappears as changes accumulate
Cladogenesis – parent species still exists

Slide showing physical similarity between two different bird species.

Speciation

- Speciation depends on 2 factors:

1. Isolation of populations
    - Allopatric – geographically separated
    - Sympatric – same geographic area but different habitats
2. Genetic divergence that keeps them from interbreeding

Six slides showing sympatric and allopatric speciation.

Two slides showing: A single squirrel population became geographically isolated about 10,000 years ago during the formation of the Grand Canyon. This led to 2 distinct populations: Kaibab squirrel (left) lives in the north rim & Abert squirrel (right) lives in the south rim. Since their separation, several distinguishing features have gradually evolved.

Sympatric speciation

Slide showing: These orchid species have overlapping ranges, yet are pollinated by different species of bees. Pollinators are attracted by the flowers' species-specific chemical attractants that mimic the female pheromones of the targeted insects.

Reproductive Isolating Mechanisms

➢Speciation occurs when 2 populations cease to breed

➢Mechanisms that prevent breeding are isolating mechanisms

●Premating
- Geographic
- Ecological
- Time
- Behavioral
- Mechanical

●Postmating
- Gamete incompatibility
- Hybrid inviability
- Hybrid infertility

Slide showing horse, donkey and mule. Postmating isolating mechanism - sterile mule hybrid

Three slides showing courtship in blue-footed boobies. Premating behavioral barrier: Courtship Rituals Blue-footed boobies will mate only after a specific dance is performed where the male "advertises" his blue feet.

Slide showing: Behavioral isolating mechanism: Courtship feeding of female Cardinal by male
Eight slides showing dolphin/whale hybrid, lion/tiger hybrids, wolf/coyote hybrid, zebra hybrids.

- Adaptive radiation - one parent species may give rise to many new daughter species when introduced to a new environment

Slide showing three cichlids. More than 300 species of cichlid fishes inhabit a lake in East Africa - All of them descended from a single ancestral population within a million years.

Slide showing different types of finches.

Extinction

●Death of all members of a species

●Competition, predators, habitat destruction

●Predisposed:
- limited range
- overspecialization
- hybridization (producing less fit offspring)

Three slides showing everglades kite and apple snails.

Dodo bird became extinct in 1600's (considered stupid because it did not fear humans). Now a tree species is becoming extinct.
Only 13 Calvaria trees remain and all are over 300 years old. The tree could only reproduce when the Dodo ate the fruit and passed the seeds of the fruit.

Slide showing devils hole pupfish.
Three slides showing Darwin's hawk moth.

Traditional Class 5 and 6 – 10/23/07 and 10/25/07

ORIGIN OF LIFE

Two Slides – Linnaen classification system

3 Domains of Life

1. Archaea
    - -no nucleus - prokaryote
    - - most primitive
    - - single celled
2. Bacteria
    - - no nucleus - prokaryote
    - - single celled
3. Eukarya
    - - HAVE nucleus
    - - single or multi-celled

Slide – ancestor of domains

Early Earth

- Formed about 4.6 bya
- Atmosphere:
    - -nitrogen, methane, carbon dioxide
- Environment
    - - asteroid impacts
    - - radioactivity
    - - lightning
    - - uv bombardment
- No water or oceans for millions of years

Three slides simulating early earth.

Origin of Life

- Organisms are made of
  - proteins, carbohydrates, lipids, nucleic acids
- Where did these come from?
- 3 Hypotheses:
  1. Meteorites

     Meteorite that landed in Australia in 1969 contained organic molecules that could have seeded life on earth

  2. Minerals in earth's crust and atmosphere
  3. Deep sea hydrothermal vents

Three slides showing lightning and meteorites.

Hydrothermal vents miles below the ocean surface on the ocean floor spew mineral rich hot water and support bacteria and archaea

What source of energy drove their assembly into larger molecules of life?

First Organisms

- Around 3.5 bya
- Nonliving materials ordered into aggregates - protocell
- Absorbed organic nutrients
- Prokaryotic & anaerobic
- Eventually capable of self replication and metabolism
- Diverged shortly after their time of origin

- One lineage was bacteria and the other was the ancestor of archaea and eukaryotes - what was their method of heredity?

Slide – ancestor of domains

First Genetic Material

- DNA → RNA → protein
- BUT…DNA needs proteins to copy itself
- First genes were probably RNA that can carry genetic information AND replicate – called ribozymes
- This first replicating cell would be the universal ancestor of all life
- RNA provided the template for DNA

Oxygen enters the picture

- By about 2-3 bya photosynthesis evolved in cyanobacteria
- Oxygen, a harmful byproduct of photosynthesis, started to accumulate

  2 outcomes:

1. Non-photosynthetic organisms used it, stayed away from it, or died
2. Ozone - blocks uv radiation from the sun

- Thanks to the atmospheric change – along came multi-celled eukaryotes and land organisms

Slide – earth's history represented as a 24 hour time period.

Endosymbiosis

- One species spends its entire life inside another species
- Some predatory eukaryotic anaerobic cells engulfed aerobic bacteria
- Some bacteria resisted digestion
- Both cells benefited
- Soon became incapable of independent life
- Engulfed bacteria eventually evolved into mitochondria – eukaryotic structures that provide energy for the cell
- Chloroplasts may have originated as engulfed cyanobacteria

Appendix D

What Darwin Never Saw

Charles Darwin saw many things in his lifetime. During his travels to the Galapagos Islands he witnessed some of the most remarkable types of life found anywhere on earth. Darwin kept detailed journals highlighting the characteristics of species which he noticed. Later, after returning to England, he started a revolution in scientific thinking by introducing the idea of evolution.

The Galapagos Islands are 600 miles west of the coast of South America in the Pacific Ocean on the equator. The islands formed by volcanic eruptions and some of the islands are still forming. There are 18 islands that make up the archipelago (cluster of islands) but only 5 are inhabited by organisms.

There are 13 species of Darwin's finches on the Galapagos Islands. They live about 5 years and vary in color, size, and food source. Peter and Rosemary Grant are studying Darwin's finches on an island called Daphne Major.

The Grants are trying to answer 3 questions:

1. Which finch species compete for resources?
2. Why are the finch populations variable in morphological traits?
3. How are new species formed?

Think about these questions as you watch the movie.

"Gradation in beak size is the secret to the origin of *species* (not life)"
After the movie you should be able to explain this idea.

1. Before the Grants venture onto the island they rinse everything thy have with them. Why?
2. What is the main enemy of the finches on Daphne Major Island?
3. No 2 islands have the same vegetation. How have the finches adapted to the vegetation on each island?
4. Environmental change brings about selective pressure. In 1977 there was a severe drought and it did not rain for 550 days. Finches with_____________ size beaks survived the drought. Why?
5. Does beak size make a difference? Why?
6. When does natural selection occur?
7. After the drought, did the medium-size ground finch evolve?
8. El Nino is the name given to a recurring but as yet unpredictable flow of warm currents along the west coast of South America. The winds, which cause cold water upwelling and aridity along that coast, weaken and allow warm surface waters to dominate. Unusually high amounts of precipitation are associated with the El Nino phenomenon in coastal Peru and Ecuador and on the Galapagos. El Nino is associated with other weather anomalies worldwide. In 1983 El Nino caused 3 times more rain in the Galapagos Islands, and it rained for 8 months straight. How did the vegetation respond to the abundant rainfall? How did the subsequent generations of finch populations respond to the change in vegetation?

9. The Grants witnessed the biological process of evolution TWICE during the 30 years they have studied the finches on the island. Describe the Grant's evidence for evolution.
10. Darwin thought evolution only occurred over hundreds or thousands of years. Was he correct? Explain.
11. What exactly is it that "*Darwin never saw*"?

Appendix E

Semi-structured interview questions

1. What type of learning environment do you typically prefer? (lectures, labs, discussions)
2. Which do you feel you learn the best in?
3. What were your thoughts on the Galapagos activity – did you feel you learned from it?
4. Did you prefer it over the activity (show Bird Beak lab)? Why or Why not?
5. Did you feel that you learned from the Goldfish activity – would you have preferred to do this activity (show lab manual handout)?
6. If I said to you “evolution is just a theory!” what would your response be?
7. Do you feel that individuals can believe in evolution and religion?

Appendix F

Instructor Post Write Up

Footprint and Box Activities

I was very nervous about some of activities and topics I had to cover. Some of the topics I had not previously covered in my introductory biology courses and felt as though I would not be able to field questions students may have. For example, I tell students that biology is based on data obtained from observations and inferences, however I do not devote time to activities that specifically address these tenets. In this case, I used an entire class period to explaining what these terms mean and how they are actively applied (for example the difference between an observation and inference). I liked the idea of using the box activity and the footprint activity to explore these ideas further. One of the major reservations I had with the footprint activity was that I did not feel as though I would be able to guide the students through it so that they would understand the purpose of the activity. I was not sure that I could confidently emphasize the point of the activity throughout each step so as to achieve the learning outcomes. I am someone who likes/needs a certain level of preparation. I felt this was especially important for the footprint activity because this was the first "inquiry-based" activity that the students had (and also because there are variations of the activity that may have had a greater impact on student learning outcomes). As a result I may have rushed through the footprint activity and some students may not have received the full benefits of the activity. On the other hand, I thought the box activity was very easy to oversee, and I feel as though it was very useful for showing students how scientists develop hypotheses. I often tell my students that there are "no definitive answers in science – everything is tentative" but the students were able to experience this first-hand - as I did not allow them to see what was on the bottom of the box. I will use the box activity in the future, because it is a very easy way to address important many tenets of science.

Finch Activity

When we started the finch activity, I was apprehensive that students would not understand exactly what they should be doing (and that was the case for a few who did not listen to the directions). Again, I did not feel that my level of preparation was adequate. I made sure that I gave clear instructions of what was expected of students, what they should be doing with their time, and what the assignment was. I tried to be very specific with my level of instruction so that students would not have many questions and could spend their time navigating through the program. Overall I was impressed by the students' response. Many of them quickly delved into the activity, even though they had never analyzed scientific data before. Students whom I previously did not feel were very strong academically (or who performed poorly on tests) were asking questions, taking notes, and giving presentations that were on par with "A" students. Although many students came up with the same conclusions, not everyone's was exactly the same, even though they were looking at exactly the same data. I think that was an important point for students to understand – that there is a subjective component to science and that interpretation is literally "in the eye of the beholder". Most instructors realize that lecturing and multiple choice tests are poor methods for instruction and assessment, however their ease of delivery makes them very popular. The outcome of this activity was a clear indication to me that lectures and exams should never be the only instruction and assessment methods used in my classrooms. I will probably use the finch activity again. I touched on various aspects of science inquiry and it allowed students to critically analyze information versus memorize and regurgitate.

Beak Lab

I thought the beak lab was an easy way to make the point about natural selection as a process. The students did not have any problems with that lab and it was a very easy lab to conduct. Students seemed to enjoy it (probably because the objectives were clear and the outcomes were straightforward). I will use that lab again in the future.

Fish Lab

I do not require formal laboratory reports, nor do I require students to design their own experiments. I always wanted to incorporate a component that involves these activities in my courses. I thought this lab was a great way to introduce students to experimental design and scientific writing. My only regret is that I did not spend enough time reviewing the proper procedure for writing a lab report and data collection. Many students were not writing down observations that would have helped support or disprove their hypotheses. Their lack of experience with experimentation and scientific writing was evident in their reports. However, assessment was based on their effort to properly conduct and experiment and articulate its results, therefore students were not penalized for lack of experience (only lack of effort). I will definitely use that activity again – probably in the beginning of the semester so that it coincides with the scientific method and the nature of science topics. I think this activity clearly presented the role of a scientist in developing a hypothesis, designing an experiment (some students were very creative), utilizing appropriate controls (some students need help with this and many did not understand the importance of a comparison data set), collecting data (many students took poor notes and were not able to adequately substantiate their conclusions because they had very little data), and report writing.

My opinion

I enjoyed incorporating new activities into my classes. I feel as though students benefited from my inclusion of various teaching styles. Equally important, I feel like I benefited from this experience. I now have a better understanding of the nature of science, and a better understanding of how to relay that to my students. I have refocused my attention to quality versus quantity. I want them to understand and retain, not memorize and regurgitate, and I think that nontraditional teaching approaches are imperative for this. I now have the mindset that 'letting them figure it out for themselves in 10 minutes' leads to better understanding than me 'telling them how it is in one in 1 minute'. The amount of preparation work was obviously more than a traditional lecture, but the rewards were greater – and of course I can find a balance that suits my outcomes and available time commitment.

Appendix G

Galapagos Finch Presentation Peer Review

Part of communicating ideas in science involves the process of peer review. In this process, your peers will scrutinize your research and your findings to determine whether it is acceptable for publication. Today we would like you to review the work of your fellow students. This will be a blind review – your classmates will receive your comments but not who they came from.

In your review consider the following:

1. Was the hypothesis or explanation made for the die off and survival of some finches supported by the data presented (your peers will be helped by providing specific examples)
2. Does the explanation follow a logical sequence?
3. Are all claims made justified with evidence?
4. Were alternative explanations discussed, with evidence that supports or refutes them?
5. Other comments/thoughts that would help your peers.

Place your review on a separate sheet of paper, with your name and presentation number at the top. Your name will not be shared with your classmates.

Appendix H

Date	Lecture Topic	Textbook
Th Sept 2	Properties of Life, Nature of Science	Ch 1
	Evolution	Ch 14
	Origin of Species	Ch 16
	Origin of Life	Ch 17
	Systematics	Ch 18
T Sept 28	EXAM 1	
	Molecular Basis of Life	Ch 2
	Biological Molecules	Ch 3
	Cell Structure & Function	Ch 4 & 5
T Oct 12	Lab Report Due	
T Oct 19	EXAM 2	
	Cellular Energetics	Ch 6
	Photosynthesis	Ch 7
	Cellular Respiration	Ch 8
Th Nov 4	EXAM 3	
	DNA	Ch 9 & 10
	Mitosis & Meiosis	Ch 11
T Nov 23	EXAM 4	
Th Nov 25	No Class Happy Thanksgiving!	
	Survey of Kingdoms	Ch 19, 20 & 22
Dec 9	Last Day of Class	
TBA	EXAM5 - Final Exam	

Date – T or Th 9:30 class meets on Tues. 11:00 class meets on Thurs.	**Lab Exercise**
Sep 7 & 9	Scientific Methodology & Experimental Design Parts of Lab 2 – Metric System
Sep 14 & 16	Group Experiments – Gold fish
Sep 21 & 23	Evolution – What Darwin Never Saw
Sep 28 & 30	Parts of Lab 2 - Microscope
Oct 5 & 7	Lab 3 - Chemical Composition of Cells
Oct 12 & 14	Lab 4 - Cell Structure and Function
Oct 19 & 21	Enzyme Lab
Oct 26 & 28	Lab 8 - Photosynthesis
Nov 2 & 4	DNA Lab DNA Project Handout
Nov 9 & 11	DNA Movie DNA Projects Due
Nov 16 & 18	Lab 5 - Mitosis and Meiosis
Nov 23 & 25	No Lab – Happy Thanksgiving
Nov 24 & 26	Microbiology Lab
Dec 1 & 3	Parts of Labs 9, 10, 26, 27 - Organization of Plants
Dec 8 & 10	Last Week of Class