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Preservice teachers' understanding of *evolution, the nature of science, and situations of chance

Louis Scott Nadelson

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PRESERVICE TEACHERS' UNDERSTANDING OF EVOLUTION,
THE NATURE OF SCIENCE, AND SITUATIONS OF CHANCE

by

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A dissertation submitted in partial fulfillment
of the requirements for the

Doctor of Philosophy Degree in Educational Psychology
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Doctor of Philosophy Degree in Educational Psychology

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ABSTRACT

Preservice Teachers’ Understanding of Evolution,
The Nature of Science, and Situations of Chance

by

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The learning and teaching of biological evolution, the nature of science and situations of chance is conceptually challenging. Attempts to increase understanding in these domains has resulted in limited occurrences of success, and the identification of many related misconceptions. The alternative conceptions have been detected in teachers as well as students, which reflects the complexity of learning the content. Teachers’ understanding of these concepts is critical to assuring they do not perpetuate misconceptions by teaching them to their students. The consistent detection of misconceptions in teachers suggests that new approaches to increasing understanding of these concepts need to be explored. In this project it was hypothesized that misconceptions of biological evolution were the result of a lack of understanding about the stochastic processes associated with evolution. The preservice teachers participating in this project were from a state university in an urban setting in a city in the southwest United States. This project began with the measurement of the preservice teachers understanding of biological evolution, situations of uncertainty, and the nature of science. Demographic data was collected to determine
the relationship between personal attributes and the understanding and acceptance in the three domains of study. The instructional intervention for the experimental group involved a combination of web based tutorials focused on misconceptions of biological evolution, and related concepts of nature of science and situations of uncertainty which were presented in the context of evolution. The control group received the same web based evolution and nature of science instruction without the situations of uncertainty instruction. To assure similar time on task the control group received an instructional model describing Darwin’s voyage on the Beagle. A delayed post test and the development of a lesson idea provided the quantitative and qualitative data necessary for the determination of the instructional impact on conceptual change and the development of content knowledge. The analysis indicates that the inclusion of situations of uncertainty content with biological evolution instruction increases understanding of the process and initiates the process of conceptual change leading to a greater comprehension of concepts. The lesson idea analysis indicates that the interventions increased teachers’ knowledge and ideas about teaching the concepts in the domains of the study. Analyses of personal characteristics provide evidence for detectable relationships between understanding and acceptance of concepts and individual attributes. The results of this study support the need for further investigation into the impact of combined curricula on promoting conceptual change, addressing learner and teacher misconceptions, and developing content knowledge.
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CHAPTER 1

UNDERSTANDING OF EVOLUTION AND CHANCE

Misconceptions

People hold many conceptions of science and mathematics that are inconsistent with the scientifically accepted positions. In an effort to expose this phenomenon, Schneep and Sadler (1985) asked Harvard University graduates, alumni, and faculty, what caused the changes in the Earth’s seasons. A large majority responded with the misconceived notion that the seasons are due to the Earth’s proximity to the Sun. Some of those interviewed had even taken extensive science coursework and yet, still held the misconception that in summer the earth is closer to the sun and in winter it is farther away. This reflects one of many commonly held misconceptions in science. Misconceptions of scientific phenomenon often result from the application of assumptions and naïve understandings developed through interactions with every day events (Smith, diSessa, & Roschelle, 1993/1994; Southerland, Abrams, & Cummins, 2001; Vosniadou, 1994). The application of these assumptions and naïve understandings may lead to correct conceptions, but may also lead to misconceptions.

Misconceptions are personal “…representations that are incorrect from the point of view of the established disciplinary knowledge – notions that interfere with subsequent learning” (Murphy & Mason, 2006, p 307). Misconceptions may also be referred to as naïve conceptions, folk conceptions, or alternative conceptions.
It is important to consider individual characteristics and attributes when examining conceptual acceptance, understanding and levels of misconceptions. Sinatra and Mason (in press), claim that individual experiences and personal traits impact the development and retention of misconceptions. Hofer and Pintrich (1997) argue that learning is influenced by personal differences such as age, and individual experiences such as years of education. Torres and Baxter Magolda (2004) present evidence supporting the influence of culture on the development and interpretation of knowledge. Baxter Magolda (1992) also makes a case for the influence of gender on college level learning. Schoenfeld, (1987) provides further support for the influence of gender and problem solving experience on mathematics learning. Seibert (1992) reports a similar trend for the gender influence found in science learning. Personal attributes such as level of religious commitment and educational background, have been revealed to be important considerations when examining certain misconceptions (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Evans, 2001; Verhey, 2005). Therefore, there is theoretical and practical justification for the examination of the individual differences measures of gender, age, intended grade level of service, years of education, the number of mathematics and science courses, and level of religiosity, in relationship to misconceptions of evolution, the nature of science (NOS) and situations of chance.

Misconceptions are common in science and mathematics because knowledge of everyday experiences is readily applied to explain seemingly related phenomenon (Driver, Squires, Rushworth, & Wood-Robinson, 1994). However, there can be very different explanations and conditions that may actually be taking place, and therefore,
interpretations may be naïve conceptions of phenomenon (Chinn & Brewer, 1998; diSessa, 1993; Vosniadou, 2003).

One of the most misconceived and widely debated scientific phenomena is biological evolution (Alters & Alters, 2001; Gallup Poll, 2006; Miller, 1999). Scientific definitions of biological evolution remain elusive to many. The problem with holding misconceptions of biological evolution is that the field of biology necessitates understanding the theory. Therefore, misconceptions of the theory may hinder the ability to grasp related concepts or may result in the development of additional misconceptions (Alters, 2005; McComas, 2006; Miller 2002). The importance of evolutionary theory to conceptualizing biology makes the lack of understanding problematic. To accurately grasp many of the biological and societal implications of processes such as genetic engineering, antibiotic resistant bacteria, and deforestation, requires an understanding of evolutionary theory. These processes and others have become societal issues which involve public decisions and policy development, and therefore necessitate an informed citizenry. Genetic engineering, genetically modified food, cloning and other biology based developments have become societal issues that involve public input and decision making. Given technological and biological advances there is an increasing need to assure citizens understand biological evolution in order to make informed decisions.

The depth and breadth of scientific research influencing evolutionary theory has resulted in the development of lengthy and complex definitions of the process. However, Miller (2002) summarizes this complex and voluminous area of scientific study offering a concise and comprehensive definition of biological evolution. From his perspective as a scientist Miller writes, "Evolutionary theory weighs the relative contributions of
mutation, variation, and natural selection, and tries to understand how the interlocking actions of heredity, sex, chance, environment, cooperation and competition drive the fine details of descent with modification” (p. 54).

The misconceptions and controversy surrounding biological evolution can range from minor misunderstandings to complete theory rejection (Alters & Alters, 2001; Dagher & Boujaoude, 2005; Evans 2001; Mazur, 2004; McComas, 2006; Miller, 1999; Sadler, 2005).

It is apparent from the definition of biological evolution offered by Miller (2002) that chance is a significant construct associated with the process. Nickerson (2004) defines chance situations as those in which all events of the same kind are reduced to a number of equally possible cases that are undecided in terms of their existence. Situations of uncertainty, or chance, are also beset with misconceptions for many of the same reasons that are found in science (Nickerson, 2004; Shaughnessy 2003). Tversky and Kahneman (1982b) argue that people tend to believe that a deterministic mechanism drives chance. Therefore, they develop conceptions of situations of uncertainty that are determined by their understanding of luck as a self correcting probability. This may be due to an inherent tendency to understand phenomena in terms of cause and effect (Tversky & Kahneman, 1982b). Yet, the processes of biological evolution rarely involve cause and effect; therefore, the comprehension of chance occurrence is fundamental to understanding the theory of evolution (Sadler, 2003). A possible source of misconceptions of biological evolution may be found in naïve conceptions of situations of uncertainty (Sadler, 2003). The links between these two concepts indicate a need to
resolve misconceptions related to both in order to accurately understand biological evolution.

Yet another influence on the misconception of biological evolution to be considered is student conceptions of the process of science itself (McComas, 2006). The process of doing science is referred to as, the nature of science (NRC, 1996; AAAS, 1993). The nature of science may be defined as a:

. . . hybrid arena which blends aspects of various social studies of science including the history, sociology and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavors. (McComas et al., 1998, p. 4)

Many people do not understand this process and hold predictable and readily identified misconceptions about the nature of science (Abd-El-Khalick & Akerson, 2004; Chinn & Malhotra, 2002; Cooper, 2002; Gibbs & Lawson, 1992; McComas, 1998; Scharmann, Smith, James, & Jensen, 2005). According to McComas (1998) one common misconception of the nature of science related to biological evolution is the understanding of what constitutes a scientific theory. Used on a daily basis, the term “theory” is applied to situations that involve educated guesses or predicted outcomes. However, in science, the term is used as a label for well developed, evidence-based explanations. Therefore, it is not uncommon for people to misconceive a scientific theory as a tentative prediction, incorrectly applying the everyday use of the term.
To accurately comprehend biological evolution, it is necessary to have an accurate conceptualization of situations of uncertainty combined with the understanding of the nature of science (Alters, 2005; McComas, 2006; Miller 1999; Sadler, 2005). Yet, all three of these areas are laden with misconceptions, compounding the barriers toward changing students’ conceptions toward scientific positions. Thus, this study proposes to address this situation, by assessing misconceptions of biological evolution, the nature of science, and situations of uncertainty and then providing instructional interventions in all three areas. This responds to the literature suggesting that it is necessary to teach the nature of science and situations of uncertainty in context (Dagher & Boujaoude, 2005; Dihindsa & Anderson, 2004; Hallden, 1999).

Teacher Preparation

The national and state educational emphasis on biological evolution reflects motivation to direct curriculum to assure k-12 students and teachers learn the concept. In response to the challenges of understanding biological evolution and its relationship to the comprehension of other biology concepts, the American Association for the Advancement of Science (AAAS), the National Research Council (NRC) and the National Science Teacher Association (NSTA) have responded by making evolutionary theory an essential component in their educational agendas. The AAAS (1993) has established biological evolution as a significant component including aspects of the theory in their benchmarks starting in the third grade. In the National Science Education Standards, the NRC (1996) places strong emphasis on biological evolution as a unifying concept. The NSTA (1997) has also included evolution as a major component of their
teacher preparation and curricular standards. Many state departments of education have responded likewise, establishing biological evolution as an essential component of their student and teacher science educational standards (Moore, 2001).

There is an abundance of biological evolution instructional materials present throughout the curriculum (NRC, 1996), and yet, the majority of the public hold misconceptions of the phenomenon (Gallup, 2006). Thus, there is a need to determine what hinders or influences the understanding of evolutionary theory. In addition, there is a need for methods of examination to determine the effectiveness of biological evolution instructional materials on knowledge acquisition and conceptual change. This research is structured to address these issues by examining learner needs and instructional content.

Research has revealed many of the students completing study in k-12 and higher education programs develop and retain misconceptions of biological evolution (Alters & Nelson, 2002; Blechmann, 2006; Cooper, 2002; Ingram & Nelson, 2006; Matthews, 2001; Mazur, 2005; Rutledge & Warden, 1999). It is also well documented that teachers hold and transfer misconceptions to their students (Jarvis, Pell, & McKeon, 2003; McComas 1996; NRC 1996; Yip 2001). To address this situation, alternative approaches need to be explored to find methods that help teachers be prepared to accurately and effectively teach age appropriate concepts of evolutionary theory (Matthews, 2001; McComas, 2006; Rutledge & Mitchell, 2002; Verhey, 2005). The current research involves preservice teachers as participants because it is important that such issues are addressed prior to educators entering service. Preservice teachers are undergraduate or graduate students who are studying education with the intention of becoming teachers.
Preservice teachers have not yet entered the profession at a level of service, and therefore, may be more impressionable (Darling-Hammond & Bransford, 2005). This suggests there may be a greater chance to address their misconceptions and prepare them to be more effective at teaching biological evolution concepts.

The growth of teacher content knowledge requires effective teaching and the subsequent assimilation of subject knowledge (Darling-Hammond & Bransford, 2005; Shulman, 1987). Darling-Hammond and Bransford (2005) recognize the influence that personal experience and successful learning have on the development of content knowledge. Thus, through engagement with learning opportunities that integrate content in ways that lead to greater understanding and higher levels of learning success, teachers can increase understanding of subject matter.

Teachers’ views of teaching and content are influenced by years of education (Hill, 2004; Hoy, Davis, & Pape, 2006; Pajares, 1992). This typically results in teachers teaching in the manner they were taught (Deemer, 2004), and instructing the content they learned (Alters & Nelson, 2002; Llinares & Krainer, 2006). However, what is taught and what students learn may not be consistent. There is evidence that students in university programs in mathematics and science may exit these programs holding a number of misconceptions of fundamental concepts (Abd-El-Khalick & Akerson, 2004; Barnett & Hodson, 2001; Sadler, 2005). The documented teaching of science misconceptions (Haidar, 1997; Lawrenz, 1986) reveals that teachers may have incomplete content knowledge, may hold misconceptions, or both. This suggests the need to examine the methods by which teachers are prepared and to address preservice teacher understanding of content prior to their entry into the profession (Pintó, Couso, & Gutierrez, 2005).
Conceptual Change

Changing conceptions is a fundamentally different process than acquiring new knowledge (Murphy & Mason, 2006). Acquiring new knowledge involves learning information for the first time and developing a conceptual understanding from new information. Changing conceptions requires modifying already learned information to form new understandings. The shifting and adoption of new understanding is known as conceptual change (Murphy & Mason, 2006). The process of conceptual change requires the altering of perspectives and assumptions allowing the individual to embrace new ideas that often conflict with a personal point of view (Driver et al., 1994; Mason & Limon, 1999; Murphy & Mason, 2006; Vosniadou, 1994). This is a difficult process because misconceptions tend to be robust and resistant to change, because once learners have formed an understanding, they are not likely to consider alternatives, especially if alternatives explanations are contradictory to their experiences (Mason & Limon, 1999; Murphy & Mason, 2006; Sinatra & Pintrich, 2003, Vosniadou, 1994). Yet, conceptual change is fundamental to learning (Vosniadou, 1994).

Vosniadou (2003) defines “conceptual change” as: “...the outcome of a complex cognitive as well as social process whereby an initial framework theory is reconstructed...this is a slow and gradual affair often accompanied by misconceptions, inert knowledge, internal inconsistencies, and lack of critical thinking” (p. 377).

Vosniadou (2003) elaborates on the complexity of conceptual change and the necessity to consider other factors such as social influences, personal affect and motivation, the setting in which learning takes place, and metacognitive abilities. Although the process of conceptual change is typically long term, a shift in preservice
teacher conceptual understanding may be possible with relatively short, but well crafted interventions (Matthews, 2001; Scharmann et al., 2005). Conceptual change typically involves significant knowledge restructuring. However, less dramatic changes or “conceptual shifts” may be evident after even brief instruction (Nussbaum, Sinatra, and Poliquin, in press). Nussbaum et al. define conceptual shifts as “nascent revisions of knowledge that can serve as precursors to more substantial knowledge restructuring or conceptual change” (p. 6).

The basic process of teaching for conceptual change involves assessing students to ascertain the nature of their prior knowledge and the levels of held misconceptions, implementing an instructional intervention intended to resolve the misconceptions, and then post assessing for change (Murphy & Mason, 2006; Posner, Strike, Hewson, & Gertzog, 1982). A variety of conceptual change instructional approaches have been identified (Sandoval, 1995), and continue to be investigated. It is possible that the impact of these conceptual change approaches may increase when combined with other instructional processes. Akerson, Abd-El-Khalick, and Lederman (2000) argue for the inclusion of explicit statements of learning to increase effectiveness of conceptual change pedagogy.

The purpose of this research is to meet the call for further understanding conceptual change in preservice teachers’ understanding of biological evolution. My study addresses educators’ conceptions of biological evolution, the nature of science, and situations of uncertainty, exploring an approach that may address misconceptions prior to service, while examining the effectiveness of biological evolution instructional materials presented using a web-based format.
Research Questions

My research questions are designed to explore preservice teachers’ conceptions of situations of chance, the nature of science, and evolutionary theory, with the goal of increasing understanding and fostering a conceptual shift in participants’ conceptions.

1. Do preservice teachers hold misconceptions of biological evolution, situations of uncertainty, and the nature of science? If so, what are these misconceptions?

2. Is instruction targeted at promoting understanding of the nature of science, situations of uncertainty, and biological evolution effective in promoting understanding and reducing misconceptions in pre-service teachers’ conceptions of these phenomena? Do preservice teachers gain a greater understanding of biological evolution when instruction in these three areas is combined? Does combining interventions result in conceptual shifts as reflected by fewer misconceptions about these three phenomena?

3. Can pre-service teachers use knowledge gained from web-based instruction in these areas in lesson plan development?

4. Do individual differences in gender, age, intended grade level of service, years of education, the number of mathematics and science courses, and level of religiosity predict the number of held misconceptions?

Hypotheses

Three lines of research provide the framework for the hypotheses of this research.

First is the evidence that preservice teachers hold misconceptions of biological evolution,
situations of uncertainty, and the nature of science (Jarvis et al., 2003; McComas 1996; NRC 1996; Yip 2001). Second, personal traits and individual differences have been determined to influence conceptual change (Pintrich et al., 2003). Finally, the contextual integration of nature of science and situations of uncertainty with biological evolution may be beneficial to gains in understanding of all three concepts (Dagher & Boujaoude, 2005; Dihindsa & Anderson, 2004; Hallden, 1999).

These hypotheses predict the outcome of this project, addressing each of the previously stated research questions.

**Hypothesis 1:** Preservice teachers hold misconceptions of biological evolution, the nature of science, and situations of uncertainty consistent with those found in undergraduate students and not unique to preservice teachers.

**Hypothesis 2:** Preservice teacher’s understanding of the nature of science, situations of uncertainty, and biological evolution will be fostered with targeted web-based instruction, reducing their misconceptions of these phenomena. An instructional intervention that integrates biological evolution, situations of uncertainty, and the nature of science in context will lead to a greater understanding of biological evolution and will show larger gains than instructional interventions that address only biological evolution and the nature of science. The combination of all three content interventions will result in a greater reduction in misconceptions in evolutionary theory, the nature of science, and situations of uncertainty, than the changes detected from the interventions of biological evolution and the nature of science.

**Hypothesis 3:** Pre-service teacher development of ideas for teaching biological evolution topics to their future students will reflect knowledge gained from instruction in
the association of evolutionary theory, the nature of science, and situations of uncertainty, as presented to them in the instructional interventions.

Hypothesis 4: Individual differences in age, intended grade level of service, years of mathematics and science courses, and level of religiosity will predict the number and type of misconceptions held. I predict that as age and the grade level of service increases the number and type of misconceptions held will decrease. I predict as the number of mathematics and science courses increases the number and type of misconceptions held will decrease. I predict that as religiosity increases the number of evolution misconceptions held will increase. Gender will not be a predictor of misconceptions.

Research Methods

My research required the formation of an experimental group and a control group. The participants in both groups were pre-assessed for individual characteristics such as age, levels of education, and religiosity. These traits were investigated as possible predictor variables of misconceptions. Both groups were pre- and post-tested for their understanding of the nature of science, understanding of situations of uncertainty, understanding of biological evolution, and their acceptance of biological evolution. Between testing, both groups received some level of instructional intervention. To determine if learning benefited from combining content, the control group received instruction in biological evolution and the nature of science, and the experimental group received instruction in biological evolution, situations of uncertainty, and the nature of science. To resolve the possible confound associated with time on task, the control group also received instruction related to the life and travels of Charles Darwin, which was not
assessed as part of this study. This assured that the intervention for both groups was similar in regards to time on task. Post-test results were used to ascertain the impact on the understanding of the three conceptual domains based on the combinations of instructional intervention. Measures of individual differences were applied as grouping variables or examined as indicator variables.

To determine the impact of the web-based instruction on the preservice teachers' content knowledge, participants were asked to develop a lesson idea based on the instructional intervention they received. Instructions for this activity directed the participants to develop a lesson idea that was appropriate for their targeted age level or content area. The products were analyzed qualitatively using a priori and emergent coding to examine responses for inclusion of concepts targeted in the instructional interventions, integration of content, and attention focused on common misconceptions.

The combination of the quantitative data from the survey instruments and qualitative data from the lesson ideas was used to determine changes in levels of understanding and the ability to transfer learning gained from instruction to the development of pedagogy. Further, the quantitative and qualitative data complemented each other providing a more comprehensive analysis of participant knowledge and the instructional impact.

Discussion of Results

My study revealed that the participating preservice teachers held many of the same misconceptions of biological evolution, situations of chance and the nature of science that are detailed by others (Alters, 2005; Alters & Nelson, 2002; McComas, 2006; Sadler, 2005; Tversky, & Kahneman, 1982b). A repeated measures ANOVA revealed that the
instructional intervention had some impact, with a significant main effect for the increased acceptance of evolution. The repeated measures analysis also revealed a significant interaction for understanding evolution and for situations of uncertainty indicating that there was a differential effect of instruction on the two groups. Although Dagher and Boujaoude (2005) suggest teaching nature of science in the context of biological evolution increases understanding of both concepts, I did not detect a benefit.

Participants in both groups included content from the web-based tutorials in their lesson ideas indicating some influence by the instructional intervention. This suggests that the tutorials could be used to meet the call for the development of models, appropriate content, and ideas for classroom practices to aid in preservice teacher preparation (Darling-Hammond & Bransford, 2005; Marion, Hewson, Tabachnick, & Blomker, 1999). However, there was also indication that both the control and experimental groups continued to hold misconceptions of the evolution and the nature of science following instruction, providing further evidence for the robust nature of misconceptions.

The examination of relationships between individual difference and conceptions of the three study concepts revealed several significant findings. Some of these results were expected, such as the relationship between religiosity and acceptance of evolution, while others were not predicted, such as the relationship between gender and understanding of situations of uncertainty and the nature of science. Yet, a discernable trend was not apparent making the use of a number of individual differences a problematical predictor of three study concepts.
CHAPTER 2

REVIEW OF LITERATURE

Introduction

Learning new knowledge or changing conceptions involves the interaction of biological and physiological factors with individual experiences, perceptions, emotions, and prior knowledge (Brunning, Schraw, Norby, & Ronning, 2004). The biological structure and physiology of the brain is relatively consistent among learners, which indicates that personal experience, perceptions, emotions, and prior knowledge are the primary determinants of individual differences in learning (Bransford, Brown, & Cocking, 1999). When studying learning the complex interaction between personal experience, perceptions, emotions, and prior knowledge necessitates the use of multiple theoretical frameworks.

In this review of literature I began with a review of learning research, since it provides a platform for examining misconceptions and the process of conceptual change. The theoretical models and supporting empirical research were examined. This is followed by an exploration of the process of conceptual change. I then explore further the perceptions and misconceptions of the nature of science, situations of uncertainty, and biological evolution. I developed an argument to support the position that these three topics are inextricably related, and the ability to conceptualize evolutionary theory requires understanding the other two concepts.
Given the impact of teachers on learning and education (Darling-Hammond & Bransford, 2005; Hoy et al., 2006; Pajares, 1992), I examined the beliefs, abilities, and conceptions, of educators and how these impact their practice. This provided the support for my research which examines and addresses preservice teacher understanding of the nature of science, situations of uncertainty, and biological evolution. Further, my research examined how the presentation of these three topics in a related context improves the understanding of each.

Prior Knowledge and Learning

Prior knowledge is a significant factor influencing the learning process (Bransford, Brown, & Cocking, 1999; Driscoll, 1994; Kirschner, Sweller, & Clark, 2006; Mayer, 1996; Schunk, 2004); therefore, it is a necessary construct to keep in mind in the development and application of cognitive theory (Bruning, Schraw, Norby, & Ronning, 2004). Individual experiences affect personal perception, which may result in very different interpretations of the same situation (Bransford et al., 1999). Thus, even though learners may experience the same learning situation, their prior knowledge may result in very different personal interpretations.

Much of learning is based on inference, with learners applying prior knowledge, and personal perception to form meaning. Research conducted by Chinn and Malhotra (2002) provides empirical evidence to support the position that prior knowledge plays an important and significant role in the process of forming both accurate and naive conceptions. Learners' construction of meaning relies on personal perceptions and prior
knowledge and if they hold inaccurate conceptions they are likely to form additional erroneous thoughts based on their beliefs (Driver et al., 1994; Vosniadou 1994).

Prior experience is vital to the acquisition of new knowledge (Reynolds, Taylor, Steffensen, Shirey, & Anderson, 1982). This is where expert learners have an advantage over novice learners. The result is different approaches to viewing and solving problems by expert and novice learners, which not only affects how people solve problems, but how they learn new ideas and change conceptions (Bruning et al., 2004; Schoenfeld, 1987). Teachers can provide expert learner guidance to student learning at the novice level, allowing for more productive learning to take place (Bruning et al., 2004; Schoenfeld, 1987).

The process of applying knowledge and determining the most effective approach impact how learning and problem solving take place (Hennessey, 2003; Reynolds & Wade, 1986; Schoenfeld, 1987). If learners have more advanced abilities they can determine productive approaches to problem solving and are more likely able to consider alternative explanations of concepts (Bruning et al., 2004). Thus, as learners gain knowledge and develop advanced problem solving skills, the process of changing conceptions is less cognitively demanding and alternative perspectives are easier to consider. For learners to engage in accurate conceptual development, their prior knowledge must be also be accurate, or they may not be attentive to the new information and perceive it in a way that is consistent with the presented explanation (Vosniadou, 1994).

The learning theories and processes discussed previously substantiate the importance of prior knowledge to developing meaning. Thus, it becomes apparent that individual
differences and experiences are significant constructs to be considered in learning and
teaching (Pintrich et al., 1993; Sinatra & Mason, in press). Familiarity with student prior
knowledge provides direction for developing ways of promoting more effective
approaches to science education (Posner et al., 1982; Scharmann et al., 2005; Verhey,
2005).

People do not view the world through the same lens. It has been recognized that
individual differences influence how learning takes place (Pintrich et al., 1993; Sinatra,
2005; Sinatra & Mason, in press). Personal views of knowledge and prior experiences
impact the ability to change conceptual understanding (Mason, 2003). For instance, if a
learner holds the belief that evolution is deterministic and has had experiences that
reinforce his/her conception then s/he is very unlikely to consider alternative explanations
of the process. The influence of prior experience and personal perspective directly impact
how learning takes place and what knowledge will be considered (Mason, 2003; Dole &
Sinatra, 1998). Misconceptions can act as barriers to knowledge acquisition and
conceptual change, and without intervention, learners are unlikely to modify their
hindering perceptions and will continue to develop additional misconceptions
compounding the situation (Andre & Windschitl, 2003; McComas, 1998).

Prior knowledge impacts how individuals acquire new information and consider
alternatives in the development of conceptions. Therefore, individual differences in
openness to change should be considered an essential aspect when working with learners
to help them change conceptions.
Conceptual Change

Vosniadou (2003) defines “conceptual change” as: “…the outcome of a complex cognitive as well as social process whereby an initial framework theory is reconstructed…this is a slow and gradual affair often accompanied by misconceptions, inert knowledge, internal inconsistencies, and lack of critical thinking” (p. 377).

There is a significant difference between knowledge acquisition and the process of changing conceptions (Murphy & Mason, 2006). Conceptual change requires more effort and takes more time than knowledge acquisition because individuals are not only learning new ideas, but also reducing commitment to held conceptions (Murphy & Mason, 2006; Sinatra & Pintrich, 2003; Vosniadou, 2002). The added effort of reducing consideration of held conceptions accounts for the additional effort required for conceptual change to take place compared to acquiring knowledge. Thus, the research on conceptual change learning necessitates different perspectives and unique investigative approaches, beyond those used to research knowledge acquisition.

The process of conceptual change in science education was formalized in the seminal work by Posner, Strike, Hewson, and Gertzog (1982) in which they proposed the Conceptual Change Model (CCM). The model proposed by Posner et al. consists of four criteria that need to be met by the learner in order to consider an alternative explanation and undergo a change conception. First, the learner needs to find his/her present conception to be dissatisfactory in explaining phenomenon. If this condition is satisfied, the new explanation must be plausible in that it makes sense, it must be fruitful in that it leads to a gain in knowledge or some other benefit, and it must be intelligible in that the learner can grasp the concept. In this model, these criteria must be satisfied otherwise
learners will not undergo conceptual change and will most likely maintain their original conceptions.

The Posner et al. model (1982) has become a framework for the examination of conceptual change in science and other domains. Additionally, the CCM spawned the development and further refinement of additional models of conceptual change (Dole & Sinatra, 1998; Grégoire, 2003). Several models have been developed to represent conceptual change, however, I am going to limit my discussion and application to the *Cognitive Reconstruction of Knowledge Model* (Dole & Sinatra, 1998).

Dole and Sinatra (1998) expanded on Posner et al. (1982) and the work of others to develop the *Cognitive Reconstruction of Knowledge Model* (CRKM). The CRKM model takes into account knowledge of cognitive and social psychology and research in science education to form a more comprehensive model of how conceptual change takes place. In developing the CRKM, Dole and Sinatra have made a significant advance toward the development of a conceptual change theory by including additional constructions such as individual goals, motivation, and intention. Although the Posner et al. seems to implicitly address these constructs, Dole and Sinatra explicitly include affect and motivation as being influential on engagement in conceptual change.

As with the Posner et al. (1982) model, the Dole and Sinatra (1998) model starts with the existing conceptions of the learner, but then examines the motivation for change from multiple perspectives. Dole and Sinatra posit that motivation to change does not necessarily require dissatisfaction with a conception, recognizing that social and personal factors may play a role in the decision to engage in the conceptual change process. Further, the Dole and Sinatra model includes a scale of engagement in the conceptual

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change process, which adds explanatory strength for the possible outcomes of weak and strong conceptual change. The CRKM addresses learner experiences and perceptions, emotions, and prior knowledge, while recognizing the difficulty individuals have in changing their commitment to their conceptions. Dole and Sinatra have attempted to provide a comprehensive framework of the conceptual change process, which can be applied in misconception and conceptual change research.

The identification of individually held misconceptions and the desire to change them provides the conditions for investigating conceptual change instruction (Murphy & Mason, 2006). Misconceptions are plentiful in science; therefore, this is a domain of extensive conceptual change research activity (Driver et al., 1994). Instructional approaches to conceptual change creates conditions in which individuals are prompted to examine their present concepts, contrast them to the accepted scientific explanations, and then proceed to either some level of change or maintenance of held misconceptions (Chinn & Brewer, 1998; Kang, Scharmann, & Noh, 2004). Achieving conceptual change is challenging because learners must intentionally suppress held beliefs, while considering and accepting alternative perspectives. This is further complicated by the possibility that a scientific explanation may be counter-intuitive to prior experience (Andre & Windschitl, 2003; Sinatra & Pintrich, 2003).

When learners hold on to misconceptions it reduces their ability to consider alternative explanations or even view a situation from another perspective (Murphy & Manson, 2006; Vosniadou, 2003). Therefore, to change misconceptions and develop new conceptions understanding learners must release or suppress their misconception schema while forming a new schema. This can happen consciously or subconsciously. In the

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subconscious situation learners, suddenly realize that an alternative explanation is more plausible and have an epiphany from which point on they embrace a new conception. When conscious effort and attention are put forth to change conceptions it requires intention. It is what Sinatra and Pintrich (2003) advance as, intentional conceptual change.

**Intentional Conceptual Change**

Intentional conceptual change acknowledges situations in which learners put forth concerted efforts to modify conceptions (Sinatra & Pintrich, 2003). This is in contrast to a more subtle form of conceptual change in which learners’ conceptions are modified through a passive learning process (Sinatra & Pintrich, 2003). In passive learning, individuals inadvertently develop new perspectives from a passive accumulation of knowledge; however, in the process of intentional conceptual change the learner is effortful in the development of new conceptions (Ferrari & Elik, 2003; Vosniadou, 2003). The required effort for intentional conceptual change is dependent on the depth of the misconception. If the misconception is the result of sufficient knowledge but incorrect conclusions, the process is referred to as weak restructuring, similar to assimilation. However, if the naïve conception is the result of embracing inaccurate concepts, then the process of intentional conceptual change requires radical restructuring, similar to accommodation (Bruning et al., 2003; Kalkanis, Hadzidaki, & Stavrou, 2003).

Sinatra and Pintrich (2003) posit that in intentional conceptual change instruction, learners are exposed to sufficient evidence and conditions that prompt the examination of information inconsistent with held conceptions. When learners suppress held conceptions and favor new thoughts, they are intentionally changing conceptions (Sinatra & Pintrich,
2003). This is a desired outcome when working with students holding misconceptions, but is not always easy to promote, for motivation is required for intentional conceptual change to take place (Sinatra & Pintrich, 2003).

Consider the process of intentionally changing the common misconception that biological evolution is teleological, to the accepted conception that it is primarily a random process. If intentional conceptual change is to take place, individuals would be motivated to question the teleological conception of evolution as a less effective explanation while considering the random event explanation as a plausible alternative. This consideration is motivated by the presentation of evidence that supports the random process of biological evolution, while contradicting the misconception. As learners consider the random event alternative perspective, they must also be motivated to accept it as a new conceptual explanation, resulting in changed conceptions (Ferrari & Elik, 2003). For the new conceptual perspective of biological evolution to become dominant, the learner must be motivated to reduce attention to the teleological misconception schema while reinforcing the new random event schema. To assure the process takes place, learners must be intentional in their conceptual change efforts (Vosniadou, 2003).

The common occurrence of misconceptions in science, and specifically in understanding evolutionary theory, necessitate the consideration of conceptual change pedagogy. Conceptual change instruction combines techniques and approaches that are not traditionally integrated or necessary for effective knowledge acquisition (Duit, 1999). Although there are consistent themes in teaching for conceptual change, there is a variety of successful instructional approaches that have been investigated and continue to be explored.
**Instructional Approaches for Conceptual Change**

Misconceptions are deceiving and concealed, residing within the mind of the learner, influencing how they perceive and interpret situations (Murphy & Mason, 2006). Because individual perception is experience dependent, it is possible for learners to hold a wide range of preconceptions making instruction particularly exigent. Almost all research investigating conceptual change instructional designs state that it is necessary to begin the process by determining what the learner knows or thinks to expose their preconceptions (Hewson & Hewson, 2003; Morrison, & Lederman, 2003). A pre-instructional concept inventory is typically administered as a first step in teaching for conceptual change (Fisher, 1998). Yet, many misconceptions may not be easily exposed, so constant monitoring may be an essential technique when teaching for conceptual change.

Although curriculum designed for conceptual change requires additional components than other forms of instruction, it still needs to be consistent with how people think and learn (Duit & Treagust, 2003). When designing curriculum it is important to align the content to be learned with appropriate instructional approaches, although it may seem obvious, it may not occur unless it is purposely addressed (Bransford et al., 1999).

Students gain more from instruction if they know what to expect, being made aware of lesson goals. This has been attributed to the notion that advanced organizers allow students to activate existing schema effectively preparing them for learning (Bruning et al., 2003; diSessa, 1993; Sandoval, 1995). Once students have activated schema, their minds are prepared for learning, yet there are other considerations that should also be
taken into account to assure students are meaningfully engaged in lessons. Thus, conceptual change instruction should begin with goals statements of intention to change misconceptions, which is followed by instructional strategies.

Conceptual change instruction is complex because students come to the learning environment with a number of preconceived ideas of fundamental concepts that influenced the development of misconceptions (Chinn & Brewer, 1998). The presence of influential previously developed conceptions necessitates instructional strategies that attend to the impact on the development of student misconceptions. In addition, learners need to be provided with plausible and attainable perspectives which facilitate the development of new conceptions (Posner et al., 1984). Thus, conceptual change instructional strategies have dual goals, the first is to provide evidence that contradicts misconceptions, and the second is to provide a process and structure for the formation of the desired conception.

Several instructional strategies have been determined to be effective at promoting conceptual change (Sandoval, 1995). These instructional strategies are effective because they present learners with situations and evidence that lead to disequilibrium with held misconceptions while exposing them to alternative explanations (Murphy & Mason, 2006, Posner et al., 1982; Sinatra & Pintrich, 2003) Thus, these instructional approaches assist students through the steps required for acceptance of a new perspective which is the goal of teaching for conceptual change.

Several conceptual change instructional techniques have been identified and studied as potential approaches for changing misconceptions. These include: refutational text (Mason, 2003; Tekkaya, 2003), argumentation and persuasion (Nussbaum, Sinatra, &
Poliquin, in press; Sinatra & Kardash, 2004), simulation (Soderberg & Price, 2003), critical comparison (Matthews, 2001), hypothetical field study (Scharmann et al., 2005), hands-on activities (Lee, 2005; McDermott, 1984; Sherman & Randolph, 2004), analogy (Bryce, & MacMillan, 2005; Paris, & Glynn, 2004), metaphors (Tobin & Tippins, 1996), and collaborative problem solving (Chan, 2001).

All of the conceptual change instructional techniques presented above have been determined to be effective to some level. Yet, no specific instructional approach has been determined to be consistently effective. This suggests there is a need to continue to investigate conceptual change instruction to determine which methods are most effective and consistent for resolving specific kinds of misconceptions. This may require the integration of conceptual change instructional approaches that address related misconceptions simultaneously.

**An Integrated Approach**

Investigations examining the effectiveness of conceptual change instructional approaches have revealed a range of effects. Study outcomes vary from modest to substantial impact. Yet, there is a gap in the literature regarding the impact that combinations of instructional approaches have on altering misconceptions. For instance, combining conceptual change pedagogy with knowledge acquisition techniques could be an effective technique for resolving misconceptions, but as yet, empirical evidence is lacking or scarce to support these possibilities.

When selecting an appropriate instructional strategy it is important to consider the capabilities and experiences of the students. The depth of misconceptions, the presence of
preconceptions, level of epistemic development, existing knowledge base, and metacognitive skills, all interact in conceptual change (Mason, 2003; Sinatra & Pintrich 2003). Therefore, combinations of instructional approaches may be most effective for facilitating conceptual change (Tekkaya, 2003). Sandoval (1995) posits that a combination of effective instructional approaches can increase understanding as much as 1.5 standard deviation units. A variety of approaches can provide opportunity to activate a range of schemas formed from a diversity of experiences, and link them in meaningful ways. The diversity of learner experiences, perspectives, abilities, and motivation, are some of the greatest challenges to designing and implementing successful conceptual change instruction.

The goal of all conceptual change instructional techniques is to provide situations that increase knowledge acquisition which changing misconception. Science curriculum is typically diverse enough to allow for a wide range of instructional approaches providing flexibility and opportunities that other content areas may not find readily accessible. Yet, some areas of science education, such as biological evolution, may require more than instructional techniques, it may also require the integration of content.

It is common that students completing traditional high school and college science and mathematics programs frequently do not develop the scientific conceptions of situations of uncertainty (Gilovich, Vallone & Tversky, 2002; Nickerson, 2004; Shaughnessy, 2003), the nature of science (McComas, 1998, 2006), or of biological evolution (Alters & Atlers, 2001; Crawford et al., 2005; Dagher & Boujaoude, 2005; Hewson, Tabachnick, Zeichner, & Lemberger, 1998; Sadler, 2005; Shtulman, 2005). Therefore, many students enter and leave these institutions holding the same misconceptions of situations of
chance, the nature of science, and biological evolution. The retention of misconceptions warrants an examination of how these three topics are related and taught, and what can be done to rectify this condition (Graeber, 1999).

Dagher and Boujaoude (2005) argue that teaching in the context of the nature of science is essential for instructional effectiveness. In consideration of this argument, it may be more effective to teach the theory of evolution and its relationship to situations of uncertainty, integrated into a nature of science framework. This would allow students to examine, address, and change misconceptions of three related topic areas that are intrinsically related. A conceptual change curriculum that integrates the related topics of the nature of science, situations of uncertainty, and evolutionary theory, may allow learners to simultaneously gain greater understanding of how three seemingly distinctly different concepts are inextricably related. This may allow for the change of several misconceptions simultaneously.

Ultimately the teacher is responsible for classroom instruction. Course content, curriculum, and instruction are impacted by the choices and abilities of the teacher (Hoy et al., 2006; Pajares, 1992). Therefore, when investigating student misconceptions and conceptual change it is prudent to examine the impact teachers have on learning and the knowledge they bring to the classroom.

Misconceptions

Frequently the domains of science are based on combinations of theories and hypothesis formed from fundamental concepts (NAS, 1998; NRC, 1996). Scientific concepts develop from experimentation and observations of the natural world (AAAS,
Some science concepts studied are obvious, such as species diversity, and others are more concealed, such as the random process of genetic drift (Driver et al., 1994). The comprehension of fundamental concepts common to most science curriculum is essential for understanding more complex ideas (Chinn & Malhotra, 2002; McComas, 2006). If students understand the basics, more complex relationships can be learned (Bransford et al., 1999; Bruning et al., 2004).

Misconceptions develop from the misinterpretation or misunderstanding of experiences with many natural phenomena, which can then influence the further development of personal conceptions (Driver et al., 1994; Schmidt, 1997; Smith et al., 1993/1994). Driver et al. (1994) elucidate the widespread misconceptions of science fundamentals, and expound on the influences that holding misconceptions of fundamental concepts has on the accurate conceptualization of more complex knowledge.

In many cases alternative conceptions are robust (Schneps & Sadler, 1985, Sinatra & Pintrich, 2003; Voniadou, 1994). Misconceptions are interesting phenomenon because learners usually are convinced they are correct and will hold on to misconceptions, defending their ideas and justifying their positions, even when confronted with contradictory evidence (Guzzetti, 2000; Luque, 2003; Southerland et al., 2001). Reinforced by motivation and sources of information, individuals that have determined that they have a plausible explanation for a concept, tend to retain their positions, guarding their schema (Schneps & Sadler, 1985). Not only does this maintain misconceptions and reinforce them, but it also hinders the possibility of considering other perspectives (Bloom, 2001; diSessa, 1993; Hammer, 1996; Sadler, 1998; Sinatra & Pintrich, 2003).
Individuals are said to hold misconceptions when they conceive phenomenon in a manner inconsistent with expert explanations. Yet, misconceptions are typically not fabricated completely out of the imagination of the learner, originating from attempts to construct intuitive connections (Stavy, Tsamir, & Tirosh, 2002). This is especially common in science, because the learner’s perspective can develop based on personal interactions and interpretations of the environment which reinforce the development of misconceptions (Driver et al., 1994). For instance, a common biological evolution misconception is to view the process as deterministic, with organisms aspiring to more efficient, improved, or complex life forms (Alters & Alters, 2001; McComas, 2006; NAS 1998). The development of this misconception may be formed by creating an association between the societal goals of creating products that are faster, lighter, and more efficient, and nature having relatively the same desired outcomes in evolution. Yet, even though two very different processes take place in these situations, knowledge of manufactured product evolution may be misapplied to conceptualize biological evolution. This application of a known phenomenon to a seemingly similar situation is essentially the same as the use of representativeness and availability heuristics in situations of uncertainty (Tversky & Kahneman, 1982b). Unlike the manufacturing process goal of developing better products, biological evolution is not directed by organism aspirations, it is largely a random process, with natural selection determining final outcomes (Alters, 2005; McComas 2006; Miller, 2002; NAS, 1998). The common misconception that evolution is deterministic, driven by organisms’ desires to become better than their ancestors, may be attributed to individual use of knowledge of the familiar situation of product development to explain the seemingly similar biological process (Sadler, 2005).
Thus, the transfer of personal interpretations to seemingly related situations can result in the development of misconceptions.

Driver et al. (1994) have conducted an in depth review of research investigating how children conceptualize scientific phenomenon. Classifying scientific concepts into biological, physical, and environmental categories, Driver et al. have compiled this extensive research into a resource revealing how children develop and change conceptions over time. As children develop, there are significant gains in acceptance of scientific explanations of some concepts, suggesting that part of conceptual change may be developmental (Driver et al. 1994; Tytler & Peterson, 2005; Vosniadou & Brewer, 1994). The developmental change in conceptions reinforces the notion that epistemic beliefs are significant influences in how learners perceive and interpret knowledge (Mason, 2003). As epistemic beliefs evolve, learners are more likely to consider and process alternative conceptions or counter-intuitive explanations (Bell & Linn, 2002). Thus, personal views of knowledge and understanding of the structures of knowledge are influential on conceptual development (Mason, 2003).

Additional sources of misconceptions are authority figures that learners trust and are unlikely to question. Ideas that are promoted by people in positions of authority add further validity and reinforcement to the acceptance of inaccurate conceptions (Novak, 2005). Textbooks, movies, television, the internet and other media are further sources for the development and retention of misconceptions. Therefore, it is important that common misconceptions are identified, and efforts are made to change the conceptions so that these naïve conceptions are not perpetuated (McComas, 1998).
In summary, misconceptions are very common to science because prior knowledge of everyday phenomenon is applied to explain seemingly related situations which results in the formation of inaccurate conceptions (diSessa, 1993; Driver et al., 1994; Hammer, 1996). Prior knowledge is a significant component in learning, especially in the domain of science, where more sophisticated ideas require understanding of fundamental concepts. Thus, learner conceptualization of the nature of science can greatly influence how they learn and interpret science concepts. In the process of learning about science, individuals use conceptions of the nature of science to develop meaning and form conceptions. Yet, there are many commonly held misconceptions of the nature of science that may interfere with the process.

Understanding the Nature of Science

The attempt by humans to understand natural processes and phenomenon of their environment can be traced back to early civilizations. Early Greek philosophers devised logical interpretations to explain natural occurrences (Kuhn, 1970). Although some of the early interpretations were naïve and misconceived, they provided a foundation for formalizing the process of science (Kuhn, 1970).

McComas, (1998) defines the nature of science as the combination of the processes, outcomes, and interpretations of science. McComas recognizes that some aspects of the nature of science can be considered foundational and constant, while other aspects are dynamic and continue to evolve, impacted by modern tools and increased means of communication.
Most scientists understand the nature of science, accepting the social construction of meaning and the implicit and explicit aspects of science communication (Chalmers, 1995; Kuhn, 1970; McComas, 1998). However, those outside the realm of scientific professions often hold misconceptions about the nature of science (Chalmers 1995; McComas, 1998). Judgments and decisions about scientific processes and theories are often made based on conceptions of the nature of science that are inaccurate or inconsistent with the professional scientific community (Fensham, 2002; Liu & Lensniak, 2005; McComas, 1998).

The lack of understanding about the nature of science is well documented (Abd-El-Khalick & Lederman, 2000; Cooper, 2002; Driver et al., 1994; Johnson 2005; Scharmann et al., 2005), with perhaps the most pragmatic work done by McComas (1996) in his development of a list of ten nature of science myths. McComas (1996) labels and explains ten common misconceptions of the nature of science and the epistemological and ontological implications. His work includes the common misconception that the tentative structure of science knowledge is a reflection of unstable and unreliable scientific research. Although there may be some aspect of this in science, the characteristic tentativeness is most often a reflection of appropriate refinement and adjustment of theories and hypotheses to accommodate new evidence. Misconceptions about tentative knowledge may lead to the belief that science lacks consistency and is incapable of accurately describing phenomenon. The misconception of science as based entirely on provable facts is common among learners with limited view of knowledge (McComas, 1996; Wiser & Amin, 2001).
The nature of science misconception that carefully accumulated evidence results in sure knowledge leads to the formation of the misconception that modification of theories is evidence of fallibility and unreliability of science (Haidar, 1997). In history, there are instances of fallible scientific theories, but with the broad scientific community sharing knowledge, these events are now relatively rare (Kuhn, 1970). Thus, if learners understand the nature of science, they will comprehend scientific knowledge as dynamic and expanding, and realize the unique occurrence of unreliability and fallacy in science (Chalmers, 1995; McComas, 1998).

Holding nature of science misconceptions affects how students perceive and learn science (Volkmann & Zgagaeez, 2004). It is a common misconception for learners to view theories as tentative guesses by scientists in an effort to explain phenomenon. This misconception leads learners to discount theories as valid knowledge structures, dismissing them as legitimate explanations (McComas, Clough, & Almazroa, 1998). This misconception supports the idea that knowledge structures in science evolve beginning with hypothesis developing into theories, and then, with enough evidence and support, theories will evolve into laws (Haidar, 1997). This is further confounded by the language associated with the nature of science (Moore et al., 2002). Moore et al. argue that the usage of the same language and terms in science and other cultural contexts, confuses meanings and leads to the development and reinforcement of misconceptions. For example, the word theory in everyday use is defined as a conjecture, however, in science a theory is a detailed explanation based on facts, observations, and laws (NAS, 1999). The evolution of scientific knowledge structures misconception and the confusion of terms interfere with acceptance and understanding of scientific theories (McComas &
Olson, 1998). Thus, in science education students do not give serious consideration to theories, but instead view them as inferior ideas lacking enough evidence to evolve into scientific laws (MeComas, 1996, 2006; NAS, 1999).

Most students do not understand the difference between belief and knowledge which further contributes to the development of nature of science misconceptions (Bryan, 2003; Matthews, 2001; Veal, 2004). Palmquist and Finley (1997) found that even professional scientists transitioning to careers in education had difficulty in distinguishing between their beliefs and knowledge and therefore held misconceptions about the nature of science. Yet, these are two distinctly different ways of classifying ideas, and should be viewed as two different paradigms (Shtulman, 2006). The distinction is that belief is based on faith and does not warrant evidence, whereas knowledge is the understanding of observations, proof, or empirical evidence (Scharmann et al., 2005). Smith and Scharmann (1999) suggest that science can provide answers to scientific questions, but issues that are moral, ethical or spiritual require a different approach. They posit that without this distinction, learners are not able to discern scientific theories from faith based conjectures.

Because of the misconceptions of the nature of science, it appears that there are two approaches to all problems, one founded on faith and one based on science, which further complicates the teaching and learning of science. This is perhaps most evident in the understanding of biological evolution (Alters & Alters, 2001). The debate between creationism and evolutionary theory as explanations of species epitomizes the lack of distinction between belief and knowledge (Miller, 1999). Misconceptions of the nature of science lead to the dismissal of biological evolution as just a theory and the acceptance of
faith based explanations for the origin of species as comparable to scientific explanations (Scharmann et al., 2005). The confusion of scientific knowledge with faith-based belief as a comparably suitable warrants and information structures, indicate that misconceptions of the nature of science are interfering with conceptualizing biological evolution (Alters & Alters, 2001; McComas, 2006; NAS, 1998; Scharmann et al., 2005). Therefore, for students to understand biological evolution, it is necessary to address their misconceptions of the nature of science.

As with other misconceptions, those of the nature of science are robust (McComas et al., 1998). Several different approaches have been attempted to promote the conceptual change of student views of the nature of science including hands-on activities (Akerson, Abd-El-Khalick, & Lederman, 1999), simulation of scientific research (Smith & Scharmann, 1999), and through courses exploring the history of science (Abd-El-Khalick & Lederman, 2000). The authors of these studies attempted to change nature of science misconceptions with mixed success, which further supports the critical need to ascertain methods that are effective at resolving naive conceptions.

Learners' ability to understand the nature of science is limited by personal views of knowledge (Mason, 2003). A learner with an absolutist of multiplist epistemological perspective may not be able to readily distinguish between belief and knowledge, which results in misconceptions (Scharmann et al., 2005). The interplay between ontological perspectives, views of knowledge, and conceptual change, suggest that developing a more meaningful understanding of the nature of science is a temporal process. Yet, efforts must be made to change misconceptions of the nature of science because they
interfere with the understanding of science conceptions such as biological evolution and the acceptance of the inherent variability of scientific phenomenon.

Situations of Uncertainty

In our daily routine we encounter many instances of situations of uncertainty. We calculate and make choices and react to situations of uncertainty or chance based on prior experience of predicted, expected, and actual outcomes. Future predictions are based on chance and uncertainty because in planning for events, prior knowledge is used to estimate possible outcomes (Armor & Taylor, 2002). This works most of the time, but can lead to a lack of understanding about chance and uncertainty (Tversky & Kahneman, 1982b).

Tversky and Kahneman (1982b) report that many of the rationalizations or heuristics that individuals typically use to explain situations of uncertainty contain fallacies and biases, which are due to misconceptions of probability and chance. The often expected outcomes of situations of uncertainty based on fallacious or bias predictions result as predicted and further reinforce the development and maintenance of these misconceptions (Bar-Hillel & Neter, 2002; Nickerson, 2004; Pronin, Puccio, & Ross, 2002). However, fallacies and bias will occasionally fail to accurately predict chance outcomes. In these situations people tend to use luck or other conditions to explain the unexpected outcome, guarding their misconceptions so that they may be applied again (Nickerson, 2004).

Tversky and Kahneman (1982a, 1982b, 1982c) report that individuals tend to view chance as a self-correcting process. For example, an individual may apply the gamblers fallacy to situations of chance, such as, the flipping of a coin, thinking that a run of heads
makes the occurrence of tails more likely. Yet, the likelihood of heads or tails is equal in each flip of a fair coin. The self correcting fallacy is applied to a wide range of situations including instances of regression towards a mean. For instance, if an average student does well on one exam and this is followed by a poor performance on an exam, the student is viewed as not applying him/herself. However, if a student does poor on a first exam and well on the second exam, the student is viewed as improving. Both of these situations are instances where the individuals are regressing toward their mean, yet, people will find a wide range of alternative explanations for outcomes because of misconceptions of chance.

Tversky and Kahneman (1982b, 1982c) also recognize the availability heuristic, representativeness heuristic, and the belief in small numbers. When applying the availability heuristic, people tend to use available ideas to explain situations, not seeing reason to explore the possibility of implicit or concealed relationships that may need to be considered to accurately describe outcomes. The representativeness heuristic is applied when people transfer understanding of one situation to another seemingly related situation, again not exploring the possibility of implicit or concealed relationships that may need to be considered to accurately describe outcomes. The belief in small numbers is problematic because people tend to view small samples as representative of the larger population, producing a situation of bias representation. The application of these heuristics and biases can be readily identified in the understanding of biological evolution and the nature of science.

Biases, heuristics and fallacies can be applied to predictions of games and sports (Cochran, 2005; Larkey, Smith, & Kadane, 1989; Nickerson, 2004), policy (Hammond,
Harvey, & Hastie, 1992) and areas of science (Einhorn, 2000; Miller, 1999). Consider the process of biological evolution and how many people fail to grasp the influence of chance on the process (Sadler, 2005). Biological evolution is driven by the chance outcomes of natural selection and mutations (NAS, 1998, McComas, 2006). Individuals holding misconceptions of probability may be unable to effectively conceptualize the randomness of biological evolution. Misconceptions of chance may prevent individuals from understanding how biological evolution can be explained by scientifically accepted random processes.

The conception that science is positivist, seeking to discover ultimate truths that are constant, is a further manifestation of the misconception of probability (McComas, 1998). Many do not understanding the role that accepted uncertainty and variability play in scientific theories, which leads to the misconception that modifications in scientific ideas is evidence that theories are inaccurate or even wrong (Nickerson, 2004). However, many concepts in science are defined by probability distributions with specific outcomes dependent on chance (Chalmers, 1995; Kuhn, 1970). Most professional scientists understand this notion and accept chance and probability as being the nature of the universe (Chalmers, 1995; NAS, 1998). Yet, holding misconceptions of chance leads to the conclusion that science is not reliable, accurate, or truthful (McComas, 1998).

Misconceptions about the accuracy and stability of scientific outcomes are reinforced by the occurrence of unexpected scientific outcomes. The misconception that accurate scientific knowledge is precise and unvarying can inhibit the ability to conceptualize fundamental theories in physics, chemistry, biology, or earth science. Therefore, if
learners are expected to change perceptions of science concepts, they need to resolve their misconceptions of situations of uncertainty (Fischhoff, 2002).

**Misconceptions of Situations of Uncertainty and Teachers**

The ability to understand and communicate situations of uncertainty and chance is extremely important for teachers, not only situations in science and mathematics, but in history, arts, and language (Konold, 1994; McComas, 1996; NCTM, 1989, 1991; Shaunghnessy, 1992, 2003). Yet, many teachers have had little exposure to situations that formally challenge their misconceptions of chance, and therefore, may not be able to accurately and effectively respond to them pedagogically (Jarvis et al., 2003; Shaunghnessy, 1992). The common occurrence of misconceptions being taught and teachers’ propensity for strong convictions (Hill, 2000, 2004; Hoy, Davis, Pape, 2006; Pajares, 1992) establishes a need to explore possible solutions.

Probability and chance are common topics in most high school and introductory college mathematics courses and are covered extensively in statistics courses; yet, many learners develop and retain misconceptions of these concepts even after instruction (Hirsch & O’Donnell, 2001; Shaunghnessy, 1992, 2003). This may be attributed to the lack of utilization of conceptual change pedagogy in the mathematics curriculum (Tirosh & Tsamir, 2004; Vosniadou & Verschaffel, 2004). Perhaps these counterintuitive concepts should be taught in context allowing for application outside of the curriculum (Hallden, 1999; Pronin, Puccio, & Ross, 2002).

Teachers develop misconceptions of probability and as Koirala (1999) found, even preservice teachers with extensive mathematical backgrounds held alternative
conceptions of situations of uncertainty. Thus, it appears that the curriculum is not resulting in the development of the accurate understanding of concepts. To gain insight into this phenomenon, it is necessary to assess preservice teachers’ misconceptions of chance. Using this data, it may be possible to develop, implement, and assess a contextual situation of uncertainty curriculum, resolving misconceptions so they are not taught so frequently to future students.

Understanding of Biological Evolution

The fundamental principles of biology are based on the theory of evolution (AAAS, 1993; NAS, 1998, 1999; NRC, 1996); therefore, to understand biology, it is necessary to comprehend evolution. In an effort to assure understanding of biology, national and state science education standards call for the instruction of evolutionary theory concepts beginning at the elementary level and continuing through high school (AAAS, 1993; NCR, 1996; NSTA, 1998). The curricular emphasis on evolutionary theory is expected to result in increased comprehension of the concept. Yet, as Mazur (2005) reports recent surveys reveal that only about 35% of Americans believe that Darwin’s theory of evolution is well supported by evidence, changing little over the past 30 years. Gallup polls (2006) of the American public further support the argument that people are not learning evolution as a scientific explanation for the origin of species, and there has been no discernable change in the levels of acceptance since 1982. Movements promoting creationism as a plausible alternative explanation to biological evolution provide further evidence that the concept is not well understood (Alters & Alters, 2001; Evans, 2001; Miller, 1999; Scharmann et al., 2005). The National Academy of Sciences (1998) defines
creationism as having the belief that, “the universe and all that is in it was created by God in essentially its present form, at one time” (p. 125).

In a recent study examining students who had completed courses in biology, Shtulman (2006) found that they continued to hold misconceptions of variation, inheritance, adaptation, domestication, speciation, and extinction which are six fundamental evolutionary theory concepts. Driver et al. (1994, 1996) report similar findings, identifying many misconceptions by young children through adolescents of the processes and theory of evolution. In a comparison of conceptions of evolutionary theory held by students majoring in biological science and those pursuing non-science degrees, Sadler (2005) found both groups held misconceptions about the processes and evidence supporting evolution. In these studies many of the participants claimed to know and understand evolutionary theory. Thus, additional research is needed to determine why learners form and hold misconceptions of biological evolution that are resistant to instruction.

The formation of misconceptions of evolution begins early in science instruction, and lacking awareness of prior conceptions, teachers are not be effectively addressing this situation (Moore et al., 2004; Sadler, 2005; Yip, 2001). The formation of biological evolution misconceptions can be attributed to a number of factors, including: teachers instructing misconceptions (Atwood & Atwood, 1996; Yip, 1998), the lack of reflection and consideration of content (Crawford et al., 2005), the lack of conceptual understanding about the nature of science (Scharmann et al., 2005), and the confusion created by other proposed explanations for the origin of species coming from non-scientific sources (Alters & Alters, 2001; Cooper, 2002). If learners’ misconceptions are
not recognized or addressed, they are likely to continue to hold their alternative conceptions and disregard conflicting data (Piquette & Heikkinen, 2005). Teachers need to address students’ misconceptions of evolution and offer plausible explanations that can lead to the development of scientifically consistent conceptions (Posner et al., 1982).

Perhaps the most common misconception held about evolution is the notion that it is just a theory and, therefore, does not warrant consideration (Dagher and Boujaoude, 2005; Moore et al., 2002; NAS, 1999; Sadler, 2005; Shtulman, 2006; Yip, 1998). Learner conceptions of theories as tentative, speculative knowledge structures, is inconsistent with the scientific use of the term (McComas, 1998; NAS, 1999). This is compounded by the common misconception that ideas become hypotheses, and with evidence become a theory, and if a theory has supporting evidence it will become a law (Dagher, Brickhouse, Shipman, & Letts, 2004; Driver et al., 1996; McComas, 1998, 2006; NAS, 1999). Gibbs and Lawson (1992) found this misconception was reinforced by some textbooks. These two nature of science misconceptions have implications for understanding evolutionary theory, and explain why many consider the natural process as tentative, uncertain, and unsupported. Dagher and Boujaoude (2005) suggest that a possible solution to this situation is to teach nature of science in the context of evolutionary theory, rectifying the misconception to allow for the learning of the more complex concepts to take place.

Biology majors and prospective teachers of biology, with advanced college work in science, hold misconceptions about evolutionary theory (Crawford et al., 2005; Dagher & Boujaoude, 2005; Hewson et al., 1998; Sadler, 2005; Shtulman, 2005). One commonly held misconception is the teleological perspective of evolution, suggesting that adaptation is somehow deterministic. Sadler (2005) posits that a deterministic perspective, rather
than a stochastic conception of biological evolution, can actually lead to contradictory views of the process. This is an important finding, for it exposes the fact that even learners with advanced biological coursework do not comprehend the random nature of species diversity, applying instead the misconception that suggests biological evolution and genetic variation is purposeful and directed. Both novice and advanced learners tended to misconceive evolution as a process of progression, with an intended goal of improving species (Sadler, 2005). The species improvement goal misconception reflects a lack of understanding of biological evolution as a stochastic process, with natural selection and mutation occurring as related events, without any intended goal. These misconceptions may be resolved by teaching about random events and situations of uncertainty in the context of biological evolution.

Given the number of learner misconceptions related to evolution and the robust quality of these alternative conceptions, it is apparent that our present instructional approaches and curriculum are not effective (NAS, 1999; NCR, 1996). The traditional approach relies on learners to integrate concepts of the nature of science, situations of uncertainty and biological evolution, which are three topics that are traditionally taught independently (Scharmann et al., 2005). Further, when learners do integrate the concepts, misconceptions of the nature of science and situations of uncertainty impacts conceptualization of biological evolution, resulting in the development of compounded misconceptions (Driver et al., 1996; NAS, 1998; McComas 2006). This may be resolved by integrating and contextualizing the nature of science and situations of uncertainty instruction into the teaching of biological evolution.
The emphasis on evolutionary theory in national and state science education standards provides a mandate to assure teachers are prepared to meet this goal (AAAS, 1993; NRC, 1996). The lack of public acceptance of biological evolution provides evidence that traditional approaches to instruction are not effective (Alter & Alters, 2001; McComas, 2006; NAS, 1998). Thus, a rationale has been established for integrating and contextualizing the conceptions of uncertainty and the nature of science as fundamental topics for understanding biological evolution. The lingering misconceptions of nature of science, situations of uncertainty, and biological evolution, need to be addressed to assure scientifically accepted conceptualization of these concepts. This requires a conceptual change approach to instruction.

Teacher Educational Beliefs

Teacher beliefs influence how they view knowledge, how they view content, and how they teach (Hoy et al. 2006; Kagan, 1992; Pajares, 1992; Salisbury-Glennon, & Stevens, 1999). Hill (2004) reports that teachers typically hold beliefs tightly and are reluctant to consider alternative perspectives. Klein (1996) posits that teachers’ exposure to sixteen or more years of education has motivated many teachers to develop preconceived beliefs of what education should look like and how learning should take place. Although these beliefs allow many teachers to achieve success, it is also these beliefs that hinder their ability to change. Teachers will use their belief systems to not only guide their actions but also to significantly filter new information (Kagan, 1992; Nespor, 1987; Pajares, 1992). This can inhibit conceptual change since many teachers are not well prepared to consider situations that conflict with their perspectives. Hill (2004) found that teachers are not
open to change, cling to their beliefs and are unprepared with methods and conceptions for considering other perspectives.

The constrained beliefs of teachers are a well established phenomenon (Hill 2004; Kikas, 2004; Franke, Carpenter, Fennema, Ansell, & Behrend, 1998; Pajares, 1992; Sinatra & Kardash, 2003). Hill (2004) determined that teacher change is a long term process with no guarantee that new conceptions will be retained. Further, Hill observed that many teachers exhibit a relatively stable understanding of knowledge which can result in situations where they will appear to have new conceptual understanding but when stressed, will revert to their previous belief systems.

The constrained belief systems of teachers may be attributed to the lack of emphasis on change in teacher education programs (Jarvis, 2003; Pajares, 1992). It has been documented that many teachers leave the university with the same beliefs about education with which they entered (Kagan, 1992; Nespor, 1987; Pajares, 1992). Kagan (1992) proposes that entrenched beliefs are further supported during student teaching where faculty and mentor teachers provide moral support but do not promote the importance of critically thinking about content and learning. Perhaps this is due to an emphasis on content knowledge, leaving little time to prepare teachers to be on-going learners and critical examiners of knowledge.

Further complicating teachers' tightly-held beliefs are their inabilities to articulate personal perspectives and express the beliefs that they hold (Kagan, 1992; Nespor, 1987; Pajares, 1992). This is reflective of the implicit nature of teacher beliefs (Kagan, 1992; Pajares, 1992). Pajares (1992) reports that teachers hold implicit beliefs about how students learn, what the process of education should look like, their roles as teacher, and
the subject matter to be taught. Yet, these beliefs are frequently held private by teachers, and are held in a manner such that it is very difficult for researchers to expose and study educators’ perspectives (Hoy et al., 2006; Kagan, 1992; Nespor, 1987; Pajares, 1992).

Teachers constrained beliefs and restricted ability to consider other perspective are primary conditions for retaining misconceptions. The condition of tightly held beliefs and being unprepared to examine or consider alternatives makes conceptual change arduous or even unattainable. This situation warrants further exploration, investigating the impact that the relationship between teacher beliefs and their misconceptions.

Teacher and Misconceptions

Misconceptions have been found to be held by novice through experts (Palmquist & Finley 1997; Tversky & Kahneman, 1982b); therefore, it is expected that teachers too hold misconceptions. As many researchers have exposed, it is common for teachers to hold a wide range of misconceptions (Hill, 2004; Kikas, 2004; Jarvis et al., 2003; Lemberger et al., 1999). Jarvis et al. (2003) elucidate on the problem with teachers holding content misconception reporting that they are nearly certain to transfer their naïve conceptions on to their students. Many science content misconceptions may have been taught to students (Alters & Nelson, 2002; Driver et al., 1994; Fisher, 2004; McComas, 1997). The evidence shows misconceptions are perpetuated by teachers, which indicates that educators are critical factors affecting student conceptual development and change (Crawford et al., 2005; Fisher, 2004; Hill 2004; Kikas, 2004; Jarvis et al., 2003; Lemberger et al., 1999; Yip, 2001).
Kikas (2004) reports that in addition to impacting student learning, misconceptions held by teachers can become obstacles for developing deeper thought. Kilas observed that once teachers have determined something to be true, they hold onto the concept very strongly. Therefore, if a teacher holds misconceptions and the building of more complex understanding requires holding the correct conception, a teacher may not be able to progress in his or her knowledge development (Kikas, 2004). Thus, teacher education curriculum should address potential misconceptions while prepare future educators to be critical examiners of knowledge.

Many situations can lead to the development of teacher misconceptions including holding fragmented knowledge (Kikas, 2004). Teachers are more likely to hold misconceptions when they lack a complete understanding of a situation. In their study of the sun and earth proximity as an explanation for the seasons, Atwood and Atwood (1996) found that teachers commonly held misconceptions of this phenomenon. They report findings consistent with other studies (Kikas, 2004; Lemberger et al., 1999) that suggest teachers seem to understand that solar radiation has something to do with heating of the earth, but many lack the scientific knowledge of how the tilt of the earth’s axis affects sun exposure and thus produces the seasons. Thus, teachers need to be made cognizant of the common misconceptions in the curriculum, so that they may resolve naïve conceptions and be prepared for teaching accurate perspectives (Driver et al. 1994).

The robust quality of misconceptions is perhaps one of the most intriguing aspects of the phenomenon. Once individuals develop conceptions they do not like to change them and may hold on to their perspectives even when presented with conflicting evidence (Driver et al., 1994; Hammer, 1996; Mason & Limon, 1999; Sinatra & Pintrich, 2003;
Smith et al., 1993/1994; Vosniadou & Brewer, 1994). As discussed earlier, teachers are particularly resistant to change, retaining perspectives and concepts even when inconsistent or unproductive. Teachers tend to hold beliefs and conceptions very tightly, not being well equipped to think critically, consider alternative explanations, or motivated to work through intellectually challenging situations (Hill, 2004; Hoy et al., 2006; Nespor, 1987; Pajares, 1992).

Although teachers may hold a number of misconceptions and may be resistant to change, it is essential to provide on-going efforts to promote their learning. Through the integration of content and combined approaches to conceptual change, teachers can be prepared to think critically while addressing potential student held misconceptions. This suggests that teacher preparation programs may need to be examined and restructured to assure content knowledge is attained, misconceptions are addressed, and critical thinking is taught using conceptual change instruction. This may appear to be an enormous challenge. Yet, these goals are related and therefore, may be achieved through the implementation of an integrated curriculum.

Teacher as Learner

Mewborn (2003) suggests that the fact that teachers leave the university with many of same beliefs that they entered with warrants examination of teachers as learners. As discussed previously, entrenched beliefs usually require radical a change because strongly held beliefs are difficult to change, and more specifically, teachers may require unique instructional approaches to achieve and sustain conceptual change. Kagan (1992) argues that teachers who experience instances of dramatic disequilibrium are more likely
to change beliefs and conceptions. Thus, teachers’ exposure to conceptual change curriculum which requires the contextual application of scientifically accepted conceptions may result in increased likelihood for the consideration of alternative perspectives (Dihinda & Anderson, 2004; McComas, 2006; NAS, 1998; Paris, & Glynn, 2004; Shaughnessy, 1992).

Viewing teachers as life-long learners reinforces the need for developing their critical thinking skills and increasing their motivation for continued professional growth (Hill, 2004). When teachers learn how to work through situations that conflict with their personal belief systems, they gain a greater understanding of how to critically examine information and consider change (King & Kitchener, 1994; Wilson & Berne, 1999). The lack of an ecology of change in schools suggests teachers will not implicitly gain the necessary skills and beliefs for conceptual change unless it is explicitly promoted and taught (Kagan, 1992).

Change and Teacher Education

The evidence from several research efforts investigating change in teacher beliefs and conceptions reveal it to be a complex process to facilitate and achieve (Kagan, 1992; Hill, 2004; Nespor, 1987; Pajaers, 1992). Kagan (1992) argues that the influence of approximately sixteen or more years of schooling has developed a foundation of beliefs that teachers hold toward education and content that make change uniquely complex for educators. Further, Kagen suggests that few pre-service teacher education programs have embraced the process of change as a major emphasis of the curriculum. This lack of emphasis on conceptual change in the curriculum and the sixteen or more years of
conceptual reinforcement make the process of teacher conceptual change complex and unique, and leave many educators ill equipped to critically examine anomalous data and situations of complexity (Franke et al., 2003).

The problem with the inability of teachers to critically examine personal conceptions is that they may hold content misconceptions that they pass on to their students (Jarvis et al., 2003; Kikas, 2004). Thus, there is a critical need to prepare teachers to examine their conceptual understandings, and when confronted with alternative rationalizations and complexity, to consider the plausibility of alternative explanations (Kagan, 1992).

Teachers must to be able to examine content for possible misconceptions, but they also need to continue to adapt and change to new policies, curriculum, and practices. Gregoire (2003) examined how teachers responded to new ideas of curriculum and practice in mathematics as promoted by the NCTM (1989). She found many teachers were unable to reconceptualize mathematics curriculum and were unwilling to consider alternative approaches. Thus, there is a need to prepare teachers with meaningful ways of examining alternative perspectives and considering situations of change. This requires teachers to be prepared with the ability to consider changes in how they view education, student learning, and their roles as educators (Gill, Ashton, & Algina, 2004; NRC, 1996; Pajares, 1992).

The education and preparation of teachers is a complex and considerable undertaking. Students enter teacher education programs with a variety preconceptions and misconceptions, along with very strongly held beliefs about learning and teaching. If misconceptions are not addressed, there is a possibility that they will be passed on to students. However, if preservice teachers are exposed to a curriculum that increases
awareness of misconceptions, requires them to think critically about alternative conceptions, and teaches them about conceptual change pedagogy, they will be more prepared as on-going learners. This may then reduce the perpetuation of teaching misconceptions while increasing awareness and the ability to teach for conceptual change.

Summary

The interactions of prior knowledge, perceptions of knowledge and the nature of science, metacognitive abilities, and preconceptions, are personal characteristics that add variability and complexity to the theories of learning. The ability to interpret and evaluate information in a manner that considers multiple perspectives is an essential process for learning (Bransford et al., 1999). Yet, when concepts conflict with held perspectives, there is a need for conceptual change pedagogy.

The process of conceptual change is vitally important in science education because as Driver et al. (1994) have illuminated, learners develop a wide range of misconceptions which affect their ability to accurately conceptualize related phenomenon. The relationships of situations of uncertainty, the nature of science, and biological evolution, suggest that if learners hold misconceptions in one of these topics it may affect the understanding of the others. Thus, it is important to appropriately conceptualize situations of uncertainty and the nature of science to accurately understand biological evolution. This provides justification for teaching these topics simultaneously and in the context of evolutionary theory. The simultaneous instruction of situations of uncertainty, the nature of science, and biological evolution may need to be considered for inclusion in teacher
education curriculum to assure misconceptions of these topics are addressed. The predicted misconceptions of these topics support the implementation of conceptual change pedagogy. National and state science education standards anticipate that almost all teachers will eventually teach some aspect of these three topics, and therefore mandate teacher understanding of the concepts. Yet, teachers are unique learners.

Research has revealed teachers to have a low propensity for change and high levels of entrenched beliefs which increases the difficulty in promoting change in their conceptions. Given the predicted presence of science misconceptions, it is apparent that examining methods for resolving naïve conceptions is critically important in science education. This is done most effectively by resolving the situation prior to classroom service. Through instructional activities that expose misconceptions and promote conceptual change, preservice teachers may be provided with a model of an effective and important instructional approach. This is the benefit of teaching for conceptual change in teacher preparation curriculum.

Conceptual change is difficult to promote and sustain and a number of instructional techniques have been applied with a range of success. It is possible that combined content may improve levels of conceptual change, especially if the instruction addresses misconceptions in context. The lack of empirical evidence of the effectiveness of this approach reflects a gap in the literature and reveals an area of research need.
CHAPTER 3

METHODOLOGY

Study Design

This study involved a mixed methods, repeated measures, experimental design (Creswell, 2003). To determine if there was a combined effect to content integration, I divided participants into two experimental groups. I pre-tested all participants to determine the existence of misconceptions, and levels of understanding and acceptance of biological evolution, understanding of the nature of science, and situations of uncertainty, and demographics. This was followed by an instructional intervention. Both groups received evolutionary theory and nature of science web-based instruction. The control group received an additional web-based tutorial focusing on the life and travels of Charles Darwin while the experimental group received additional situations of uncertainty instruction. By providing both the experimental and control group with content of similar length, I equated, to the extent possible, time on task. The life and travels of Charles Darwin was appropriate because it is somewhat consistent with the general area of instruction, but knowledge of this was not measured by the instruments. Both groups were post-tested on levels of understanding and acceptance of biological evolution and understanding of the nature of science and situations of uncertainty. Appendix A contains the experimental design table. Data were analyzed using ANOVA, repeated measures ANOVA, ANCOVA, and correlational analysis.
To gain additional evidence of the instructional intervention impact, the participants created a classroom lesson idea, based on the instruction, which was appropriate for their targeted levels of inservice teaching. The lesson idea is an informal version of a lesson plan, which included a title, objectives or goals, an activity, and an assessment strategy. The lesson ideas were analyzed using a priori and emergent codes to reveal evidence of instructional transfer, specifically searching for evidence of understanding of concepts of biological evolution, the nature of science, and situations of uncertainty. In addition, the data gathered from the lesson ideas provided an opportunity to gain additional evidence for the impact of the instructional interventions of the development of content knowledge.

To assure compliance with the necessary legal and institutional requirements, a research protocol proposal was submitted to the Institutional Review Board for approval prior to the project implementation (see Appendix XIV). Once authorization was been granted, I implement the project as outlined below.

Participants

The participants in my study were preservice teachers recruited from the Department of Educational Psychology research subject pool. An effort was made to recruit 50 experimental participants and 50 control participants. In return for their participation they received credit toward meeting their participation in course required research activities. The participants were randomly selected to be in one of two groups, a control and experimental, resulting in a potential for fifty participants per group. The random
assignment of participants to groups increased the likelihood of more accurate representative sampling.

Instruments and Measures

I used a demographic instrument to collect quantitative and qualitative data on participant personal characteristics. I used four additional instruments to determine the level of conceptual understanding of biological evolution, acceptance of biological evolution, understanding of situations of uncertainty, and perspectives on the nature of science. These instruments have been shown to provide reliable results in previous research in data collection and to provide an efficient means of data collection with this number of study participants.

Demographics

The demographic instrument was used to gather information related to age, gender, race, years of education, number of college level science courses, number of college level mathematics courses, intended grade level of instruction, intended subject of instruction, college major and college minor, and level of religiosity (See Appendix II).

The demographic background instrument was administered to assess individual differences. These measures were used as grouping or predictor variables. This allowed for the examination of understanding of evolutionary theory, nature of science, and situations of uncertainty based on personal characteristics.

Concept Inventory of Natural Selection

The Concept Inventory of Natural Selection (CINS) instrument (Anderson, Fisher, & Norman, 2002) was used for measuring the understanding biological evolution. This
instrument evaluates students’ understanding of evolutionary concepts and uses common misconceptions as distractors. Piloted and developed with undergraduate students, this 20 item instrument was appropriate for use with preservice teachers in this study. The instrument was determined to have appropriate reliability and validity for the instructional use of exposing misconceptions with distractor options that are common alternative conceptions in previous research. Anderson, Fisher, and Norman (2002) report, “The KR$_{20}$ for the test was 0.58 for Section A and 0.64 for Section B. A good classroom test should have a reliability coefficient of 0.60 or higher...so the CINS values are acceptable.” (p. 963). This demonstrates the instruments proved to be reliable in related contexts, and therefore was deemed appropriate for this application (see Appendix III)

The CINS was used to determine the presence of participant misconceptions and levels of understanding of evolutionary theory. Measurement took place before the instructional interventions and again after intervention. A comparison of pre-test and post-test scores was conducted to determine if changes had taken place in students’ understandings. Thus, the instrument was administered twice, pre-intervention, and post-intervention to all participant groups.

Measure of Acceptance of the Theory of Evolution

The Measure of Acceptance of the Theory of Evolution (MATE) instrument (Rutledge & Warden, 1999) was used to determine participants’ acceptance of evolutionary theory. This is a 20-item Likert-scaled questionnaire that is scored from 20-100 possible points. In previous research, the reliability of the instrument was determined to be 0.98 with an item total correlation of $r = .65$ indicating all items contributed to the total reliability of
the instrument. The instrument was developed to determine high school teacher acceptance of evolutionary theory. The prior reliability values and intended application of the instrument suggest that it was appropriate for use in this study (see Appendix IV).

The MATE was used to determine the levels of participant acceptance of the theory of biological evolution. Measurement took place before the instructional interventions and again after the interventions. A comparison of pre-test and post-test scores was conducted to determine if changes in acceptance of biological evolution had taken place. Thus, the instrument was administered twice, pre-intervention, and post-intervention to all participant groups.

Statistical Reasoning Assessment

The Statistical Reasoning Assessment (SRA) instrument (Garfield, 2003) was used to evaluate conceptual understanding of situations of uncertainty. The 20 items in this instrument are related to the stochastic processes in evolution and therefore, are deemed appropriate to determine participant contextual conceptualization of situations of uncertainty. The instrument uses distractors that are consistent with common misconceptions, making it an appropriate choice for examining conceptual understanding of situations of chance. The authors report reliability to be .70 for test-retest analysis, indicting reliability was acceptable in previous research. Prior reliability results suggest that this was a suitable instrument for determining levels of student knowledge and misconceptions of situations of uncertainty (see Appendix V).

The SRA was used to determine the presence of participant misconceptions and levels of understanding of stochastic processes. Measurement took place before the instructional interventions and again after the interventions. A comparison of the pre-test and post-test
scores was conducted to determine if conceptual shifts in participants’ understandings had taken place. Thus, the instrument was administered twice, pre-intervention, and post-intervention to all participant groups.

*Scientific Attitude Inventory II*

The *Scientific Attitude Inventory II* (SAI II) instrument (Moore & Foy, 1997) was used to measure levels of conceptual understanding of the nature of science. This 40 item instrument was used to determine both emotional attitude toward science and intellectual understanding of the nature of science. The SAI II has been revised from the original instrument SAI instrument and has been utilized widely in science education research. The instrument uses a combination of positive and reverse statement items, which are combined to form six conceptual domains in the nature of science. These subgroups are then combined to form the intellectual understanding and emotion toward science factors (see Appendix VI). The reliability of this instrument was previously determined using split-half correlation which produced a value of .805, and the Chronbach’s Alpha analysis produced a value of .781, when examined using over 500 participants (Moore & Foy, 1997).

The SAI II was used to determine the presence of participant acceptance and levels of understanding of nature of science. Measurement took place before the instructional interventions and again after the interventions. A comparison of pre-test and post-test scores was conducted to determine if a conceptual shift had taken place. Conceptual shifts were characterized as a significant decrease in misconceptions from pre-intervention to post-intervention. Thus, the instrument was administered pre-intervention and post-intervention to all participant groups.
Understanding Evolution SVT Assessment

The Understanding Evolution Assessment (UEA) instrument was used to determine participant retention of the Understanding Evolution tutorial content. The outcome from this assessment allowed for the determination and verification of intervention fidelity. Using the sentence verification technique (SVT) as described in Royer, Greene, and Sinatra (1987) twelve sentences from the instructional content were selected for the development of the SVT instrument. Three sentences remained unchanged, three sentences were rewritten retaining the same content, three sentences had minor modification that resulted in changed meaning, and three sentences were rewritten changing the meaning of the content (see Appendix VII).

The UEA was used to determine the levels of participant comprehension of the Understanding Evolution content. Measurement took place immediately after the instructional interventions and again one week later. A comparison of group scores allowed for the determination of difference in content comprehension.

I developed digital forms of the instruments which were administered from Zoomerang, an internet based survey provider which allowed for ease of administration, data recording, and data retrieval.

Lesson Idea

All participants developed a lesson idea, which was essentially a mini lesson plan. Participants were instructed to develop a lesson idea integrating the information gained from their exposure to the content of the research instructional interventions that targeted the grade level or content area they intend to teach. The content for the lesson idea included targeted age group, content/subject area, title of the lesson, lesson goals,
description of lesson activities, and an assessment plan (See Appendix VIII for the specific format and content). These lesson ideas were coded for occurrences of misconceptions, correct conceptions of evolutionary theory, integration of the nature of science, and the integration of situations of uncertainty.

Instructional Interventions

The web-based tutorials in biological evolution misconceptions (see Appendix IX) and the nature of science (see Appendix X) used as instructional interventions were created by the University of California Museum of Paleontology (2006) and appear on the Understanding Evolution (http://evolution.berkeley.edu/). The Understanding Evolution web site focuses on the teaching and learning of the science and history of biological evolution. Funded by a National Science Foundation Grant, this website explains how evolutionary biology research is conducted, and how ideas about evolution have changed over time.

To monitor participant navigation through the instructional materials, the tutorials were ported to a local server. Permission was granted by the University of California Museum of Paleontology to store the information on a local retrieval system. Many different concepts are addressed in the Understanding Evolution tutorials; therefore the content presented in this study was specifically limited to the Misconceptions tutorial. For an example of the pages contained within this intervention see Appendix IX. All parts of the Understanding Evolution Nature of Science tutorial were used as instructional interventions. For an example of the pages contained within this intervention see Appendix X. The evolution misconception intervention contained 23 linked pages of
information and the nature of science intervention had eleven linked pages information. Each page combined about 150 to 200 words of content with a related graphic to address a specific concept.

I developed the situation of uncertainty instructional intervention using public domain content, graphics, animations, and interactive applets. I designed this intervention to be consistent with the format of the Understanding Evolution website. I limited the text and took efforts to include supporting graphics that combine to address a specific concept.

For an example of the pages contained within this intervention, see Appendix XI. This intervention uses text and graphics spread over five linked pages to provide instruction of situations of chance in the context of biological evolution. The interactive applets included in the instruction provide animations depicting binomial probability distribution and a random branching tree generator. Associated with each of these applets is text intended to increase understanding of the relationship of the simulation to situations of uncertainty and biological evolution. This instructional intervention was placed on a local retrieval system to monitor and restrict participant access.

To assure equal time on task for the control and experimental groups, an additional web-based tutorial was developed. This tutorial is similar to the length (five pages) and format (combining graphics and text) of the Situations of Uncertainty tutorial, but focused on the life and travels of Charles Darwin. This tutorial was administered to the control group but not the experimental group, in an effort to assure both groups had relatively the same amount of content to read and comprehend. For an example of the pages contained within this intervention see Appendix XIII.
All tutorials were intended to provide the participants with the context and condition for the initiation of conceptual shifts. The web-based tutorial interventions were intended to increase participant understanding of the targeted concepts by providing a step by step explanation of the key concepts associated with biological evolution, the nature of science, and situations of uncertainty.

All instructional materials and tutorials were placed on a local retrieval system to allow for ease of participant access and monitoring of participant interaction and progress. This provided the assurance that treatment interventions were taking place in a manner as predicted and desired in the research design.

Procedure

As previously stated, all instruments and instructional interventions were delivered digitally. I converted all survey instruments to an electronic form, and ported them to the Zoomerang secure server where I was able to control and monitor access. The instructional interventions were already in digital form. I placed these on the campus web server where I was able to control and monitor student access.

Data collection took place over a four week period. I began by recruiting 100 preservice teachers for participation, who were equally and randomly divided into two groups: Group 1 the experimental group and Group 2 the control group. Ultimately there were 38 who began participation in the experimental group, and 36 who began participation in the control group. Each group was informed of the general purpose of the project and expectations for their involvement.
I used the Zoomerang internet based survey server to control and monitor data collection utilizing the interface to manage survey instrument distribution, data collection and data retrieval. Instructional interventions were made accessible from a local web server allowing me to control content access by participants. Through this process I was able to monitor implementation fidelity. A single web page used to provide the participants with instruction, links to the surveys and links the interventions (see Appendix IX).

Participants in both groups received information stating that the objective of their involvement in the projects was to learn more about biological evolution and situations of uncertainty, and increase their ideas for teaching the concept. The objective statements were supported by references to state and national science and mathematics standards for improving curriculum and instruction.

Prior to the intervention, both participant groups were pre-tested with the following instruments: Demographics, Measure of Acceptance of the Theory of Evolution (Rutledge & Warden, 1999), Conceptual Inventory of Natural Selection (Anderson et al., 2002), The Scientific Attitude Inventory (Moore & Foy, 1997), and the Statistical Reasoning Assessment (Garfield, 2003).

Following the completion of the survey instruments, participants were provided access to the instructional interventions. Participant interaction with the instructional interventions involved viewing web-based tutorials through computer interaction. There were three distinct instructional interventions; misconceptions of biological evolution (see Appendix X), nature of science (see Appendix XI) and situations of uncertainty (see Appendix XII). The control group received instructional interventions in biological
evolution and nature of science, with filler instruction on the life and travels of Charles Darwin. The experimental group received instructional interventions in biological evolution, nature of science, and situations of uncertainty. The instructional intervention was immediately followed by the administration of the UEA to determine if the retention and comprehension of the instructional interventions was consistent between groups.

One week after the completion of the pre-test data collection and the administration of the instructional interventions, I post-tested all participants. The following instruments were used in the post-test: Measure of Acceptance of the Theory of Evolution (Rutledge & Warden, 1999), Conceptual Inventory of Natural Selection (Anderson et al., 2002), The Scientific Attitude Inventory (Moore & Foy, 1997), Statistical Reasoning Assessment (Garfield, 2003) and the Understanding Evolution Assessment. This provided the data necessary to determine the impact of the interventions. The pre-test and post-test data were compared to ascertain levels of change.

Following the completion of the pre-tests, instructional interventions, and the post-tests, participants were instructed to complete a lesson idea. The instructions for the lesson idea were administered to participants in all groups. I instructed them to use their knowledge and insights gained through the instruction to develop a one page lesson idea. I emphasized that level of detail for the lesson idea should be less than a fully developed lesson plan. I provided the participants with a template for the lesson idea (see Appendix H) with instructions not to exceed one page in length. The template fields included; title, grade level, subject area, goals, lesson activities, and method of assessment. The participants completed the lesson idea template through access to the Zoomerang internet based survey provider. The analysis of the qualitative data gathered was used to
determine levels of intervention transfer and impact of the development of content knowledge.

Following participant pre-testing, completion of instructional interventions, post-testing, and submission of the lesson ideas, I began data analysis. The process used for data analysis is described below.

Analysis

This was a repeated measures, mixed methods design, which requires a variety of analyses. All data analyses were conducted using SPSS software.

Following the administration of the pre-tests, I entered and coded all data in SPSS. I conducted an initial analysis of the data immediately following the pre-test administration. This was done to determine participant knowledge level and the presence of misconceptions through an examination of Measure of Acceptance of the Theory of Evolution (Rutledge & Warden, 1999), Conceptual Inventory of Natural Selection (Anderson et al., 2002), The Scientific Attitude Inventory (Moore & Foy, 1997), Statistical Reasoning Assessment (Garfield, 2003) and the Understanding Evolution Assessment. I scored all of the data collected by these instruments to determine the levels of correct responses using the scoring keys which accompany each of the instruments. This allowed me to determine the participants’ level of understanding of biological evolution, situations of uncertainty, and the nature of science. Levels of misconceptions held by the groups were compared using ANOVA with evolutionary theory, situations of uncertainty, and nature of science each considered independently. Thus, I compared the scores for each of the survey instruments within and between both groups.
The *Demographics* data was entered and coded in SPSS. I used this data to determine the similarity of composition of the groups. I used ANOVA to determine if age, years or college education, number of science course and number of mathematics course and intended grade level of instruction were the same for both groups. In addition, the years of school, number of science courses, number of mathematics courses, age and religiosity, were considered as predictor variables of the level of misconceptions held of the nature of science, situations of uncertainty, and biological evolution. This was verified using ANOVA with groups as an independent variable and number of inaccurate responses to the research instruments as the dependent variables. Evolutionary theory, situations of uncertainty, and the nature of science were each considered independently and then collectively to determine if there was an interaction among the variables.

Following the intervention and the second administration of the instruments, I entered and coded the post-test data in SPSS for evaluation. Variation of the ANOVA method of data analysis was appropriately applied in this repeated measures research design. It allowed for the comparison of the pre-test and post-test results to determine if there were significant changes in attitudes, knowledge and perceptions of the mathematical and scientific concepts. In addition, it allowed for the comparison between groups to determine if there were significant interactions.

The lesson ideas were coded using a priori and emergent qualitative techniques (Cresswell, 2003; Miles & Huberman, 1994). The qualitative analysis applied content analysis techniques as defined by Miles and Huberman (1994). The coding focused on categories using language that reflected correct conceptions, misconceptions, conceptual change pedagogy, and the integration of content from the instructional models.
Specifically, coding sought to expose evidence to support instances of intervention and survey content transfer to ideas that participants intend on applying in their teaching. This provided evidence for the impact of the conceptual change instruction, and the impact of the interventions on increasing participant content knowledge.
CHAPTER 4

RESULTS AND ANALYSIS

Introduction

The analysis of the data follows the sequence and content of the research questions. I began with an examination of held misconceptions, moved to an analysis of the instructional impact comparing the scores of the control and experimental groups. I examined the data for trends and relationships between personal traits and understanding of the related concepts, and completed my analysis with coding and reporting the outcomes from the lesson idea activity.

Participants

The participants in my study were preservice teachers recruited from the Department of Educational Psychology research subject pool. I made an effort to recruit 50 experimental participants and 50 control participants. Participants were assigned by the experimenter to either the experiment or the control group based on which data collection time periods they attended. The participants were not aware of the group to which they had been assigned. Data collection took place for 1.5 hours on two days one week apart. The participants were expected to be present for both sessions. Those participants that were present for just one of the sessions were eliminated from the data analysis. The final
number of experimental participants was 34 and the number of control participants was 34. Their demographic characteristics are presented below in Table 1.

Table 1

*The Demographic Measures for the Control and Experimental Groups*

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of Participants</th>
<th>Age</th>
<th>Yrs of College</th>
<th>Gender</th>
<th>Ethnicity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>18-20</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>21-25</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>26-35</td>
<td>5</td>
<td>Female</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>36-45</td>
<td>1</td>
<td>Male</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Experimental</td>
<td>34</td>
<td>2.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18-20</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>21-25</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>26-35</td>
<td>4</td>
<td>Female</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46+</td>
<td>2</td>
<td>Male</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>34</td>
<td>1.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>18-20</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>21-25</td>
<td>17</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>26-35</td>
<td>4</td>
<td>Female</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46+</td>
<td>2</td>
<td>Male</td>
<td>6</td>
</tr>
</tbody>
</table>

Further, the dataset was conditioned by eliminating any participant who attended only one session and replacing any absent data points using the linear interpolation function within SPSS to generate an appropriate value for missing data.

**Misconceptions**

The first research question asked:

Do preservice teachers hold misconceptions of biological evolution, situations of uncertainty, and the nature of science? If so, what are these misconceptions?

The goal of this analysis was to determine whether participants held misconceptions regarding the three study domains prior to instructional intervention. I determined the
descriptive statistics for each of the misconceptions measures. Given the subject nature of the determination of levels of misconceptions, an analysis of the descriptive statistics coupled with plots of means provided me with a foundation for the reporting of participant conceptions. This was followed by a content analysis of those items or groups of items that appeared to be representative of misconceptions. The order of examination of concepts follows the sequence of presentation in the research question; biological evolution, situations of uncertainty, and the nature of science.

*Misconceptions of Biological Evolution*

To determine the stability of the CINS measure of misconceptions of biological evolution, I entered all 20 item responses from this instrument into a reliability analysis. The Cronbach’s Alpha reliability was determined to be .55, N = 68. This indicated the measure had modest reliability.

Each item in the CINS instrument has four responses, the correct response and three distractors. Each of the distractors represents a potential misconception. Figure 1 displays the percent correct for each of the CINS items. Table 2 presents the means and standard deviation for each of the 20 CINS items.

An examination the data displayed in Figure 1 and Table 2 revealed that items 4, 6, 8, 13, and 15, have noticeably lower scores than the remaining fifteen items. Content analysis revealed that these five items reflect two commonly held misconceptions of biological evolution. The selected distractors for items 6, 8, and 15 were representative of a deterministic view of biological evolution. Determinism is the view that evolutionary
change is driven by the desires and goals of organisms to improve. The distractors selected by participants to items 4 and 13 represent reveal a misconception related to the beneficial outcomes of mutations. This misconception implies that mutations lead to increased organism survivability.

Acceptance of Biological Evolution

Understanding evolution and accepting it as an explanation of species diversity is considered to be two different constructs. Research has shown that it is possible that participants understand evolution, but do not accept it (Sinatra et al., 2003). Therefore, it
Table 2

The Means and Standard Deviations for the 20 CINS Items

<table>
<thead>
<tr>
<th>Item</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N = 68</td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>.72</td>
<td>.45</td>
</tr>
<tr>
<td>Q2</td>
<td>.77</td>
<td>.42</td>
</tr>
<tr>
<td>Q3</td>
<td>.76</td>
<td>.43</td>
</tr>
<tr>
<td>Q4</td>
<td>.13</td>
<td>.34</td>
</tr>
<tr>
<td>Q5</td>
<td>.57</td>
<td>.50</td>
</tr>
<tr>
<td>Q6</td>
<td>.11</td>
<td>.31</td>
</tr>
<tr>
<td>Q7</td>
<td>.59</td>
<td>.50</td>
</tr>
<tr>
<td>Q8</td>
<td>.19</td>
<td>.39</td>
</tr>
<tr>
<td>Q9</td>
<td>.63</td>
<td>.49</td>
</tr>
<tr>
<td>Q10</td>
<td>.53</td>
<td>.50</td>
</tr>
<tr>
<td>Q11</td>
<td>.63</td>
<td>.49</td>
</tr>
<tr>
<td>Q12</td>
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<td>Q13</td>
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<td>.50</td>
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<td>Q15</td>
<td>.35</td>
<td>.48</td>
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<tr>
<td>Q16</td>
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<td>.40</td>
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<td>.50</td>
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<td>.49</td>
</tr>
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<td>.37</td>
<td>.49</td>
</tr>
<tr>
<td>Q20</td>
<td>.39</td>
<td>.49</td>
</tr>
</tbody>
</table>

is necessary to also examine acceptance of evolution as a critical measure when examining views of evolution.

To determine the stability of the MATE measure of acceptance of biological evolution, I entered all 20 item responses from this instrument into a reliability analysis. The Cronbach’s Alpha reliability was calculated to be .90, N = 68, indicating high stability of this instrument for this sample.
The MATE instrument is used to determine acceptance of evolution using a five item Likert scale rated from strongly disagree to strongly agree. The 20 items of the MATE instrument are scored from one to five and are compiled into a single acceptance score with 20 representing the lowest level of acceptance to 100 representing the highest level of acceptance (Rutledge & Warden, 1999). The participants had an average composite score of 70.37, SD = 14.840, which indicates an above neutral level of acceptance of biological evolution.

Although the composite score on the MATE indicates an overall level of acceptance of evolution, it does not illuminate levels of acceptance of specific concepts. To examine the data for specific concept acceptance, I determined the means for each of the MATE items. Figure 2 displays the means for each item, and Table 3 presents the means and standard deviation for 20 MATE items.

Figure 2. The means for the 20 items of the MATE survey.
Table 3

The MATE Survey Means and Standard Deviations

<table>
<thead>
<tr>
<th>Item</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>3.76</td>
<td>1.23</td>
</tr>
<tr>
<td>Q2</td>
<td>3.30</td>
<td>1.13</td>
</tr>
<tr>
<td>Q3</td>
<td>3.35</td>
<td>1.42</td>
</tr>
<tr>
<td>Q4</td>
<td>3.19</td>
<td>1.14</td>
</tr>
<tr>
<td>Q5</td>
<td>3.65</td>
<td>.88</td>
</tr>
<tr>
<td>Q6</td>
<td>3.03</td>
<td>1.07</td>
</tr>
<tr>
<td>Q7</td>
<td>3.82</td>
<td>1.08</td>
</tr>
<tr>
<td>Q8</td>
<td>3.50</td>
<td>1.09</td>
</tr>
<tr>
<td>Q9</td>
<td>3.72</td>
<td>1.12</td>
</tr>
<tr>
<td>Q10</td>
<td>3.46</td>
<td>1.21</td>
</tr>
<tr>
<td>Q11</td>
<td>3.51</td>
<td>1.00</td>
</tr>
<tr>
<td>Q12</td>
<td>3.20</td>
<td>1.03</td>
</tr>
<tr>
<td>Q13</td>
<td>3.45</td>
<td>.89</td>
</tr>
<tr>
<td>Q14</td>
<td>3.41</td>
<td>1.35</td>
</tr>
<tr>
<td>Q15</td>
<td>3.41</td>
<td>1.28</td>
</tr>
<tr>
<td>Q16</td>
<td>3.34</td>
<td>1.15</td>
</tr>
<tr>
<td>Q17</td>
<td>3.73</td>
<td>.90</td>
</tr>
<tr>
<td>Q18</td>
<td>3.49</td>
<td>1.05</td>
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<tr>
<td>Q19</td>
<td>3.35</td>
<td>1.04</td>
</tr>
<tr>
<td>Q20</td>
<td>3.32</td>
<td>1.23</td>
</tr>
</tbody>
</table>

An examination the data displayed in Figure 2 and Table 3 reveals that items 4, 6, and 12 to have noticeably lower levels of acceptance than the remaining seventeen items. I conducted a content analysis to determine which acceptance concept is represented by these three items. The results indicate that participants responded as undecided on their acceptance of the scientific evidence supporting the theory of evolution.
Misconceptions of Situations of Uncertainty

The presence of misconceptions of situations of uncertainty was found through an examination of the responses to the SRA. The 20 SRA items include responses that represent misconceptions of situations of uncertainty distractors.

To determine the stability of the SRA measure of understanding of situations of uncertainty, I entered all 20 item responses from this instrument into a reliability analysis. The Cronbach's Alpha reliability was calculated to be .38, N = 68, indicating low to moderate stability of this instrument for this sample.

An examination of the occurrence of participant selection of identified distractors provides evidence for misconceptions. For the 20 SRA items the participant selected an average of 48% misconception responses. This indicates a moderate level of held misconception of situations of uncertainty.

The items of the SRA address various misconceptions related to statistical reasoning and situations of uncertainty; therefore, additional in-depth examination of the item responses was conducted. I began the examination with the determination of the mean level of misconceptions for each of the corresponding SRA items. Figure 3 displays the mean level of misconception responses for each SRA item, and Table 4 presents the means and standard deviation for SRA items of the misconception distractors. An examination of the item means revealed that items 2, 7, 9 and 11 were noticeably lower than the remaining twelve items. In order to classify the misconceptions of situation of uncertainty a content analysis of the responses to the twelve items was conducted using the scoring guide provided with the SRA instrument (see Appendix V).
Figure 3. The mean misconception scores for the SRA survey.

The outcome of the item response content analysis indicates that the item could be classified into four misconceptions groups (see Table 5). The first group includes items 18, 19, and 20. A content analysis of the SRA list of misconceptions identifies these items are linked to distractor responses consistent with equiprobability bias, a misconceptions associated with the belief that all outcomes are equally possible. The second group includes items 1 and 17, of which the responses are representative of misconceptions of random sampling, the impact of extreme values, and its relationship to generating accurate averages. The third factor includes items 3, 11, 13, and 16 which include distractors related to misconceptions of outcome orientation, over estimating or the over prediction of possible outcomes to situations, and representativeness bias. Factor four includes items 6, 12, and 14, and which include distractors representing the law of
Table 4

**The 16 SRA Items with Significant Levels of Misconceptions When Tested Against 0**

<table>
<thead>
<tr>
<th>Item</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>0.53</td>
<td>0.50</td>
</tr>
<tr>
<td>Q2</td>
<td>0.10</td>
<td>0.30</td>
</tr>
<tr>
<td>Q3</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>Q6</td>
<td>0.43</td>
<td>0.50</td>
</tr>
<tr>
<td>Q7</td>
<td>0.25</td>
<td>0.43</td>
</tr>
<tr>
<td>Q9</td>
<td>0.12</td>
<td>0.33</td>
</tr>
<tr>
<td>Q11</td>
<td>0.34</td>
<td>0.48</td>
</tr>
<tr>
<td>Q12</td>
<td>0.48</td>
<td>0.50</td>
</tr>
<tr>
<td>Q13</td>
<td>0.74</td>
<td>0.44</td>
</tr>
<tr>
<td>Q14</td>
<td>0.43</td>
<td>0.50</td>
</tr>
<tr>
<td>Q15</td>
<td>0.81</td>
<td>0.40</td>
</tr>
<tr>
<td>Q16</td>
<td>0.49</td>
<td>0.50</td>
</tr>
<tr>
<td>Q17</td>
<td>0.56</td>
<td>0.50</td>
</tr>
<tr>
<td>Q18</td>
<td>0.59</td>
<td>0.50</td>
</tr>
<tr>
<td>Q19</td>
<td>0.75</td>
<td>0.43</td>
</tr>
<tr>
<td>Q20</td>
<td>0.62</td>
<td>0.49</td>
</tr>
</tbody>
</table>

small numbers, averaging misconceptions and samples size fallacies, which are reflective of the naïve conception of the bias associated with the transfer of the outcomes of samples to the greater population.

It is apparent that the participants held misconceptions of situation of uncertainty that could impact their understanding and perceptions of biological evolution. Misconceptions of averages, representativeness, equiprobability and law of small numbers, can all lead to a lack of understanding of the impact of random mutation and the uncertain processes associated with biological evolution.

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Table 5

SRA Item Response Content Analysis to Reveal Misconceptions

<table>
<thead>
<tr>
<th>Question</th>
<th>Misconceptions Revealed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Q18</td>
<td></td>
</tr>
<tr>
<td>Q19</td>
<td></td>
</tr>
<tr>
<td>Q20</td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td></td>
</tr>
<tr>
<td>Q17</td>
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<td>Q3</td>
<td></td>
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<tr>
<td>Q12</td>
<td></td>
</tr>
<tr>
<td>Q14</td>
<td></td>
</tr>
</tbody>
</table>

Misconceptions of Nature of Science

The evidence of participant misconceptions of the nature of science was found through an examination of the responses to the SAII. The SAII uses 40 forward and reverse coded items and a five-point Likert scale to measure various aspects of the nature of science. The responses to groups of six items are used to determine understanding and acceptance of five nature of science concepts, with a sixth concept, attitude toward a career in science, determined by combining ten items. I coded the responses so that low scores on the SAII represent a low understanding and negative emotion toward science and high scores represent a high understanding and positive emotion toward science. The scoring guide for the instrument can be viewed in Appendix VI.
To determine the stability of the SRA measure of understanding of situations of uncertainty, I entered all 40 item responses from this instrument into a reliability analysis. The Cronbach’s Alpha reliability for this instrument was calculated to be .80, N = 68, indicating moderate to high stability of this instrument for this sample.

I began the analysis by combining and averaging the scores of the items associated with the six SAI II concepts for each participant. This resulted in the creation of a composite value representative of each SAI II nature of science concept, which I used to calculate the mean for each nature of science concept. The descriptive statistics for the responses to the six SAI II subgroups is listed below in Table 6, which is followed by Figure 4 which provides a plot of the means.

Table 6

_The Means and Standard Deviations for the Six SAI II Subgroups_

<table>
<thead>
<tr>
<th>NOS Subgroup</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laws_in_Science</td>
<td>3.57</td>
<td>.40</td>
</tr>
<tr>
<td>Limitations_of_Science</td>
<td>3.83</td>
<td>.48</td>
</tr>
<tr>
<td>Alter_Positions_in_Science</td>
<td>4.10</td>
<td>.43</td>
</tr>
<tr>
<td>Idea_Generation_in_Science</td>
<td>3.02</td>
<td>.38</td>
</tr>
<tr>
<td>Progress_of_Ideas_Science</td>
<td>3.70</td>
<td>.52</td>
</tr>
<tr>
<td>Careers_in_Science</td>
<td>3.11</td>
<td>.80</td>
</tr>
</tbody>
</table>
In my examination of the means of the nature of science concepts I determined that four nature of science concepts were noticeably above the undecided category. This indicates that the participants held a positive understanding of law and theories as approximations of scientific truth, the limitations of science to answer questions, the importance of altering perspectives when faced with new evidence, and a positive acceptance of the public benefits of science.

Further analysis of the descriptive statistics for the six SAI II composite scores revealed an undecided understanding of science as an idea generating endeavor and an undecided score for a career in science. This indicated that participants tended to be
undecided as to whether science is a technological endeavor or an idea generating enterprise, and do not have a positive view toward working in a science related job.

**Summary**

I examined the sample for the presence of misconceptions of the understanding of biological evolution, acceptance of biological evolution, situations of uncertainty, and understanding of the nature of science. The determination of whether participants held misconceptions is somewhat subjective. There are no specific criteria for determining significant levels of misconceptions for any of the three instruments. Therefore, I determined a more qualitative and general approach to be more appropriate for identifying and reporting misconceptions, using a combination of descriptive statistics and item response content analyses.

The analysis exposed noticeable levels of misconceptions in all three conceptual domains. Analysis of the CINS and MATE scores indicates that the participants hold deterministic misconceptions of the process of biological evolution and are undecided about evidence for the evolutionary process. The variety of situation of uncertainty misconceptions related to representativeness, equiprobability, averaging, and the laws of small numbers, all of which could contribute to alternative conceptions of biological evolution. The SAI II subgroup measuring the intellectual understanding of science as an idea generating enterprise was identified as being near undecided. The limited understanding of the idea generating processes of science may lead to more of a mechanistic perspective of scientific concepts. This could limit the ability to combine the wide variety of evidence supporting scientific concepts which in turn could lead to a limited understanding of complex scientific theories like biological evolution. In
summary, the evidence provides support for my hypothesis associated with Question #1, which predicted that the participants would hold misconceptions about all three content areas.

Instructional Impact

The second research question addressed the instructional impact of the interventions: Is instruction targeted at promoting understanding of the nature of science, situations of uncertainty, and biological evolution effective in promoting understanding and reducing misconception in pre-service teachers' conceptions of these phenomena? Do pre-service teachers gain a greater understanding of biological evolution when instruction in these three areas is combined? Does combining interventions result in greater conceptual change as reflected by reduced misconceptions about these three phenomena?

Group Differences on All Measures

Table 7 presents the means and standard deviations for the pre- and post-test scores for the experimental and control groups on each of measures contributing to the analysis of differences due to instruction.

Understanding Evolution Assessment

As a preliminary analysis of participants’ comprehension of the two tutorials common to both experimental and control groups, I conducted a repeated measures ANOVA of the UEA percent correct for the UEA post-test and delayed post-test scores. The UEA instrument was designed to measure participant comprehension of the two common
tutorials. The third instructional tutorial was not included in the analysis because the content was not common across groups. The Cronbach’s Alpha reliability for this instrument was calculated to be .65, N = 68 indicating modest stability of this instrument for this sample.

Table 7

The Means and Standard Deviations for the Pre- and Post Test Measures for the Experimental and Control Group

<table>
<thead>
<tr>
<th>Measure</th>
<th>M</th>
<th>SD</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experimental</td>
<td>Control</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>n = 34</td>
<td>n = 34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UEA_SVT_Pre</td>
<td>.66</td>
<td>.20</td>
<td>.62</td>
<td>.22</td>
</tr>
<tr>
<td>UEA_SVT_Post</td>
<td>.67</td>
<td>.22</td>
<td>.70</td>
<td>.21</td>
</tr>
<tr>
<td>CINS_Pre_Composite</td>
<td>9.35</td>
<td>3.42</td>
<td>9.79</td>
<td>2.58</td>
</tr>
<tr>
<td>CINS_Post_Composite</td>
<td>10.21</td>
<td>3.92</td>
<td>9.35</td>
<td>3.63</td>
</tr>
<tr>
<td>MATE_Pre_Composite</td>
<td>71.54</td>
<td>14.06</td>
<td>69.35</td>
<td>15.53</td>
</tr>
<tr>
<td>MATE_Post_Composite</td>
<td>74.19</td>
<td>14.25</td>
<td>72.44</td>
<td>13.51</td>
</tr>
<tr>
<td>SRA_Pre_Correct</td>
<td>7.24</td>
<td>2.70</td>
<td>7.85</td>
<td>2.48</td>
</tr>
<tr>
<td>SRA_Post_Correct</td>
<td>8.19</td>
<td>2.25</td>
<td>7.69</td>
<td>2.42</td>
</tr>
<tr>
<td>SRA_Pre_Misconcepts</td>
<td>7.78</td>
<td>2.06</td>
<td>7.53</td>
<td>2.00</td>
</tr>
<tr>
<td>SRA_Post_Misconception</td>
<td>7.10</td>
<td>1.90</td>
<td>7.76</td>
<td>2.27</td>
</tr>
<tr>
<td>SAI_Pre_Understanding</td>
<td>87.31</td>
<td>5.84</td>
<td>87.03</td>
<td>5.86</td>
</tr>
<tr>
<td>SAI_Post_Understanding</td>
<td>87.79</td>
<td>5.20</td>
<td>86.79</td>
<td>7.81</td>
</tr>
<tr>
<td>SAI_Pre_Emotion</td>
<td>71.31</td>
<td>11.46</td>
<td>71.56</td>
<td>9.87</td>
</tr>
<tr>
<td>SAI_Post_Emotion</td>
<td>70.43</td>
<td>10.76</td>
<td>71.40</td>
<td>10.35</td>
</tr>
</tbody>
</table>

The results revealed there was no significant main effect for group $F(1,66)=.05$, $p>.05$, indicating that the groups did not differ in their comprehension of the two
tutorials. There was also no main effect of time $F(1,65)=1.92$, $p>.05$, indicating that participants in the experimental and control groups did not differ in their levels of comprehension of the content of the interventions over time (see Table 8). Finally, the interaction between group and time was also not significant $F(1,66)=1.08$, $p>.05$.

Therefore, all further analysis will be conducted based on the acceptance of the findings that the two groups did not differ significantly in comprehension and retention of the instructional interventions.

Table 8

<table>
<thead>
<tr>
<th>Effect</th>
<th>df</th>
<th>$F$</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>1</td>
<td>1.92</td>
<td>.17</td>
</tr>
<tr>
<td>Group</td>
<td>1</td>
<td>.05</td>
<td>.83</td>
</tr>
<tr>
<td>Time * Group</td>
<td>1</td>
<td>1.08</td>
<td>.30</td>
</tr>
<tr>
<td>Error</td>
<td>66</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

To begin the analysis of the impact of the instructional intervention, I calculated the correlations between all pre-test scores for each measure. These include understanding evolution (CINS), acceptance of evolution (MATE), situations of uncertainty correct answers (SRA), situations of uncertainty misconceptions (SRA), the emotional acceptance of the nature of science (SAI II), and the intellectual understanding of the nature of science (SAI II). I used the correlations to determine if there were significant relationships between any of variables (see Table 9). Tabachnick and Fidell (2007) report that correlations between dependent variables in an ANOVA provide redundant

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information. Therefore an omnibus analysis of the instructional effects is not appropriate because the results do not accurately represent the relationships between the dependent and independent variables.

Table 9

Correlations Among Pre-test Measures

<table>
<thead>
<tr>
<th></th>
<th>CINS</th>
<th>MATE</th>
<th>SRA_Correct</th>
<th>SAI_Und</th>
<th>SRA_Miscon</th>
<th>SAI_Emo.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CINS</td>
<td>1</td>
<td>.16</td>
<td>.48**</td>
<td>.38**</td>
<td>-.30*</td>
<td>.35**</td>
</tr>
<tr>
<td>MATE</td>
<td>1</td>
<td>.18</td>
<td>.14</td>
<td>.00</td>
<td>.20</td>
<td></td>
</tr>
<tr>
<td>SRA_Correct</td>
<td>1</td>
<td>.30*</td>
<td></td>
<td>-.67**</td>
<td>.26*</td>
<td></td>
</tr>
<tr>
<td>SAI_Und</td>
<td>1</td>
<td>-.18</td>
<td>.29*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRA_Miscon</td>
<td>1</td>
<td></td>
<td>-.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAI_Emo.</td>
<td></td>
<td></td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N = 68

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The results of the correlation analysis indicated that there were significant correlations among the pre-test measures which necessitated conducting separate repeated measures ANOVA for each measure. This will be conducted at the .05 level of significance without error correction. Rossi, Lipse, and, Freeman, (2004) provide justification for maintaining a higher level of significant (alpha = .05) with smaller sample sizes, to compensate for the reduced power and the increased probability of type II error.
Biological Evolution

A repeated measures ANOVA was conducted on the CINS scores using the experimental and control groups as a between group factor and the pre-test and post-test a within subjects factor. The results revealed that there was no significant main effect for group, $F(1,66)=.08$, $p>.05$, indicating that the groups did not differ in their understanding of biological evolution. There was also no significant main effect of time $F(1,66)=.33$, $p>.05$, indicating that there was no significant change in participants’ understanding of biological evolution following instruction. Further, there was no significant interaction effect, $F(1,66)=3.22$, $p>.05$, indicating there was not a differential impact of instruction for the two groups.

The correlation analysis presented in Table 9 above indicates that the CINS measure of understanding of biological evolution is significantly correlated with the SRA correct scores ($r = .48$, $p < .01$) and the SIA understanding scores ($r = .38$, $p < .01$). This suggests that there is shared variance among the measures that could be reduced through the use of the SRA and SAI scores as covariates. Therefore, there is methodological justification for including these variables as covariates in a repeated measures ANCOVA examination of the CINS pre-test and post-test scores. Furthermore, the understanding of biological evolution has been linked to understanding stochastic processes (Sadler, 2005) and to understanding the nature of science (Scharmann et al., 2005). This provides theoretical justification for the inclusion of these two covariates in the analysis.

The results of the ANCOVA indicate that there was no significant main effect for group $F(1,64)=.74$, $p>.05$, indicating that the groups did not differ in their understanding of evolution. Also there was no significant main effect for time $F(1,64)=2.08$, $p>.05$,
indicating that there was no detectable change in participants' understanding of biological evolution following instruction. However, the results did reveal a significant interaction \( F(1,64)=4.31, p<.05, \text{ power }=.53, \text{ effect size }=.07, \) indicating that there was a differential effect of instruction for the treatment and control groups when I accounted for the shared error variance among these measures (see Table 10).

![Estimated Marginal Means of CINS](image)

**Figure 5:** The means plot for the ANOVA calculations of the CINS.

**Table 10**

*The Pre-test and Post-Test CINS Means and Standard Errors from the ANCOVA*

<table>
<thead>
<tr>
<th>Group</th>
<th>CINS scores</th>
<th>M</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>Pre-Test</td>
<td>9.35(a)</td>
<td>.45</td>
</tr>
<tr>
<td>( n = 34 )</td>
<td>Post-Test</td>
<td>10.21(a)</td>
<td>.57</td>
</tr>
</tbody>
</table>

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Acceptance of Evolution

The acceptance of evolution tends to be independent of understanding of evolution and may be resistant to change (Rutledge & Warden, 1999; Sinatra et al., 2003), and change in this measure over time is not expected. I conducted a repeated measures ANOVA to examine MATE scores using study group as the between group factor and pre-test and post-test scores as the within subjects factor. The means and standard errors for the pre-test and post-test scores are presented in Table 11. The results of the repeated measures ANOVA revealed there was no significant main effect for group $F(1,66) = .39$, $p > .05$, indicating that the groups did not differ in their comprehension of the two tutorials. However, there was a main effect of time $F(1,66) = 3.99$, $p > .05$, indicating that participants in the experimental and control groups differed in their levels of acceptance over time (see Figure 6). Further, the results also revealed no significant interaction $F(1,66) = .02$, $p > .05$, indicating that instruction did not have a differential effect on acceptance. These results indicate that the acceptance of the theory of evolution increased equally for both groups. I attribute this change to the common instructional tutorials that focused on misconceptions of evolution and on the nature of science in the context of evolution.
Situations of Uncertainty

The SRA measures situations of uncertainty is divided into scores for correct responses and scores for misconception responses. The scoring guide for this instrument can be viewed at the end of Appendix V. Not every item of the SRA has misconception distractors, therefore, the correct scores and misconception scores were analyzed separately. The score for SRA correct represents the number of correct responses, and likewise the score of SRA misconceptions represents the number of misconception responses selected.

Table 11

The Pre-test and Post-Test MATE Means and Standard Errors From the MANCOVA

<table>
<thead>
<tr>
<th>Group</th>
<th>MATE Test</th>
<th>Mean</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>Pre-Test</td>
<td>71.54</td>
<td>2.54</td>
</tr>
<tr>
<td></td>
<td>Post-Test</td>
<td>74.19</td>
<td>2.38</td>
</tr>
<tr>
<td>Control</td>
<td>Pre-Test</td>
<td>69.35</td>
<td>2.54</td>
</tr>
<tr>
<td></td>
<td>Post-Test</td>
<td>72.44</td>
<td>2.38</td>
</tr>
</tbody>
</table>
Figure 6: The means plot for the ANOVA calculations of the MATE.

I conducted a repeated measures ANOVA comparing SRA scores of correct responses using study group as the between group factor and pre-test and post-test scores as the within subjects factor. The results reveal that there was no significant main effect for time $F(1,66) = 2.47$, $p>.05$, indicating that the scores did not change from pre- to post-test. Also that there was no significant main effect for group, $F(1,66) = .02$, $p>.05$, indicating that the groups did not differ in their scores. However, results did reveal a significant interaction, $F(1,66) = 4.9$, $p<.05$, indicating that there was a differential effect of instruction on the two groups. The means and standard errors for the experimental and control group are displayed in Table 12.
Table 12

*The Pre-test and Post-Test SRA Means and Standard Errors used in the ANOVA.*

<table>
<thead>
<tr>
<th>Group</th>
<th>SRA scores</th>
<th>M</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental Pre-Test</td>
<td>7.194</td>
<td>.478</td>
<td></td>
</tr>
<tr>
<td>n = 34</td>
<td>Post-Test</td>
<td>8.097</td>
<td>.423</td>
</tr>
<tr>
<td>Control</td>
<td>Pre-Test</td>
<td>7.879</td>
<td>.463</td>
</tr>
<tr>
<td>n = 35</td>
<td>Post-Test</td>
<td>7.727</td>
<td>.410</td>
</tr>
</tbody>
</table>

The power analysis was .59 and the effect size was .07, which are reflective of the limited sample size. Although the groups did not differ in their scores, the manner in which they changed over time was detectably different. I attribute this difference to the situations of uncertainty tutorial that was presented in the context of evolution to the experimental group. The significant interaction provides evidence to support the benefits of the contextual instruction of situations of uncertainty to changing understanding over time. A plot of the pre- and post-test in correct SRA situations of uncertainty scores is displayed in Figure 7.
Figure 7: A plot of the average SRA correct scores for pre (1) and post (2) for both experimental and control groups.

Following the examination of correct scores, I conducted a repeated measure ANOVA on the SRA misconception scores, using study group as the between group factor and pre- and post-test scores as the within subjects factor. The results showed that there was no significant main effect for group $F(1,66) = .23, p > .05$, which indicates that the groups did not differ in the number of misconception responses. Also there was no significant main effect for time, $F(1,66) = .74, p > .05$, indicating that the number of misconceptions did not differ between the pre- and post-test scores. Further, there was no significant interaction, $F(1,62) = 3.16, p > .05$, signifying that there was no differential effect of instruction on reducing misconceptions.
The outcome of SRA analysis indicates that the change in correct conceptions of situations of uncertainty is not necessarily accompanied with the change in misconceptions of situations of uncertainty. This is possible because the SRA has a different number of items for the scores for correct understanding and held misconceptions. Therefore, an incorrect score on the SRA does not necessarily indicate the selection of a misconception response, and a change to a correct response on some items from the pre-test to the post-test would not necessarily result in a decrease in the number of misconception responses. My results indicate that changes in correct scores may not be an indicator of change in misconceptions.

Understanding of Nature of Science

The SAI II uses 40 items to measure both understanding and emotion. The SAI II requires the formation of composite scores formed from groups of items to measure various concepts related understanding and emotional perspectives of the nature of science. The scoring guide and nature of science concept item groups can be viewed in Appendix VI. Since the SAI II measures both intellectual understanding of science and emotional perspectives toward science, I conducted two repeated measures ANOVA analyses to determine differences on the SAI II composite scores. One ANOVA was conducted to examine intellectual understanding of the nature of science and a second to examine emotions toward science.

I conducted a repeated measures ANOVA of the SAI II pre-test and post-test composite scores representing the intellectual understanding of the nature of science, using the study group as the between group factor and pre and post-test scores as the within subjects factor. The results revealed no significant main effect for time $F(1,66) =$
.04, p>.05], indicating that scores for intellectual understanding did not change over time. Also there was no main effect for group $F(1,66) = .22$, p>.05, which indicates that the scores did not differ between groups. Further, there was no significant interaction $F(1,66) = .29$, p>.05, which reveals that there was no differential effect on nature of science understanding.

I also conducted a repeated measures ANOVA on the SAI II pre-test and post-test composite scores for emotions toward science, again using study group as the between group factor. The findings were similar to those for understanding the nature of science with no significant main effect for time $F(1,66) = .52$, p>.05, which shows that the pre- and post-test scores do not differ. There was no main effect for group $F(1,66) = .06$, p>.05, which indicates that the control and experimental groups did not differ in their scores. The results also showed that there was no significant interaction $F(1,66) = .25$, p>.05, indicating that there was not a differential effect on this measure. These results indicate that the nature of science instruction had no impact on participants' intellectual understanding of the nature of science or emotions toward science.

**Summary**

I conducted separate repeated measures ANOVAs on the pre-test and post-test scores for the understanding of biological evolution (CINS), the acceptance of the theory of evolution (MATE), the levels of correct responses and misconceptions of situations of uncertainty (SRA), and intellectual understanding and emotions toward the nature of science (SAI II).

The significant correlation between the pre-test measures of situations of uncertainty and understanding of the nature of science with the measures of biological evolution
indicates that understanding of these concepts is related. This is further supported by the significant outcome of the repeated measures ANCOVA analysis of the CINS that resulted from the inclusion of the SRA and SAI II as covariates.

The results for all measures revealed one main effect. The acceptance of evolution changed with time for both the experimental and control groups. This indicates that the intervention had the same impact on both groups, significantly increasing acceptance over time. The results also revealed a significant interaction effect for correct conceptions of situations of uncertainty. This indicates that the control and experimental groups responded differently over time, which I attributed to the situations of uncertainty intervention that was unique to the experimental group.

The analyses of the measures of misconception of situations of uncertainty, the intellectual understanding of the nature of science, and emotional perspectives toward the nature of science reveal no significant results. My instructional interventions may not have effectively targeted the complexity of these concepts or the specifics of the misconceptions. It may also be possible the participants held robust perspectives that were resistant to instruction.

Application of Web-Based Instruction

The third research question asked:

Can pre-service teachers use knowledge gained web-based instruction in these areas in lesson plan design?

The theoretical framework guiding the qualitative data analysis is comparative analysis (Miles & Hubermann, 1994). The lesson ideas generated by the participants were examined for evidence of developing content knowledge in relation to the concepts
presented in the instruction. The combination of a priori and emergent coding used in the analysis was consistent with the accepted procedures and theoretical approaches typified by a comparative analysis of qualitative data.

The a priori and emergent coding used in analysis of the lesson ideas is centered on the concepts encountered in the instruction of biological evolution, situations of uncertainty, and the nature of science. I selected the a priori coding used for analysis of the lesson ideas to expose participant utilization and application of key terms related to the three main instructional concepts. In conducting this analysis, I searched for language related to the biological evolution instruction, coding terms such as “adaptation” and “evolution” and “natural selection” that were used in lesson ideas and applied in ways that reflect application of the instructional information. In the coding related to situations of uncertainty, I focused on the key terms such as “probability” and “uncertainty” and “chance” and any inclusion of mathematical concepts. In conducting the nature of science coding, I selected to examine both emotional and intellectual aspects of the construct and therefore, used terms such as “evidence” and “theory” and “acceptance.”

The results of the coding and the representative content for the lesson ideas along with the corresponding identification of codes of the participants are presented below. The control and experimental groups are presented separately. I have developed a table of the coding frequencies to further elucidate the data analysis, the data extraction approach, and the subject numbers for those who addressed the concepts in their lesson ideas (see Table 13).

I began this analysis with an examination of the control group data which provided a baseline for comparison to the experimental group. This was followed by an analysis of
the experimental group lesson idea data which were compared and contrasted with the control data. I applied the coding scheme as presented in Table 4, and recorded the frequencies in terms of subject identification codes. Examples of data representative of the participant responses are presented along with the last four digit phone code identifier, which allows for ease of tracking the responses of individual participants.

*Control Group: Instructional Influence*

It is apparent that from an analysis of the content of the control group’s proposed lesson ideas that there was integration of concepts presented in the two instructional interventions (evolution and nature of science). Evolutionary theory was mentioned in nearly half of the lesson ideas. The following lessons are representative of the inclusion of instructional content and the focus on theory that is evident throughout the sample:

I would definitely have them read the readings you provided us on how the theory of evolution is believed to work and how different groups feel about it. - Though I didn't spend a lot of time in the readings, some things that I did catch were enlightening/interesting. (Subject 6598)

For first graders I would have the students participate in an open lecture with me and ask them questions about our ancestors and what they think. I would guide them along a watered down version of the evolution theory so they could grasp it as best as possible. I would also include the stories about the Galapagos finches because that would really capture their intention. I might also provide worksheets or coloring sheets of the finches and evolution human figures to provide creativity to the lesson program. (Subject 8805)

Table 13

*A List of the a Priori Codings (Deductive), the Post Hoc (Inductive) Codings, and the Subjects From the Control and Experimental Groups That Addressed the Coding Concept*

<table>
<thead>
<tr>
<th>Coding/Terms</th>
<th>Extraction</th>
<th>Content</th>
<th>Control Subject(s)</th>
<th>Experimental Subject(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolve</td>
<td>Deductive</td>
<td>Evolution</td>
<td>1226, 6563, 7997</td>
<td>1434, 1486, 5083, 6268</td>
</tr>
<tr>
<td>Natural Selection</td>
<td>Deductive</td>
<td>Evolution</td>
<td>4901, 5312, 7946, 9391</td>
<td>4362</td>
</tr>
<tr>
<td>-------------------</td>
<td>-----------</td>
<td>-----------</td>
<td>------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Mutation</td>
<td>Deductive</td>
<td>Evolution</td>
<td>Not Addressed</td>
<td>3233</td>
</tr>
<tr>
<td>Fossils</td>
<td>Deductive</td>
<td>Evolution</td>
<td>5277</td>
<td>Not Addressed</td>
</tr>
<tr>
<td>Diversity/</td>
<td>Inductive</td>
<td>Evolution</td>
<td>3037, 3140, 9391, 9766</td>
<td>3233</td>
</tr>
<tr>
<td>Different Species</td>
<td></td>
<td></td>
<td>0220, 1434, 2446,</td>
<td>4695, 5083, 9059</td>
</tr>
<tr>
<td>Guppies/Finches</td>
<td>Inductive</td>
<td>Evolution/CINS</td>
<td>3037, 5544, 8805</td>
<td>1434, 5083, 6866</td>
</tr>
<tr>
<td>Religion</td>
<td>Inductive</td>
<td>Evolution/NOS</td>
<td>5277, 6132</td>
<td>5900</td>
</tr>
<tr>
<td>Theory</td>
<td>Deductive</td>
<td>Evolution/NOS</td>
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Keeping in mind that not everyone believes in evolution, I would teach this lesson only as a theory. I would however show the different physical evolutionary changes that man has gone through. (Subject 9766)

These lesson ideas typify the wide variety of responses contained within the data. Subject 6598 recognizes the value of the instruction from the Understanding Evolution website, and would use it for instruction. The integration of the Galapagos finch research to capture students’ attention by Subject 8805 provides support for the influence of the
instructional interventions on the development of pedagogy. Yet, it is also apparent from the last statement written by Subject 9766 that even though the instruction explicitly addressed nature of science and misconceptions of biological evolution, alternative conceptions persist for this participant. This suggests that the instructional impact may be influential on the lesson designs but not necessary on changing personal conceptions.

The relationship between religious perspectives and scientific perspectives was represented in the lesson ideas. The lesson idea developed by Subject 9766 includes a statement that evolution is "only a theory" which reflects the presence of a misconception of the nature of science, that is, scientists' use of the word theory. Some participants' lesson ideas provide evidence of an attempt to validate pedagogy that compares science and religious perspective as equally valid explanations of evolution. The following lesson ideas represent the range of responses that address the ideologies of both religion and science:

Inform students of evolutionary theory and explain it's relation to other sciences, as well as it's independence from moral and religious ideas. (Subject 6132)

Begin class with an overview of evolution and let the guided discussion begin and continue with myths and facts regarding evolution. (Subject 6753)

Use the models listed above to further explain and to broaden the students' minds of how humans and animals fit into the evolutionary picture. Explain that this is science and not total truth. However, there is significant amount of evidence that proves that at least part of the theory of evolution is correct. Also, explain that to believe in both church and science is alright. Do not talk more about religion, your main focus here is science. (Subject 5277)

Keeping in mind that not everyone believes in evolution, I would teach this lesson only as a theory. I would however show the different physical evolutionary changes that man has gone through. (Subject 9766)

Teacher: Discuss with students the different ideas of evolution- biblical and scientific.  
Students: Discuss with each other which theory they believe in. Based on their
choice, the students will write and draw what they learned and how they understand evolution. (Subject 7946)

Over half of the lesson ideas had references related to the instructional content. In the process of coding the lesson ideas I was able to identify several instances in which participants included content that was very unlikely to have occurred randomly. For instance, one lesson idea includes the incorporation of content which addresses the misconception of the conflict between evolution and religion, by presenting a position in which these ideologies recognized as two distinct ways of knowing. This indicates the Understanding Evolution tutorial had an instructional impact. Further examples provided by the lesson ideas developed by Subjects 6132 and 5277 which reflect a clear distinction between the theories of science and the belief of religion. Yet, Subjects 9766 and 7946 place limitations on scientific theories and suggest that religious beliefs can be considered as equally valid and comparable approaches to explaining species diversity. This reveals the limited impact the instruction had on promoting conceptual shifts.

In further analysis of the lesson ideas for concepts directly related to biological evolution, a search was conducted for the presence and application of terms related to key concepts. The processes of natural selection and adaptation were addressed in several different lesson ideas, indicating the awareness of the relationship of these processes to biological evolution. In this lesson idea Subject 5312 focused on adaptation and alludes to natural selection:

Students will learn about certain animals environments, their adaptive characteristics to those environments and create their own explanation for how those animals may have adapted to survive. Another aspect of this lesson would be to have student explore concepts of competition and to relate this to humans. (Subject 5312)
The subsequent passage drafted by Subject 4901 signifies misconceptions of the process of natural selection as related to biological evolution, suggesting that natural selection is somehow different from biological evolution:

Study the differences between evolution and natural selection. Allow the students to choose an animal to study and research. (Subject 4901)

This passage extracted for the lesson idea developed by Subject 9391 also reflects misconceptions of the natural selection process in biological evolution, implying organisms fight to be the best:

Students would probably watch a video on natural selection, then we would look at some different animals in different habitats that fight to be the best. They would do some sort of activity where they would create their own species and explain what the species' strengths and weaknesses were and as a class as a whole we would play a game to see which animal comes out on top as the strongest. (Subject 9391)

Misconceptions of evolution and natural selection were found in many forms. The misconception that is evident in the next passage suggests that there are different kinds of evolution that can take place:

Students will understand the different kind of evolution that occur in humans. (Subject 6685)

Overall, the lesson idea data provides some evidence that the control group was influenced by the instructional interventions, with over half of the products containing coding outcomes that could be attributed directly to the content of the instructional intervention. Yet, even through the content of the instructional interventions explicitly addressed misconceptions, they persisted, with many subjects drafting lesson ideas that included the teaching of misconceptions.

Control Group: Other Influences
In addition to the influence of the instructional intervention there is also evidence of a recognizable influence of the survey instruments on the content of participants’ lesson ideas. For example, several of the participants incorporated studies of finches and guppies into their lesson idea which comes from the CINS instrument but was not addressed extensively in the instructional intervention. For example three participants had lesson ideas very similar to this one developed by Subject 3037:

Students would be organized into 14 different groups (2 to 3 students in a group) and would move through stations that would have pictures, island information, food and water sources, and other information for each distinct kind of finch. (Subject 3037)

This lesson is nearly a duplicate of the CINS finch scenario and the related survey items.

Further evidence of the influence of the research instruments can be discerned from this passage as Subject 8918 incorporated probability into her/his lesson idea and stated:

After a short lesson on evolutionary theory, (assuming that students have taken a Biology course in high school) the students will use mathematical formulas to determine the probability of an organism changing as a result of evolution. (Subject 8918)

Which was followed by:

Students will solve probability math problems similar to those that were solved during the lesson activities. (Subject 8918)

Aside from a brief component of the instructional intervention addressing misconceptions of evolutionary theory, the control group did not receive instruction detailing the association of probability and biological evolution. Therefore, it can be assumed that Subject 8918 transferred concepts from the SRA instrument which measured understanding of situations of uncertainty to the development of her/his lesson idea. Four of the 35 control group participants included aspects of the instruments into their lesson ideas.
Overall, the control group lesson ideas did incorporate aspects of the instruction. There were 12 instances of scientific content related directly to the study of biological evolution, 17 instances of the inclusion of nature of science concepts, and seven instances of time or chance related themes found within the data. The survey instruments also influenced participants' lesson idea development, with four lesson ideas containing content directly linked to the SRA and CINS instruments. Although there are many correct applications of concepts, there are also at least five instances in which misconceptions overtly apparent and were being promoted by the participants as acceptable instructional content.

**Experimental Group: Instructional Influence**

There are both notable similarities and differences in the lesson ideas of the experimental group when compared to the control group. As with the control group, approximately a third of the 37 experimental group's lesson ideas explicitly addressed evolutionary theory. The components of the following three lesson ideas are representative of the content of items produced that specifically examine the process of evolution as a theory:

- I would test them to see if they understand what evolution is and how scientists came about with the theory of evolution. (Subject 1942)

- To teach students about different theories that scientists believe according to the way animals and humans advance and change over time (Subject 5987)

- Teach the student about the theory of evolution, when it started and the life span of our existence. (Subject 0037)

- To track the origins of the theory of evolution and how the ideas themselves have evolved. (Subject 6268)
The lesson idea component above that was developed by Subject 6268 address aspects of scientific theories as they pertain to the nature of science. The passage alludes to the dynamic characteristics of theories as they evolve in response to new evidence and understanding. This concept is covered extensively in the nature of science instructional intervention. The passage presented above provides evidence of the influence of both the evolution and the nature of science instruction of student ideas for designing lessons.

Unlike the control group, several experimental group lesson ideas incorporated the concept of time a significant component of their lesson ideas, using it to promote student understanding of evolution as a relatively long term process. The situation of uncertainty instruction explains the role that time plays in evolution. Thus, the inclusion of time in the lesson ideas provides evidence for the impact of the situations of uncertainty instruction. Four lesson ideas place much emphasis on the use of timelines to learn about evolution, producing ideas similar to these:

Watch a tadpole go through it's changing in order to allow the students to observe this foreign idea I am placing before them. Compare the evolutionary theory to that making sure to explain that this is actually something that happens over a vast amount of time and is not as observable as the tadpoles change. (Subject 5987)

Student will summit journal entries and then report of comparing their own growth. The report will include their measurements and charts. They should be able to explain that they have changed over time. (Subject 1516)

A PowerPoint of a timeline could be used for this lesson. Each animal, starting with the oldest, such as Dinosaurs, Saber tooth tigers, the platypus etc, would have a designated slide with a picture and description, along with the time line. This would continue until present day animals. (Subject 1641)

The emphasis on time in the lesson ideas may reflect an understanding of the temporal attribute of biological evolution. Yet, even with conceptions that are consistent with current understanding, other misconceptions of evolution may persist eclipsing these
scientifically accepted perspectives. Thus, individuals may hold misconceptions of biological evolution, integrating them with scientifically accepted perspectives. This may result in the misconception dominating the comprehension and communication of evolution. For example, the previously presented lesson idea developed by Subject 1641 was followed by this:

Students will have the option of choosing a prehistoric animal or present day animal of their choice. They will then have to draw the animal, list the type of environment it lived or lives in, and the approximate date of its creation/discovery. (Subject 1641)

It is apparent from the second passage that Subject 1641 is concerned with teaching a balanced view of evolution and creationism by presenting them as an equally valid explanation. However, the lesson idea developed by Subject 1641 is the only experimental group lesson idea involved teaching evolution and religion as equally valid. Several others addressed the ontological differences in the two ways of knowing, such as in this lesson:

Students will be able to know the differences and similarities between evolutionary science and religious dogmas. (Subject 5900)

Which was followed by:

Students will work in groups of four (4). They will read through small, basic articles depicting similarities and differences in science and religion. (Subject 5900)

Similarly Subject 4330 developed this lesson idea:

Be able to know that my kids will understand the difference between and evolution and creation. And also how everything started to form in the earth. (Subject 4330)

The lessons developed by Subjects 5900 and 4330 reflect an understanding of the differences between religion and science as ways of knowing that are consistent with the
nature of science and misconceptions of evolution instructional interventions. This data provides evidence for the influence of the instructional interventions on these subjects. The consistency between the lesson idea content and the instructional intervention provides evidence that suggests that the tutorials influenced these participants understanding of the ontological differences between the two ways of knowing.

Although the following lesson components propose to explore science as a way of knowing, they also reflect misconceptions of the scientific theory construct as defined by the nature of science:

The students will understand the definition of evolution and understand the process of evolution as well as the opposed theory that evolution does not exist. The students will be able to know how old earth is and all of the stages of life that have existed on this planet. (Subject 2446)

Students will write a one page summary of their visit to the museum which will include their factual support of the evolutionary process from the examples that they say at the museum. Students will choose one animal to compare and contrast with its ancestors in order to prove the theory of evolution. (Subject 1379)

Subject 2446 suggests that there are alternate theories to biological evolution, and Subject 1379 suggests that “proof” is needed for evolutionary theory. Both of these passages provide evidence for a lack of understanding of scientific theories and instead promote a position that is more consistent with considering theories as whimsical ideas and not as evidence-based explanations.

The experimental group received instruction related to situations of uncertainty in the context of biological evolution, and yet this lesson idea developed by Subject 1434 was the only product that incorporated any concepts from the instructional intervention. Subject 1434 applied the instructional presentation of finch beak size which was used to
discuss random variation. However, beak size is also addressed in a scenario in the CINS survey instrument; thus it is difficult to discern the source for this lesson idea:

1. Research different Finch beaks and how they have evolved
2. Compare/contrast different sizes
3. Explain why the beaks are different (Subject 1434)

The conception of random mutation is a significant component of the situations of uncertainty instruction, yet the concept was explicitly mentioned in only one lesson idea (Subject 3233) in the experimental group. The lesson idea states:

For children to see that mutation is a form of evolution. Species grow and adapt to new things in order to survive. (Subject 3233)

Similarly, the concepts of natural selection and adaptation were presented in several places in the instructional interventions, but the concepts were explicitly included in only one lesson idea (Subject 3576). The component of this lesson idea is written as:

This lesson will be in the course of 4 days.
Day 1- The first day we will watch a video which introduces the lesson and gives the students some background information on animal adaptation, and key words such as habitat, and animal environment. As the end of the video, the students will be given the chance to select an animal of interest as their group project. There should be a total of 3-4 students in each group.
Day 2- Once each group selects an animal, they will be responsible for researching the following points...
   a. How the animal lives, (i.e. in the tundra region, in the rain forest, in the dessert) They should be able to tell their classmates during their presentation, what kind of habitat their animal lives in and their surrounding environment.
   b. How does this animal live, (i.e. get its food, fight predators, sleep)
   c. Most importantly how does their animal adapt to their environment. (for example, certain birds genetically adapted to their environment by having larger beaks).
Day 3- the students will have classroom time to continue their research and develop their animal presentation for the next day.
Day 4- Students will present their projects to the class. Students observing the presentation will be given a chance to evaluate how their fellow classmates did on their project, by the use of evaluation slips. (Subject 3576)
Some aspects of the instructional interventions found in some of the experimental group lesson ideas, perhaps the most obvious is this lesson idea that specifically addresses misconceptions of evolution (Subject 7120). The object of the lesson idea is followed by the specific activity:

Students will understand the differences between common misconceptions of the theory of evolution and scientific studies/results. (Subject 7120)

Which is followed by this activity description:

Students will be lectured on the common misconceptions concerning evolutionary theory, including viewing a slide show presentation. During and after, students will be encouraged to add to the discussion with their own thoughts about the subject matter. Note-taking is encouraged but by no means necessary. (Subject 7120)

An examination of the experimental groups' lesson ideas revealed 16 instances in which the content of the product was reflective of the instructional interventions. This suggests that the instructional interventions may impact knowledge that could potentially be applied to teaching biological evolution. Thus, it is possible that the instructional interventions increased content knowledge providing a foundation from which concepts from biological evolution, the nature of science and situations of uncertainty could be taught.

*Experimental Group: Instrument Influence*

Unlike the control group, the experimental group did not overtly incorporate as many ideas from the survey instruments into their lesson ideas. There was no mention of guppies which was presented in the CINS instrument as a scenario or any evidence for inclusion of the probability concepts as related to the SRA instrument.
Summary

Overall, it appears that the instruction intervention had an influence on the development of lessons and pedagogy related to teaching biological evolution and the nature of science. However, the lack of lesson ideas specifically incorporating situations of uncertainty suggests that the concept did not transfer to understanding of biological evolution. Lesson ideas were found in both the control and experimental group that reflect the retention of misconceptions. Fragmented understanding along with the communication of misconceptions indicates that the instructional interventions increased understanding but did not resolve the retention of misconceptions. The incorporation of the instructional content into lesson ideas provides evidence to suggest that it is possible to increase content knowledge with a rather brief instructional intervention.

Individual Traits as Predictors

My fourth research question asks:

Do individual differences in gender, age, intended grade level of service, years of education, the number of mathematics and science courses, and level of religiosity predict the number of held misconceptions?

In answering this question, I began with a correlational analysis of individual differences variables and the measures of the three study domains. The individual differences measures included; age, gender, ethnicity, years in college, the number of mathematics courses, the number of science courses, intended grade level of teaching and level of religiosity. The measures of understanding and acceptance included: understanding of biological evolution (CINS), the acceptance of biological evolution (MATE), understanding of situations of uncertainty (SRA), and the various concepts of
the nature of science (SAI II). The results of this correlational analysis can be seen below in Table 14. I reported the correlation between the scores for the instruments previously in , and therefore, I omitted these from Table 14.

Table 14

The Correlations Between the Instrument Scores and Measures of Personal Differences.

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* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

I used the values from the correlation analysis as guidelines for the determination of relationships between measures of individual differences and the measures of the three study domains that warranted further exploration.

All measures of individual differences are in the form of nominal or ordinal measures. Due to the relatively small sample size and the associated reduction in statistical power, I
made the decision to dichotomize the measures of individual differences. I determined
the criteria for variable dichotomization based on theoretical and logical divisions of the
measures. I discuss the criteria used for the dichotomization of the measures as I present
each individual difference and its relationship to the measures of the three study domains.

The findings for each of the relationships are presented and discussed in detail in the
order in which the individual differences appear in the research question: gender, age,
intended grade level of service, years of education, the number of mathematics and
science courses, and level of religiosity.

Gender

The correlation matrix above (see Table 14) reveals gender was significantly related
to both the SRA correct pre-test scores and SRA misconceptions pre-test scores. As
previously discussed, it is important to examine gender because mathematics reasoning
ability has been shown to differ between the two genders (Baxter Magolda, 1992;
Schoenfeld, 1987). To determine the nature of the relationships between gender and
understanding of situations of uncertainty, I began by conducted a one-way ANOVA
using the pre-test correct SRA scores as the dependent variable and gender as the
between group factor. The results of the analysis revealed a significant difference in
correct SRA pre-test scores $F(1,67)=11.96, p<.01$, which indicates that males and
females scored differently on the SRA pre-test measure of correct understanding of
situation of uncertainty. The average score for males was 9.62 ($n = 13$), while females
scored an average of 7.06 ($n = 55$), which reveals that males significantly outperformed
females on this measure of situations of uncertainty reasoning.
For the examination of the relationship between SRA misconceptions pre-test scores and gender, I also conducted an ANOVA using the misconception scores at the dependent variable and gender as the between group factor. The results of the analysis revealed a significant difference, $F(1,67) = 6.01$, $p < .05$, indicating that males and females also differed significantly in the pre-tests measure of misconceptions of situations of uncertainty. The average male ($n = 13$) score was 6.46, while females ($n = 55$) scored an average of 7.94.

The results of the analysis of the SRA revealed a gender difference for understanding of situation of uncertainty, with males exhibiting significantly lower levels of misconceptions of situations of uncertainty than females.

As with mathematics, there is evidence indicating that there are gender differences in science learning (Baxter Magolda, 1992; Seibert, 1992), providing motivation for the examination of gender relationship to the SAI II nature of science measure. The correlational analysis above (see Table 14) indicates that intellectual understanding of the nature of science is modestly correlated with gender ($r = .23$, $p = .06$). The SAI II measure of intellectual understanding of the nature of science is composed of four subgroups, each of which represents a different NOS concept. Given the modest level of correlation it is possible that one or more of the SAI II subgroups is significantly related to gender. To explore this relationship further, I conducted an ANOVA using the four SAI II subgroups representing intellectual understanding of the nature of science as the dependent variables and gender as the between group factor. The results revealed no significant differences in the SAI II scores for the intellectual understanding subgroups.
Similarly, the evidence indicating that there are gender differences in science learning (Baxter Magolda, 1992; Seibert, 1992), provides impetus for the additional examination of the modest level of correlation scores \( r = .2, p = .10 \), between gender and the SAI II subgroups for emotions toward science. The SAI II measure of emotions toward the nature of science is composed of three subgroups, each of which represent a different NOS concept. Given the modest level of correlation, it is possible that one or more of these SAI II subgroups is significantly related to gender. To explore this relationship further, I conducted an ANOVA using the SAI II emotional perspectives of science subgroups as the dependent variable and gender as the between group factor. The results of this analysis also revealed no significant differences in emotional perspectives toward science subgroups for gender.

**Age**

Hofer and Pintrich (1997) argue that learning is influenced by personal differences such as age, which provides motivation for examining the relationships between age and the study domain measures. I began my examination of the relationship of age with the other measures of understanding by dichotomizing the measures of age to form two groups to represent this variable. I dichotomize this variable based on the ages of the traditional and non-traditional undergraduate students. I placed the participants in the 18-20, and 21-25 age categories, which are representative of the age of traditional undergraduate students, into one group. I then placed the remaining 26-35, 36-45 and 46+ age category participants into a second group representative of the ages of non-traditional undergraduate students. This effectively dichotomized the variable increasing statistical
power, while providing a useful criterion for examining age as an indicator of misconceptions held of the study domains.

I examined the correlations displayed in Table 14 to determine if age was significantly correlated to any of the three study domain measures. There were no significant correlations detected. However, age and the SAI II emotional perspectives of science were correlated at a moderate level ($r = .19$, $p = .11$). As with gender, I determined that further examination of the three SAI II emotions toward the nature of science subgroups was warranted because one or more of these subgroups might be significantly related to age.

I conducted an ANOVA using the SAI II emotional perspectives of science subgroups as the dependent variables and dichotomized age variable as the between group factor. The results revealed a significant difference for the SAI II career in science subgroup, $F(1,67)=4.32$, $p<.05$, indicating that the two age groups differed in their emotions toward a career in science. The traditional undergraduate student age group scored an average of 3.02 on the SAI II career measures while the non-traditional student age group scored an average of 3.53. This indicates that non-traditional older undergraduate students had a more positive attitude toward a career in science than their younger peers. Further, the results indicate that the dichotomous age group variable was an effective indicator of emotional perspective of science.

*Ethnicity*

Torres and Baxter Magolda (2004) present evidence supporting the influence of culture on the development and interpretation of knowledge. Therefore, I determined that ethnicity was an important measure to examine in relationship to the understanding of the
study domains. I began the examination of ethnicity as a predictor of misconceptions by dichotomizing the variable. I dichotomized the ethnic categories by placing Caucasians participants into one category and all other ethnicities into a second category. The criterion for this dichotomization was determined on the basis of the anticipated cultural similarities within Caucasians and the presumed cultural difference between the Caucasians and the other three ethnic groups (Asian, Latino, and African American). The dichotomization process placed 47 participants into a Caucasian group and the other 17 participants into the other ethnic group. The dichotomization increased the numbers for each of the ethnicity variable groups, which in effect increased statistical power.

An examination of the correlations presented in Table 14 revealed no significant relationships between the ethnic group variable and the understanding or acceptance of biological evolution, understanding and emotions toward the nature of science or conceptions of situations of uncertainty. Additionally, there were no correlations found in Table 14 that could justify more in-depth statistical analysis. The results of this analysis indicate that the dichotomized ethnic group variable is not an effective indicator of levels of understanding or held misconceptions of the three study domains.

**Intended Grade Level of Service**

Educational background has been revealed to be important considerations when examining certain misconceptions (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Evans, 2001; Verhey, 2005). This provides motivation to examine intended grade levels of service as an indicator of misconceptions due to the anticipated differences in K-12 preservice teacher preparation curriculum. I began this examination by dichotomizing the intended grade level of service variable by appropriately placing the preservice
teacher participants into an elementary school group or a secondary school group. Applying this criterion, I combined 39 participants intending to teach at the K-2 or 3-5 levels into an elementary group and combined the remaining 37 participants intending to teach grades 6-8 or 9-12 into a secondary group. The formation of these groups is further supported by the differential course requirements for teacher licensure at the elementary and secondary levels.

I examined the correlations displayed in Table 14 and determined that intended grade level of was significantly related to the SRA misconceptions of situations of uncertainty scores ($r = .31$, $p < .05$). Given the relationship between correct and misconceptions scores on the SRA, I conducted a ANOVA including both SRA scores as dependent variables and the intended grade level of service groups as the between subject factor. The outcome of the analysis revealed a significant relationship for SRA misconceptions scores, $F(1,67)=7.01$, $p < .05$, indicating that the grade level of service groups differed in their misconception of situations of uncertainty score. The average score of 8.18 for the elementary group and an average score of 6.91 for the secondary group indicates the secondary group held significantly lower levels of misconceptions. This reveals that the dichotomized intended grade level of service is an indicator of held misconceptions of situations of uncertainty.

The results of the analysis of the SRA correct scores were not found to be significant, $F(1,67)=3.88$, $p = .053$, indicating that the groups did not differ on their correct conceptions of situations of uncertainty. However, the measure is marginally non-significant ($p = .053$) and for this measure, the elementary group mean was 7.04 and secondary mean was 8.27. The marginal outcome suggests that a larger sample size is
likely to reveal the expected significant difference in correct SRA scores that should logically accompany the significant difference in SRA misconceptions scores. However, the results do indicate that intended grade level of service was an indicator of misconceptions of situations of uncertainty.

As more females than males consider careers at the elementary level, there is a possibility that the influence of gender on grade level of service could result in a spurious relationship with SRA misconception scores. The intended grade level of service is significantly correlated with gender ($r = .353, p<.01$). As established previously there is a significant effect for both gender and intended grade level of service with SRA misconceptions. The means plot for gender for both elementary and secondary levels of service (see Figure 8) suggests that relationship is consistent for both levels, and supports my prediction that intended grade level of service and gender are independent predictors of situations of uncertainty understanding.

The results of the examination of intended grade level of service revealed a significant relationship with held misconceptions of uncertainty. This reveals intended grade level of service as an indicator of understanding and misconceptions of situation of uncertainty. Further, my dichotomous elementary and secondary group formations were determined to be effective at discriminating levels of conceptions of situations of uncertainty.
Figure 8: The means plots for elementary and secondary SRA misconception scores by gender.

Years of Education

The years of education was determined to be highly correlated with age \( r = .41, p < .01 \). Therefore, I decided that it would be redundant to use the measure for the years of education as an indicator of understanding and acceptance of the three domains, therefore, an additional analysis using this variable was not conducted.

Number of Mathematics Courses

Schoenfeld, (1987) contents that problem solving and mathematics experience are influential factors influencing mathematics ability and learning. This led to the
examination of the number of mathematics course as a indicator of understanding of situations of uncertainty and the related science concepts. I began this examination by establishing the criterion for dichotomizing the number of college level mathematics courses based on the mathematics course requirements for generalized and specialized teacher licensure. A general certification for teaching requires students to take two college level mathematics courses. Therefore, if students take more than two college level mathematics courses, they are most likely pursuing an area of certification with specialized requirements. Using this information, I dichotomized the variable using the number of college level mathematics courses at the criterion, placing those with two or less into one group (n = 42), and those with three or more mathematics courses into a second group (n = 26). This dichotomization allowed me to compare students who are meeting the general requirements for certification with those with a specialized certification goal. The dichotomization also allowed me to the increase the statistical power of the analysis as I conducted analysis to determine significant levels of understanding and acceptance as related to number of mathematics courses.

I examined the correlations presented in Table 14 and determined that the number of college level mathematics courses was not significantly correlated with any of the study domain measures. Further, there were no correlations that were marginally insignificant to provide justification for further analysis. This indicates that the dichotomized grouping for the number of college level mathematics courses is not a useful indicator of acceptance, understanding, or levels of misconceptions of the three study domains.
Number of Science Courses

Similar to the number of mathematics course, there is research to support for the examination of the number of science courses as an indicator of understanding and acceptance of science and science related mathematics concepts (Crawford, Zembal-Saul, Munford, & Friedrichsen, 2005; Evans, 2001; Verhey, 2005). Thus, the science number of science courses in relationship to the study domains was examined. I began this examination by dichotomizing the number of college level science courses variable. Similar to the criterion I established for the number of mathematics courses, I examined the science course requirements for teacher certification. General teacher certification requires students to take two college level science courses; therefore, if students take more than two college level science courses, they are most likely pursuing specialized certification that has different course requirements. Using this information, I dichotomized the science course variable into two groups, with one group represented by participants taking two or less science courses (n = 42) and those that have taken three or more science courses placed into a second group (n = 26). The dichotomize variable allowed me to compare students enrolling into science courses to meet the general requirements for certification with those taking additional course due to a specialized educational focus. The dichotomization also increased statistical power, thereby, increasing the probability of detecting the actual differences in understanding and acceptance in relationship to the number of college level science courses.

I examined the correlations presented in Table 14 and determined that the number of science courses was not significantly correlated with any of the measures of understanding and acceptance. However, the moderate correlation between the number of
science courses and emotions toward science \((r = .2, p = .1)\) was deemed worthy of further exploration due to possible relationships with the three SAI II emotions subgroups. I conducted an ANOVA using the three SAI II emotions subgroups as the dependent variables and the dichotomized number of science courses variable as the between subjects factor. The results of the analysis revealed a significant outcome for the SAI II career in science subgroup, \(F(1,67) = 5.18, p < .05\), indicating that the science course variable groups differed significantly on their scores on emotions toward a career in science. The two or less science course group had an average score of 2.94 indicated a less than undecided attitude toward a career in science, while three or more science courses group had an average score of 3.38, indicating a greater than undecided attitude toward a career in science.

The results revealed the number of science courses as an indicator of attitude toward a career in science. The results also support the ability for the dichotomized number of science courses variable to be an effective indicator of emotions toward the nature of science.

*Level of Religiosity*

Sinatra and Mason (in press) claim that individual experiences and personal traits impact the development and retention of misconceptions. This provided motivation to examine the level of religiosity in relationship to understanding and acceptance of the study domains. I began this examination by dichotomizing the level of religiosity variable. The level of religiosity question on the demographics instrument required participants to rate their level of religious commitment on a scale from one to 10. The ten point scale on this measure created a unique situation of analysis complexity. The
complexity involves the most effective way to interpret the religiosity scores and conduct corresponding appropriate analysis. Zumbo and Zimmerman (1993) argue that Likert like scales with more than five items can be considered continuous or discrete. I made the decision to treat the religiosity variable as a discrete measure and dichotomize it into two variables. This allowed me to maintain consistency in my examination of individual measures. I dichotomized the religiosity variable by placing those participants that responded to the item with a five or less into a low to moderate religious commitment group \((n = 33)\), and those who responded with a six or more into a moderate to high religious commitment group \((n = 35)\). Therefore, I created a situation in which I was able to compare the understanding and acceptance of the three domain measures with participants having a low to moderate level of religious commitment group and a moderate to high level of religious commitment group. The dichotomized variable also increased statistical power allowing me to distinguish actual differences as I examined measure for level of religiosity in relation to understanding, acceptance, and levels of misconception of the three study domains.

I examined the correlations found in Table 14 and determined that the level of religiosity was significantly correlated with the MATE measures of acceptance of the theory of evolution \((r = -.52, p<.01)\). I conducted an ANOVA using the measure MATE scores as the dependent variable and the level of religiosity group as the between subject factor. The analysis reveals a significant relationship, \(F(1,67) = 24.09, p<.01\), indicating that low religious commitment group and high religious commitment group differed significantly in their MATE scores. The low religious commitment had an average MATE score of 78.24 and those with a high level of religious commitment scoring 63.1.
These results show that low religious commitment is an indicator of higher level of acceptance of evolution, and likewise that the measure of high religiosity is an indicator of low levels of evolution acceptance. This supports the use a dichotomized variable to distinguish low to moderate religious commitment and moderate to high levels of religious commitment as a useful indicator of evolution acceptance.

Analysis Summary

An analysis of the pre-test measures of understanding and acceptance of the three study domains indicates that the participants held misconceptions of biological evolution, the nature of science, and situations of uncertainty. Because of the lack of discrete criteria for the determination of misconceptions, these were determined using a somewhat subject and relative examination of means.

Analysis of the post-test data revealed an effect of the instructional interventions on the experimental group with significant increases in understanding of biological evolution and situations of uncertainty. The intervention analysis also indicated that acceptance of evolution increased for both the experimental and control group over time.

A content analysis of the lesson ideas exposed some instances of application of the instructional intervention, but also the existence of misconceptions. Only one control group participant directly addressed the stochastic process of evolution in the lesson idea. The overall content of the lesson ideas did not noticeably differ between the experimental and control groups.

The final analysis of the relationship of individual differences and measures of the three study domain exposed several significant relationships. Analysis also revealed
measures of individual differences that were not associated with differences in understanding. The ramifications of these results will be discussed next in the context of the original research questions.
CHAPTER 5

DISCUSSION

Introduction

In this chapter I summarize the findings of this research in the context of the posed research questions. I continue this discussion with an exploration of the significance of the results with regards to the learning and teaching of evolution, the nature of science, and situations of uncertainty, raised in the literature and in the calls for further research. I conclude with a discussion of study implications and contributions, limitations of this research, and suggestions for future research.

Misconceptions

The examination of the participant responses to the survey instruments measuring the understanding of biological evolution, nature of science and situations of uncertainty indicated a generally developed level of knowledge of these concepts. However, further analysis of the specific item responses revealed the presence of some misconceptions and lower levels of understanding.

Schnep and Sadler (1985) also found that those who appeared to understand the Earth’s seasons conveyed a very different line of reasoning when pressed for a more detailed explanation. A similar situation has been detected in this study. The outcome from the analysis of the complete instruments did not provide supporting evidence of
misconceptions. The lack of evidence for misconceptions from the composite scores could have led me to conclude that the participants did not hold misconceptions of the three study domains. Yet, when I conducted the in-depth analysis of the item responses, I exposed misconceptions, indicating that the participants' alternative conceptions existed implicitly. The seemingly contradictory result between the comprehensive and by item analysis of the participant responses to the study measures is indicative of the difficulty of identifying misconceptions. The hidden aspect of misconceptions provides motivation for putting forth additional efforts to investigate and analyze in greater depth individuals' understanding and perspectives of knowledge. The additional investigation may expose the fragments of naïve conceptions that individual may hold, but do not readily communicate.

The misconception evidence indicates that the preservice teacher participants in this project held the same misconceptions of evolution that Sadler (2005), Miller (1999), and Alters (2005) have determined to be impediments to the development of a deeper understanding of the theory.

Through the content analysis of the exposed misconceptions in the three study domains, a trend became apparent. The preservice teachers participating in this project held many of the predicted misconceptions in evolution, the nature of science and situations of uncertainty which are anticipated to interfere with learning. When combined, these misconceptions may further compound the difficulty of attaining comprehension and acceptance of the theory of evolution. Biological evolution is a multifaceted complex process making it difficult to explain and challenging to learn. It is anticipated that the participants are more readily accepting of abstract and complex
theories when presented with empirical evidence and concrete examples that are easy to comprehend. Because evolution requires knowledge of many areas of science and conceptualization of the vast amount of time involved in the process, it is can perceived as esoteric and contrived (McComas 2006; Miller, 1999). This may be attributed to their misconceptions of the nature of science and situations of chance.

As argued previously, many concepts and processes in science, mathematics and other domains involve aspects of uncertainty. The lack of comprehension of these concepts by the participants will likely impact their ability to accurately perceive, comprehend, or teach related concepts. Therefore, their misconceptions of situations of uncertainty may be a proxy for their misconceptions in other domains that require knowledge of this concept.

Futuyma (2002) argues that there are processes of biological evolution that occur by chance and if evolution was to be “run” again, the outcome would most certainly be different. Without an understanding of situations of uncertainty, it is likely the participants would not fully comprehend the evolutionary implications of the “running evolution again” scenario. Therefore, by holding misconceptions of situations of chance the participants are most likely to encounter conceptual obstacles interfering with their development of accurate understanding of the theory of biological evolution. As Sadler (2005) posits, the comprehension of stochastic processes influences the development of accurate understanding of biological evolution.

The results reveal a lack of acceptance for evolution and the lack of understanding of science as an idea-generating enterprise which indicates that participants conceptions of scientific knowledge is different than those held by professional scientists. It is likely that
the participants perceive scientific theories as similar to ideas, leading to their undecided positions about the support for evolution. The participants most likely view scientific theories as tentative which contributes to a perspective of science as lacking validity or reliability. This finding is consistent with those of McComas (2006), and Alters and Nelson (2002) who report similar findings as explanations for the limited understanding of evolution. This could explain why the participants were unsure about evidence supporting evolutionary theory.

The study results provide support for additional evolution curriculum for preservice teachers prior to entering service. The preservice teachers in the project were nearing the time in their program when they would begin their practicum and field experience. Therefore, they were unlikely to enroll in further additional mathematics and science coursework prior to entering service. Science and mathematics methods courses could include this content and address these misconceptions prior to service. Additionally, as Sadler (2005) reports many students enter and exit content specific science courses holding the same misconceptions. Therefore, the participants are unlikely to encounter curriculum that addresses their misconceptions of evolution, leaving many of them insufficiently prepared to teach this concept. This indicates there is a need to explicitly address the misconceptions of evolution held by students in a manner that promotes conceptual change. The ramification for addressing this situation in teacher education curriculum is the potential for widespread teaching of correct conceptions of science, thereby, reducing the occurrence of taught misconceptions.

Some of the detected misconceptions could be resolved through the integration of conceptual change pedagogy into the teacher education curriculum that specifically
targets their commonly held alternative perspectives. The influence of misconceptions on the ability to accurately teach evolution, situations of uncertainty, and the nature of science, increases the importance of assuring accurate understanding. Therefore, there is a need for almost all K-12 teachers to have accurate understanding of these concepts to assure they are teaching the scientifically accurate conceptions and not transferring misconceptions to their students.

This research confirmed the latent and compound aspects of misconceptions held by preservice teachers. The compound nature of these misconceptions reflects the need for learning these concepts in context and developing understanding to assure the formation and expression of correct conceptions in seemingly unrelated domains. As found in this study; misconceptions of situations of uncertainty, and understanding of the nature of science, appear to be coincide with the misconceptions of biological evolution.

Changes in Understanding

One of the objectives of this research was to promote conceptual shifts in participant understanding of evolution. This was used to guide the selection and development of the appropriate instructional interventions. I selected the evolution and nature of science tutorials from the Understanding Evolution website (University of California Museum of Paleontology, 2006, October) for my instructional intervention because they were specially designed to promote conceptual change in teachers and students.

The initial analysis of changes in understanding of evolution did not reveal any significant results. The additional analysis conducted using the participant understanding of situations of uncertainty and the nature of science as covariates revealed different
results. This analysis revealed a significant interaction, indicating a differential response to instruction by the control and experimental groups which could be discerned when variance due to prior knowledge was taken into account.

The interpretation of this outcome indicates that there was a significant differential response in understanding of biological evolution between the experimental and control groups. This provides support for further consideration for the hypothesized relationship between situations of uncertainty and understanding of evolution. Thus, there is reason to suggest that the grouping of seemingly unrelated instructional content of situations of uncertainty with evolution instruction coupled with a conceptual change instructional approach created a differential response to in understanding of biological evolution.

My results also revealed a consistent change in acceptance of evolution for both the experimental and control groups. This result was unexpected because acceptance of evolution has been determined to be fairly constant and robust to instruction (Miller, 1999). However, both groups responded to the intervention with significant increases in levels of acceptance indicating that the instructional intervention impacted their acceptance of evolution. The increase in acceptance may be explained by the instructional intervention that approached misconceptions of evolution using an engaging combination of text and graphics. The result is particularly interesting because changes in acceptance of evolution were not accompanied by correspondingly similar change in its understanding. This indicates that there is independence of acceptance and understanding of evolution. This situation signifies the need for further investigation to determine the cause of the change in acceptance and to determine why understanding did not result in a correspondingly similar change.

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The situation of uncertainty instruction delivered in the context of biological evolution was shown to increase understanding of chance in the experimental group. Given the relationship between evolution and situations of uncertainty, there is reason to speculate that the increase in understanding of chance may have impacted understanding of biological evolution. This provides motivation for further investigation of my hypothesis positing that increased understanding of situations of uncertainty in the context of biological evolution provides conceptual benefits when learning about evolution.

Comprehending the role chance plays in the process of biological evolution addresses two major misconceptions of the process; the deterministic view of evolution, and the purposeful motivation driving organism mutations. By presenting the situations of uncertainty in the context of evolution, I was able to directly address the application of the availability and representative heuristics as applied to the conceptions of evolution. My results provide encouraging evidence for the advantage of combining instruction of contextual content. Further, I have exposed indications of the benefit of including instruction on situations of chance when promoting conceptual change in the understanding of biological evolution.

In contrast, my results did not reveal any indication that the inclusion of the nature of science instruction increases understanding of evolution. As a covariate, the nature of science appears to account for unexplained variance associated with the understanding of evolution, which indicates a relationship between these two constructs. Yet, the lack of a main effect for increased understanding of the nature of science suggests that neither group gained knowledge of this concept from the instruction. Although both groups
received the same nature of science tutorial, it did not appear to impact understanding of evolution. This result is inconsistent with the predictions made by Alters (2005) and McComas (2006) who promote the relationship of understanding the nature of science as necessary for increased understanding of evolution. This situation may be reflective of the levels of complexity of both the nature of science and biological evolution. It also suggests that the nature of science instruction may need to be combined with uncertainty, or more likely, the instructional intervention was too modest to influence understanding of this concept. I speculate that conceptual change of misconceptions associated with the highly complex topics of evolution and the nature of science requires more intense interventions than the modest intervention that I provided.

My results provide reason to conjecture that the correct combination of content can have a differential impact on the knowledge of evolution and lead to a conceptual shift in understanding and acceptance of evolution. There is a need for further investigation exploring the complexity of the relationship between these conceptual domains. Uncovering the conceptual connections between domains may require in-depth examinations of the specific misconceptions and the perceptions of the relationships between concepts. The challenge extends to the determination of the design and delivery of instruction that effectively promotes conceptual change to modify evolution and related misconceptions. There is insufficient research the to support the compound nature of evolution misconceptions, suggesting a need to further explore the common misconceptions and determine if there are additional situations of related concepts that need to be addressed simultaneously to promote conceptual change. This approach may be effectively applied to the exploration of other misconceptions, and used to reveal other
conceptual combinations of content that are essential to address simultaneously to assure the promotion of conceptual change.

Impacting Teacher Knowledge

The goal of my research project was to increase the participating preservice teachers’ content knowledge, an essential process for designing lesson plans as well as the development of pedagogical content knowledge. The development of pedagogical content knowledge is a career long process (Shulman, 1987). I hypothesized that participant interaction with the instructional interventions would increase their content knowledge of the association and integration of the three conceptual domains. The content analysis of the lesson ideas exposed evidence of varying degrees of influence by the instructional interventions on participants’ development of content knowledge.

I anticipated that the lesson ideas would reflect a higher degree of integration of instructional content. Additionally, I anticipated that several of the participants in the experimental group would develop evolution lesson ideas integrating situations of uncertainty. Interestingly, only one lesson idea was found that integrated chance and evolution and it was generated by a control group participant who did not receive the situations of uncertainty instruction. Although both groups did receive a one page of tutorial on the role that chance plays in the evolutionary process, this participant retained and applied that information in a lesson idea in a manner that I had expected to see from the experimental group. The particular lesson idea that integrated chance contained content that reflected understanding of many mathematical concepts. The cognitive and prior knowledge demands required for association of the concepts between chance and
evolution may limit the comprehension of this relationship. Therefore, one might speculate that limited mathematical knowledge impedes the development of the ability to apply and communicate the conceptual integration of situations of uncertainty with evolution. This is certainly an area that is in need of further research.

The lack of the experimental group participants' integration of situations of uncertainty into the lesson ideas suggests that the tutorial was either too brief or not engaging enough to have the intended instructional impact. Further, the lack of integration of chance into the lessons suggests that participants did not find the information salient. This might be remedied using direct instruction to help establish the conceptual development of the relationship between chance and evolution. Further, the understanding and application of situations of uncertainty should be explicitly taught in context, because the transfer of chance to evolution may be more difficult to achieve than I had anticipated. Direct instruction which addresses misconceptions while providing examples and models of the wide range of application of chance to other concepts, such as evolution, may be essential to achieve the desired educational impact. Research exploring the impact of the instructional process would provide verification of this suggestion.

The content analysis also exposed the integration of fossils, timelines, field trips, books, and museums, into the lesson ideas. The integration of these approaches and resources indicates that the participants are seeking additional relevant ideas and experiences to communicate their knowledge of evolution. Many of the concepts applied in the lesson ideas were not discussed in the tutorials, indicating that the participants combined prior experience with the instructional intervention content.
The many occurrences of evidence for the integration of the nature of science and biological evolution concepts suggest that it may be easier to understand the relationship between these concepts than with uncertainty and evolution. Unlike the situations of uncertainty, the content analysis revealed many instances of the integration of nature of science concepts. I suspect that this is due to the relatively close link between the nature of science and evolution concepts in the instructional interventions, and the fact that evolution has been taught in science classes. Perhaps a connection had already been established. Yet, even as the integration of nature of science concepts in the lesson ideas indicated assimilation of the instructional content, misconceptions of both domains lingered. This is further evidence for the robust nature of misconceptions, and the importance of providing situations where these can be uncovered and addressed prior to service.

The results revealing a lack of acceptance for evolution and the lack of understanding of science as an idea generating enterprise which indicates that participants' conceptions of scientific knowledge is different than those held by professional scientists. It is likely that the participants perceive scientific theories as similar to ideas, leading to their undecided positions about the support for evolution. The participants most likely view scientific theories as tentative which contributes to a perspective of science as lacking validity or reliability. This finding is consistent with that of McComas (2006), and Alters and Nelson (2002) who report similar findings as explanations for the limited understanding of evolution. This could explain why the participants were unsure about evidence supporting evolutionary theory.
Interestingly, the content analysis of the lesson ideas also revealed evidence for the influence of the research instruments. Although there is some level of expected influence of instruments in research, the level detected in my project exceeded my expectations and had unintended impact. The results suggest that the scenarios used in the instruments were engaging, attainable, and acceptable, and impacted participant conceptions of evolution. The negative outcome of the instrument influence is its undesirable impact on my research process. The results indicate that the instruments I used in this research may have confounded my study, suggesting that alternatives should be considered in future research. The positive outcome of instruments’ influence is awareness of the situation and the development of the opportunity to examine their contents to potentially create additional effective approaches to promoting conceptual shifts.

My results suggest that as preservice teachers develop their content knowledge, they may need to experience and learn from situations that can be directly applied and easily transferred (Darling-Hammond & Bransford, 2005). The lack of integration of situations of uncertainty into the lesson ideas suggests that even though learning may have taken place, as seen in the increased uncertainty understanding, the application of uncertainty content may not have been initiated due to the lack of instruction explicitly promoting the integration of concepts. One possible solution to this situation may be to expose preservice teachers to an integrated curriculum modeling the application of content. It is encouraging to find evidence for a limited increase in preservice teachers’ content knowledge using brief instructional interventions. Yet, additional instructional approaches may prove to be more effective at increasing the transfer of content between domains. A combination of explicit instructional techniques and content may prove to be
the most effective way to foster the development of teacher declarative and curriculum knowledge.

Individual Characteristics

The results of the analysis examining personal characteristics and individual attributes as predictors of misconceptions confirmed my hypothesis. The results revealed gender, age, intended grade level of service, the number of science courses and religiosity as significant indicators of understanding. The number of mathematics course, and ethnicity were not found to be significant indicators of misconceptions.

The results of the analysis revealed that only part of my list of identified measures of individual differences are indicators of misconceptions. I examined the results of the indicator variables for detectable trends in the relationships. I sought to determine explanations for the relationship between personal differences indicators and the corresponding variation in conceptions, and based on similar combinations of indicators place the participants accordingly. However, the results were not consistent enough for the formation of discernable groups, suggesting that the indicators are representative of a latent variable or the trend I am seeking lies outside of the data.

An examination of the college course work associated with intended level of service may be fruitful for explaining the significance or insignificance of indicators. Certainty college level course work leading toward certification is related to the number of science and mathematics courses taken, which would account for the role of the number of science courses as an indicator of understanding of evolution and the nature of science. However, this would not account for the insignificance of the number of math courses as
an indicator. Certification coursework may explain gender differences. Since more females pursue positions at the elementary level, they may be less likely to pursue an education that would prepare them with the mathematical and scientific background and experience that would lead to their exposure and subsequent in-depth learning of situations of uncertainty. Yet, the expected relationship between situations of uncertainty and the number of mathematics courses was not detected.

Age as an indicator would not necessarily be reflective of certification coursework but perhaps representative of life experience. Further, level of religiosity and other personal interests outside of professional teacher certification requirements will also impact individual differences as indicators and provides additional explanation of the variations in conceptions within the study domains. This suggests that the trend I am seeking to detect may be a complex combination of college degree coursework, life experience, and personal interest, making the trend difficult to readily identify and apply.

The lack of a discernable trend in the individual difference indicators of conceptions suggests a need for further examination of these variables. Although significant indicators were detected, how they might be applied and used for teaching evolution, the nature of science and situations of uncertainty is in need of further investigation. I would suspect that groups of indicators may be useful for detecting specific misconceptions and for guiding the corresponding instruction. It is possible that my sample size limited the ability to detect significance in the personal differences indicators of misconceptions that could lead to the appearance of discernable trends. However, the results of my study are not consistent enough to be used for making general curricular modification to promote conceptual change.
Study Limitations

There are several limitations to this study. First, sample size for this study was relatively small, with only 68 cases available for final data analysis. Further, the sample was divided between the experimental and control groups leaving each group with 34 participants, which reduced power of the between group comparisons. A larger sample size may reveal additional pertinent relationships and significant measures. For example, the relatively small sample size prohibited the inclusion of confirmatory factor analysis as an option for data analysis. There were several non-significant results that may prove to be significant with the increased power that results from larger sample sizes. Thus, a larger sample size would increase validity, reliability and statistical power.

Another limitation for this study is the format of the instructional interventions. The interventions were delivered individually through a campus based web server in a lab environment to approximately 25 participants at time, with each participant controlling the pace of the instruction. Although instructions were provided and participation was monitored and time on task was consistent, there were aspects of individual interaction with the content that could not be controlled. Individual attention to the content and depth of comprehension of content could not be controlled for during the instructional interventions. The Understanding Evolution SVT Assessment (UEA) was used to determine if the experimental and control groups differed significantly in their comprehension levels, and the analysis revealed that there was not a significant difference. The time on task analysis also revealed no significance difference. However, there may be a greater impact and greater levels of comprehension if the instructional
content is delivered using different methods, such as face-to-face direct instruction that allows for participant interaction and discussion.

A related limitation is the nature of the instruments used in the study. With the exception of the lesson idea, all data collection occurred with self-reporting, forced response instruments. In addition, the instruments appeared in the lesson ideas indicating a potential confound. The instruments that I used do not allow for the exposure of the thoughts and ideas of the participants related to the content. The lesson idea did allow for the freedom of individual expression, but did not provide for further interaction clarifying participant perspectives. Therefore, participant perspective was not illuminated in a manner that interview, observations or other qualitative methods might provide. Further, the instruments did not address the concepts in an integrated manner and in context. Therefore, the instruments did not directly measure participant ability to integrate the content from the study domains and apply it accordingly.

The final limitation to be discussed addresses concerns regarding the participants selected for involvement in my study. Although the participants in my study were all preservice teachers, they were also all undergraduate students and therefore, limited in their college experience. The limitation of college level experience may be an important consideration influencing the results. As discussed previously students with less education tend to view knowledge as absolute (Perry, 1970), and therefore, may be limited in their openness to change. The inclusion of graduate level preservice teachers in the research may result in different outcomes and provide a difference perspective that would increase generalizability to a wider range of preservice teachers.
Suggestions for Future Research

As teachers may transfer misconceptions to their students, it is important to identify the specific misconceptions preservice teachers hold and attend to them through conceptual change pedagogy. This provides two areas for future research. The first area involves the further identification and documentation of preservice teacher misconceptions of science and mathematics concepts associated with curriculum common to all levels of k-12 education. The second area of research involves the investigation of effective conceptual change pedagogy to assist preservice teachers in achieving conceptual change and preparing them to be effective professionals.

The impact of combinations of content on conceptual change and shifts is an area of research with much potential. This may have even more potential in areas that integrate content from seemingly unrelated domains. As misconceptions are exposed and documented and the corresponding curriculum is developed, the content of the curriculum needs to be critically examined to determine if seemingly unrelated content may impact conceptual change. Thus, there are tremendous opportunities for future research investigating the instructional impact that combinations and integration of content have on conceptual change.

As research continues to investigate effective development of preservice teacher pedagogical content knowledge, a potentially new area for exploration involves the impact that exposure to combined content has on the process. This offers research potential to many curriculums, with the integration of content impacting a wide range of subject matter and developmental levels. Further associated with this body of research is
the impact of rather brief instructional interventions on the development of content knowledge.

The impact that individual differences have on learning, understanding and misconceptions is another phenomenon that this research has exposed as an area for future investigations. The impact of individual traits and attributes on learning and conceptual change has been previously reported. However, the documentation of the relationships between personal traits and specific misconceptions is an area of limited research. Thus, this is an area of need and could be of benefit, for individual characteristics are predictors of misconceptions and therefore, may also be considered predictors of the needs for conceptual change pedagogy.

Further, there is a lack of adequate instruments for examining several areas of my research. Thus, there is a need for an instrument to measure levels of understanding of macro-evolution. There is a need for an instrument to measure the understanding of situations of uncertainty in the context of evolution, and there is a need for an instrument that measures understanding of the nature of science in the context of evolution. Instruments that allow for contextual measure of these areas are critical to our understanding of the complexity of the various facets of knowledge impacting evolutionary biology education.

My research has provided evidence suggestive of an association between comprehension of situations of uncertainty and understanding biological evolution. However, there is a need for a theoretical model that combines these and other constructs to explain the complex process of learning biological evolution. This model would inform additional research exploring the teaching and learning of evolutionary biology.
## APPENDIX I

### RESEARCH DESIGN AND SEQUENCE

**Control Group**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Pretest</th>
<th>Treatment</th>
<th>Post-test</th>
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<tbody>
<tr>
<td>Data Collection</td>
<td>• MATE</td>
<td>• Instructions stating context and instructional goals</td>
<td>• MATE</td>
</tr>
<tr>
<td></td>
<td>• CINS</td>
<td>• Nature of Science Instruction</td>
<td>• CINS</td>
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<td></td>
<td>• OMT</td>
<td>• Evolutionary Theory Instruction</td>
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<tr>
<td>Treatment</td>
<td>• Instructions stating context and instructional goals</td>
<td>• Nature of Science Instruction</td>
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<td>• Evolutionary Theory Instruction</td>
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<td>Qualitative data Collection</td>
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<td>• Lesson Idea</td>
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<tr>
<td>Process represented graphically</td>
<td>X</td>
<td>O (Without Situation of Uncertainty Instruction)</td>
<td>X</td>
</tr>
</tbody>
</table>
### Experimental Group

<table>
<thead>
<tr>
<th>Activity</th>
<th>Pretest</th>
<th>Treatment</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Collection</td>
<td>• MATE</td>
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<td>• CINS</td>
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<td>• Demo</td>
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<td>Treatment</td>
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<td>• Instructions stating context and instructional goals</td>
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<td>Qualitative data collection</td>
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<td>• Lesson Idea</td>
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<tr>
<td>Process represented graphically</td>
<td>X</td>
<td>O</td>
<td>X</td>
</tr>
</tbody>
</table>
APPENDIX II

PARTICIPANT INFORMATION

ID # (last 4 digits of your SSN):________
(To be used for identifying and organizing data)

Demographic Information

1. Age:  18-20____  21-25____  26-35____  36-45____  46+____
2. Gender: Female____  Male____
3. Ethnicity: African American____  Native American____  Asian____  Latino____  Caucasian____
4. Number of Years of College Education: ______
5. Number of Mathematics Courses ______
6. Number of Science Courses ______
7. Intended grade level you plan to teach K-2____  3-5____  6-8____  9-12____
8. Educational major: Business____  Computers____  English____  Fine Arts____
   World Language____  Health/PE/Careers____  Math____  Performing Arts____
   Science____  Social Studies____  Education____
   Other____________________

   World Language____  Health/PE/Careers____  Math____  Performing Arts____
   Science____  Social Studies____  Education____
   Other____________________
10. Rate your level of religious commitment from 1 (non-religious) to 10 (strongly religious).
    1 2 3 4 5 6 7 8 9 10
Galapagos finches

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to the islands one to five million years ago (Lack, 1940). Recent DNA analyses support the conclusion that all of the Galapagos finches evolved from the warbler finch (Grant, Grant & Petren, 2001; Petren, Grant & Grant, 2001). Different species live on different islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch occupies another island. One of the major changes in the finches is in their beak sizes and shapes, as shown in this figure.

Choose the one answer that best reflects how an evolutionary biologist would answer.

1. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived?
   Given enough time
   a. the finch population would stay small because birds only have enough babies to replace themselves.
   b. the finch population would double and then stay relatively stable.
   c. the finch population would increase dramatically.
   d. the finch population would grow slowly and then level off.
2. Finches on the Galapagos Islands require food to eat and water to drink.
   a. When food and water are scarce, some birds may be unable to obtain what they need to survive.
   b. When food and water are limited, the finches will find other food sources, so there is always enough.
   c. When food and water are scarce, the finches all eat and drink less so that all birds survive.
   d. There is always plenty of food and water on the Galapagos Islands to meet the finches' needs.

3. Once a population of finches has lived on a particular island for many years,
   a. the population continues to grow rapidly.
   b. the population remains relatively stable, with some fluctuations.
   c. the population dramatically increases and decreases each year.
   d. the population will decrease steadily.

4. In the finch population, what are the primary changes that occur gradually over time?
   a. The traits of each finch within a population gradually change.
   b. The proportions of finches having different traits within a population change.
   c. Successful behaviors learned by finches are passed on to offspring.
   d. Mutations occur to meet the needs of the finches as the environment changes.

5. Depending on their beak size and shape, some finches get nectar from flowers, some eat grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?
   a. Most of the finches on an island cooperate to find food and share what they find.
   b. Many of the finches on an island fight with one another and the physically strongest ones win.
   c. There is more than enough food to meet all the finches' needs so they don't need to compete for food.
   d. Finches compete primarily with closely related finches that eat the same kinds of food, and some may die from lack of food.

6. How did the different beak types first arise in the Galapagos finches?
   a. The changes in the finches' beak size and shape occurred because of their need to be able to eat different kinds of food to survive.
   b. Changes in the finches' beaks occurred by chance, and when there was a good match between beak structure and available food, those birds had more offspring.
   c. The changes in the finches' beaks occurred because the environment induced the desired genetic changes.
   d. The finches' beaks changed a little bit in size and shape with each successive generation, some getting larger and some getting smaller.

7. What type of variation in finches is passed to the offspring?
   a. Any behaviors that were learned during a finch's lifetime.
   b. Only characteristics that were beneficial during a finch's lifetime.
   c. All characteristics that are genetically determined.
   d. Any characteristics that were positively influenced by the environment during a finch's lifetime.
8. What caused populations of birds having different beak shapes and sizes to become distinct species distributed on the various islands?
   a. The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
   b. All finches are essentially alike and there are not really fourteen different species.
   c. Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.
   d. Different lines of finches developed different beak types because they needed them in order to obtain the available food.

Venezuelan Guppies

Guppies are small fish found in streams in Venezuela. Male guppies are brightly colored, with black, red, blue and iridescent (reflective) spots. Males cannot be too brightly colored or they will be seen and consumed by predators, but if they are too plain, females will choose other males. Natural selection and sexual selection push in opposite directions. When a guppy population lives in a stream in the absence of predators, the proportion of males that are bright and flashy increases in the population. If a few aggressive predators are added to the same stream, the proportion of bright-colored males decreases within about five months (3-4 generations). The effects of predators on guppy coloration have been studied in artificial ponds with mild, aggressive, and no predators, and by similar manipulations of natural stream environments (Endler, 1980).

Choose the one answer that best reflects how an evolutionary biologist would answer.

9. A typical natural population of guppies consists of hundreds of guppies. Which statement best describes the guppies of a single species in an isolated population?
   a. The guppies share all of the same characteristics and are identical to each other.
   b. The guppies share all of the essential characteristics of the species; the minor variations they display don’t affect survival.
   c. The guppies are all identical on the inside, but have many differences in appearance.
   d. The guppies share many essential characteristics, but also vary in many features.

10. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Which feature would a biologist consider to be most important in determining which guppies were the “most fit”?
   a. large body size and ability to swim quickly away from predators
   b. excellent ability to compete for food
   c. high number of offspring that survived to reproductive age
   d. high number of matings with many different females.
11. Assuming ideal conditions with abundant food and space and no predators, what would happen if a pair of guppies were placed in a large pond?
   a. The guppy population would grow slowly, as guppies would have only the number of babies that are needed to replenish the population.
   b. The guppy population would grow slowly at first, then would grow rapidly, and thousands of guppies would fill the pond.
   c. The guppy population would never become very large, because only organisms such as insects and bacteria reproduce in that manner.
   d. The guppy population would continue to grow slowly over time.

12. Once a population of guppies has been established for a number of years in a real (not ideal) pond with other organisms including predators, what will likely happen to the population?
   a. The guppy population will stay about the same size.
   b. The guppy population will continue to rapidly grow in size.
   c. The guppy population will gradually decrease until no more guppies are left.
   d. It is impossible to tell because populations do not follow patterns.

13. In guppy populations, what are the primary changes that occur gradually over time?
   a. The traits of each individual guppy within a population gradually change.
   b. The proportions of guppies having different traits within a population change.
   c. Successful behaviors learned by certain guppies are passed on to offspring.
   d. Mutations occur to meet the needs of the guppies as the environment changes.

Canary Island Lizards

The Canary Islands are seven islands just west of the African continent. The islands gradually became colonized with life: plants, lizards, birds, etc. Three different species of lizards found on the islands are similar to one species found on the African continent. Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks.
washed out to sea. The Canary Islands and the location of the three lizard species are shown in the map above.

Choose the one answer that best reflects how an evolutionary biologist would answer.

14. Lizards eat a variety of insects and plants. Which statement describes the availability of food for lizards on the Canary Islands?
   a. Finding food is not a problem since food is always in abundant supply.
   b. Since lizards can eat a variety of foods, there is likely to be enough food for all of the lizards at all times.
   c. Lizards can get by on very little food, so the food supply does not matter.
   d. It is likely that sometimes there is enough food, but at other times there is not enough food for all of the lizards.

15. What do you think happens among the lizards of Species 1 when the food supply is limited?
   a. The lizards cooperate to find food and share what they find.
   b. The lizards fight for the available food and the strongest lizards kill the weaker ones.
   c. Genetic changes that would allow lizards to eat new food sources are likely to be induced.
   d. The lizards least successful in the competition for food are likely to die of starvation and malnutrition.

16. Populations of lizards are made up of hundreds of individual lizards. Which statement describes how similar they are likely to be to each other?
   a. All lizards in the population are likely to be nearly identical.
   b. All lizards in the population are identical to each other on the outside, but there are differences in their internal organs such as how they digest food.
   c. All lizards in the populations share many similarities, but there are differences in features like body size and claw length.
   d. All lizards in the population are completely unique and share no features with other lizards.

17. Which statement could describe how traits in lizards pass from one generation of lizards to the next generation?
   a. Lizards that learn to catch a particular type of insect will pass the new ability to offspring.
   b. Lizards that are able to hear, but have no survival advantage because of hearing, will eventually stop passing on the "hearing" trait.
   c. Lizards with stronger claws that allow for catching certain insects have offspring whose claws gradually get even stronger during their lifetime.
   d. Lizards with a particular coloration and pattern are likely to pass the same trait on to offspring.
18. Fitness is a term often used by biologists to explain the evolutionary success of certain organisms. Below are descriptions of four fictional female lizards found on Hierro Island.

<table>
<thead>
<tr>
<th></th>
<th>Lizard A</th>
<th>Lizard B</th>
<th>Lizard C</th>
<th>Lizard D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body length</td>
<td>20 cm</td>
<td>12 cm</td>
<td>10 cm</td>
<td>15 cm</td>
</tr>
<tr>
<td>Offspring surviving to adulthood</td>
<td>19</td>
<td>28</td>
<td>22</td>
<td>26</td>
</tr>
<tr>
<td>Age at death</td>
<td>4 years</td>
<td>5 years</td>
<td>4 years</td>
<td>6 years</td>
</tr>
<tr>
<td>Comments</td>
<td>Lizard A is very healthy, strong, and clever</td>
<td>Lizard B has mated with many lizards</td>
<td>Lizard C is dark-colored and very quick.</td>
<td>Lizard D has the largest territory of all the lizards.</td>
</tr>
</tbody>
</table>

Which lizard might a biologist consider to be the “most fit”?
- a. Lizard A
- b. Lizard B
- c. Lizard C
- d. Lizard D

19. According to the theory of natural selection, where did the variations in body size in the three species of lizards most likely come from?
- a. The lizards needed to change in order to survive, so beneficial new traits developed.
- b. The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
- c. Random genetic changes and sexual recombination both created new variations.
- d. The island environment caused genetic changes in the lizards.

20. What could cause one species to change into three species over time?
- a. Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
- b. Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.
- c. There may be minor variations, but all lizards are essentially alike and all are members of a single species.
- d. In order to survive, different groups of lizards needed to adapt to the different islands, and so all organisms in each group gradually evolved to become a new lizard species.

APPENDIX IV

MEASURE OF THE ACCEPTANCE OF THE THEORY OF EVOLUTION (MATE)

For the following items, please indicate your agreement/disagreement with the given statements using the following scale:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Agree</td>
<td>Agree</td>
<td>Undecided</td>
<td>Disagree</td>
<td>Strongly Disagree</td>
</tr>
</tbody>
</table>

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

2. The theory of evolution is incapable of being scientifically tested.

3. Modern humans are the product of evolutionary processes which have occurred over millions of years.

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

5. Most scientists accept evolutionary theory to be a scientifically valid theory.

6. The available data are ambiguous (unclear) as to whether evolution actually occurs.

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

8. There is a significant body of data which supports evolutionary theory.

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

10. Evolution in not a scientifically valid theory.

11. The age of the earth is at least 4 billion years.

12. Current evolutionary theory is the result of sound scientific research and methodology.
13. Evolutionary theory generates testable predictions with respect to the characteristics of life.

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

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

16. Evolutionary theory is supported by factual, historical and laboratory data.

17. Much of the scientific community doubts if evolution occurs.

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

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

20. Evolution is a scientifically valid theory.

*MATE Scoring Instructions*

To account for positively and negatively phrased items, the scaling of responses must be appropriately reversed so that responses indicative of a high acceptance of evolutionary theory receive a score of 5 while answers indicative of a low acceptance receive a score of 1. To score the MATE, follow the three steps below:

**Step 1.** Scoring of items 1, 3, 5, 8, 11, 12, 13, 16, 18, and 20 is as follows:

- Strongly Agree = 5
- Agree = 4
- Undecided = 3
- Disagree = 2
- Strongly Disagree = 1

**Step 2.** Scoring of items 2, 4, 6, 7, 9, 10, 14, 15, 17, and 19 is as follows:

- Strongly Agree = 1
- Agree = 2
- Undecided = 3
- Disagree = 4
- Strongly Disagree = 5

**Step 3.** An individual’s score on the MATE is equal to the sum of the scaled responses of all 20 items.

Scoring: Items 1, 3, 5, 8, 11, 12, 13, 16, 18, and 20 contain positively phrased statements concerning evolutionary theory, while items 2, 4, 6, 7, 9, 10, 14, 15, 17, and 19 contain negatively phrased statements. Scoring for the items is performed by Likert-scaling of responses. Answers indicative of a low acceptance of evolutionary theory receive a score of 1 while answers indicative of a high acceptance of evolutionary theory receive a score of 5. Possible scores for the MATE range from a high of 100 to a low of 20, indicating high and low levels of acceptance, respectively.
APPENDIX V

STATISTICAL REASONING ASSESSMENT (SRA)

Purpose The purpose of this survey is to indicate how you use statistical information in everyday life.

Take your time The questions require you to read and think carefully about various situations.

The following pages consist of multiple-choice questions about probability and statistics. Read the question carefully before selecting an answer.
1. A small object was weighed on the same scale separately by nine students in a science class. The weights (in grams) recorded by each student are shown below.

6.2  6.0  6.0  15.3  6.1  6.3  6.2  6.15  6.2

The students want to determine as accurately as they can the actual weight of this object. Of the following methods, which would you recommend they use?

- Use the most common number, which is 6.2.
- Use the 6.15 since it is the most accurate weighing.
- Add up the 9 numbers and divide by 9.
- Throw out the 15.3, add up the other 8 numbers and divide by

2. The following message is printed on a bottle of prescription medication:

**WARNING:** For applications to skin areas there is a 15% chance of developing a rash. If a rash develops, consult your physician.

Which of the following is the best interpretation of this warning?

- Don’t use the medication on your skin — there’s a good chance of developing a rash.
- For application to the skin, apply only 15% of the recommended dose.
- If a rash develops, it will probably involve only 15% of the skin.
- About 15 of 100 people who use this medication develop a rash.
- There is hardly a chance of getting a rash using this medication.

3. The Springfield Meteorological Center wanted to determine the accuracy of their weather forecasts. They searched their records for those days when the forecaster had reported a 70% chance of rain. They compared these forecasts to records of whether or not it actually rained on those particular days.

The forecast of 70% chance of rain can be considered very accurate if it rained on:

- 95% - 100% of those days.
- 85% - 94% of those days.
- 75% - 84% of those days.
- 65% - 74% of those days.
- 55% - 64% of those days.
4. A teacher wants to change the seating arrangement in her class in the hope that it will increase the number of comments her students make. She first decides to see how many comments students make with the current seating arrangement. A record of the number of comments made by her 8 students during one class period is shown below.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Comments</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>22</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

She wants to summarize this data by computing the typical number of comments made that day. Of the following methods, which would you recommend she use?

a. Use the most common number, which is 2.
b. Add up the 8 numbers and divide by 8.
c. Throw out the 22, add up the other 7 numbers and divide by 7.
d. Throw out the 0, add up the other 7 numbers and divide by 7.

5. A new medication is being tested to determine its effectiveness in the treatment of eczema, an inflammatory condition of the skin. Thirty patients with eczema were selected to participate in the study. The patients were randomly divided into two groups. Twenty patients in an experimental group received the medication, while ten patients in a control group received no medication. The results after two months are shown below.

<table>
<thead>
<tr>
<th>Experimental group (Medication)</th>
<th>Control group (No Medication)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved</td>
<td>Improved</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>No Improvement</td>
<td>No Improvement</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>

Based on the data, I think the medication was:

1. somewhat effective
2. basically ineffective

If you chose option 1, select the one explanation below that best describes your reasoning.

a. 40% of the people (8/20) in the experimental group improved.
b. 8 people improved in the experimental group while only 2 improved in the control group.
c. In the experimental group, the number of people who improved is only 4 less than the number who didn’t improve (12-8).

If you chose option 2, select the one explanation below that best describes your reasoning.

a. In the control group, 2 people improved even without the medication.
b. In the experimental group, more people didn’t get better than did (12 vs 8).
c. The difference between the
while in the control group the difference is 6 (8-2).

---

d. 40% of the patients in the experimental group improved (8/20), while only 20% improved in the control group (2/10).

d. In the experimental group, only 40% of the patients improved (8/20).

6. Listed below are several possible reasons one might question the results of the experiment described above. Place a check by every reason you agree with.

   a. It's not legitimate to compare the two groups because there are different numbers of patients in each group.
   b. The sample of 30 is too small to permit drawing conclusions.
   c. The patients should not have been randomly put into groups, because the most severe cases may have just by chance ended up in one of the groups.
   d. I'm not given enough information about how doctors decided whether or not patients improved. Doctors may have been biased in their judgments.
   e. I don't agree with any of these statements.

7. A marketing research company was asked to determine how much money teenagers (ages 13 - 19) spend on recorded music (cassette tapes, CDs and records). The company randomly selected 80 malls located around the country. A field researcher stood in a central location in the mall and asked passers-by who appeared to be the appropriate age to fill out a questionnaire. A total of 2,050 questionnaires were completed by teenagers. On the basis of this survey, the research company reported that the average teenager in this country spends $155 each year on recorded music.

Listed below are several statements concerning this survey. Place a check by every statement that you agree with.

   a. The average is based on teenagers' estimates of what they spend and therefore could be quite different from what teenagers actually spend.
   b. They should have done the survey at more than 80 malls if they wanted an average based on teenagers throughout the country.
   c. The sample of 2,050 teenagers is too small to permit drawing conclusions about the entire country.
   d. They should have asked teenagers coming out of music stores.
   e. The average could be a poor estimate of the spending of all teenagers given that teenagers were not randomly chosen to fill out the questionnaire.
   f. The average could be a poor estimate of the spending of all teenagers given that only teenagers in malls were sampled.
8. Two containers, labeled A and B, are filled with red and blue marbles in the following quantities:

<table>
<thead>
<tr>
<th>Container</th>
<th>Red</th>
<th>Blue</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>B</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

Each container is shaken vigorously. After choosing one of the containers, you will reach in and, without looking, draw out a marble. If the marble is blue, you win $50. Which container gives you the best chance of drawing a blue marble?

- a. Container A (with 6 red and 4 blue)
- b. Container B (with 60 red and 40 blue)
- c. Equal chances from each container

9. Which of the following sequences is most likely to result from flipping a fair coin 5 times?

- a. H H H T T
- b. T H H T H
- c. T H T T T
- d. H T H T H
- e. All four sequences are equally likely

10. Select one or more explanations for the answer you gave for the item above.

- a. Since the coin is fair, you ought to get roughly equal numbers of heads and tails.
- b. Since coin flipping is random, the coin ought to alternate frequently between landing heads and tails.
- c. Any of the sequences could occur.
- d. If you repeatedly flipped a coin five times, each of these sequences would occur about as often as any other sequence.
- e. If you get a couple of heads in a row, the probability of a tails on the next flip increases.
f. Every sequence of five flips has exactly the same probability of occurring.

11. Listed below are the same sequences of Hs and Ts that were listed in Item 8. Which of the sequences is least likely to result from flipping a fair coin 5 times?
   _____ a. H H H T T
   _____ b. T H H T H
   _____ c. T H T T T
   _____ d. H T H T H
   _____ e. All four sequences are equally unlikely

12. The Caldwells want to buy a new car, and they have narrowed their choices to a Buick or an Oldsmobile. They first consulted an issue of Consumer Reports, which compared rates of repairs for various cars. Records of repairs done on 400 cars of each type showed somewhat fewer mechanical problems with the Buick than with the Oldsmobile.

   The Caldwells then talked to three friends, two Oldsmobile owners, and one former Buick owner. Both Oldsmobile owners reported having a few mechanical problems, but nothing major. The Buick owner, however, exploded when asked how he liked his car:
   First, the fuel injection went out — $250 bucks. Next, I started having trouble with the rear end and had to replace it. I finally decided to sell it after the transmission went. I’d never buy another Buick.

   The Caldwells want to buy the car that is less likely to require major repair work. Given what they currently know, which car would you recommend that they buy?
   _____ a. I would recommend that they buy the Oldsmobile, primarily because of all the trouble their friend had with his Buick. Since they haven’t heard similar horror stories about the Oldsmobile, they should go with it.
   _____ b. I would recommend that they buy the Buick in spite of their friend’s bad experience. That is just one case, while the information reported in Consumer Reports is based on many cases. And according to that data, the Buick is somewhat less likely to require repairs.
   _____ c. I would tell them that it didn’t matter which car they bought. Even though one of the models might be more likely than the other to require repairs, they could still, just by chance, get stuck with a particular car that would need a lot of repairs. They may as well toss a coin to decide.

13. Five faces of a fair die are painted black, and one face is painted white. The die is rolled six times. Which of the following results is more likely?
14. Half of all newborns are girls and half are boys. Hospital A records an average of 50 births a day. Hospital B records an average of 10 births a day. On a particular day, which hospital is more likely to record 80% or more female births?

   ____ a. Hospital A (with 50 births a day)
   ____ b. Hospital B (with 10 births a day)
   ____ c. The two hospitals are equally likely to record such an event.

15. Forty college students participated in a study of the effect of sleep on test scores. Twenty of the students volunteered to stay up all night studying the night before the test (no-sleep group). The other 20 students (the control group) went to bed by 11:00 p.m. on the evening before the test. The test scores for each group are shown in the graphs below. Each dot on the graph represents a particular student’s score. For example, the two dots above the 80 in the bottom graph indicate that two students in the sleep group scored 80 on the test.

   Examine the two graphs carefully. Then choose from the 6 possible conclusions listed below the one you most agree with.

   ____ a. The no-sleep group did better because none of these students scored below 40 and the highest score was achieved by a student in this group.

   ____ b. The no-sleep group did better because its average appears to be a little higher than the average of the sleep group.
c. There is no difference between the two groups because there is considerable overlap in the scores of the two groups.

d. There is no difference between the two groups because the difference between their averages is small compared to the amount of variation in the scores.

e. The sleep group did better because more students in this group scored 80 or above.

f. The sleep group did better because its average appears to be a little higher than the average of the no-sleep group.

16'. For one month, 500 elementary students kept a daily record of the hours they spent watching television. The average number of hours per week spent watching television was 28. The researchers conducting the study also obtained report cards for each of the students. They found that the students who did well in school spent less time watching television than those students who did poorly.

Listed below are several possible statements concerning the results of this research. Place a check by every statement that you agree with.

a. The sample of 500 is too small to permit drawing conclusions.

b. If a student decreased the amount of time spent watching television, his or her performance in school would improve.

c. Even though students who did well watched less television, this doesn’t necessarily mean that watching television hurts school performance.

d. One month is not a long enough period of time to estimate how many hours the students really spend watching television.

e. The research demonstrates that watching television causes poorer performance in school.

f. I don’t agree with any of these statements.

17. The school committee of a small town wanted to determine the average number of children per household in their town. They divided the total number of children in the town by 50, the total number of households. Which of the following statements must be true if the average children per household is 2.2?

a. Half the households in the town have more than 2 children.

b. More households in the town have 3 children than have 2 children.

c. There are a total of 110 children in the town.

d. There are 2.2 children in the town for every adult.

e. The most common number of children in a household is 2.
18. When two dice are simultaneously thrown it is possible that one of the following two results occurs:

**Result 1:** A 5 and a 6 are obtained.
**Result 2:** A 5 is obtained twice.

Select the response that you agree with the most:

a. The chances of obtaining each of these results is equal
b. There is more chance of obtaining result 1.
c. There is more chance of obtaining result 2.
d. It is impossible to give an answer. (Please explain why)

19. When three dice are simultaneously thrown, which of the following results is MOST LIKELY to be obtained?

a. Result 1: "A 5, a 3 and a 6"
b. Result 2: "A 5 three times"
c. Result 3: A 5 twice and a 3"
d. All three results are equally likely

20. When three dice are simultaneously thrown, which of these three results is LEAST LIKELY to be obtained?

a. Result 1: "A 5, a 3 and a 6"
b. Result 2: "A 5 three times"
c. Result 3: A 5 twice and a 3"
d. All three results are equally unlikely

Correct Reasoning Skills and Misconceptions Measured by the SRA and the Corresponding Items and Alternatives for Measuring Each Conception and Misconception

<table>
<thead>
<tr>
<th>Correct Reasoning Skills</th>
<th>Corresponding Items and Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Correctly interprets probabilities</td>
<td>2d, 3d</td>
</tr>
<tr>
<td>2. Understands how to select an appropriate average</td>
<td>1d, 4ab, 17c</td>
</tr>
<tr>
<td>3. Correctly computes probability</td>
<td>8c</td>
</tr>
<tr>
<td>a. understands probabilities as ratios</td>
<td>13a, 18b, 19a, 20b</td>
</tr>
<tr>
<td>b. uses combinatorial reasoning</td>
<td>9e, 10df, 11e</td>
</tr>
<tr>
<td>4. Understands independence</td>
<td></td>
</tr>
<tr>
<td>5. Understands sampling variability</td>
<td>14b, 15d</td>
</tr>
<tr>
<td>6. Distinguishes between correlation and causation</td>
<td>16c</td>
</tr>
<tr>
<td>7. Correctly interprets two-way tables</td>
<td>51d*</td>
</tr>
</tbody>
</table>

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8. Understands importance of large samples 6b, 12b

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Corresponding Items and Alternatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Misconceptions involving averages</td>
<td>1a, 17c</td>
</tr>
<tr>
<td>a. Averages are the most common number</td>
<td>1c</td>
</tr>
<tr>
<td>b. Fails to take outliers into consideration when computing the mean</td>
<td>15bf</td>
</tr>
<tr>
<td>c. Compares groups based on their averages</td>
<td>17a</td>
</tr>
<tr>
<td>d. Confuses mean with median</td>
<td>2e, 3ab, 11abd, 12c, 13b</td>
</tr>
<tr>
<td>2. Outcome orientation misconception</td>
<td>7bc, 16ad</td>
</tr>
<tr>
<td>3. Good samples have to represent a high percentage of the population</td>
<td>12a, 14c</td>
</tr>
<tr>
<td>4. Law of small numbers</td>
<td>9abd, 10e, 11c</td>
</tr>
<tr>
<td>5. Representativeness misconception</td>
<td>16be</td>
</tr>
<tr>
<td>6. Correlation implies causation</td>
<td>13c, 18a, 19d, 20d</td>
</tr>
<tr>
<td>7. Equiprobability bias</td>
<td>6a</td>
</tr>
</tbody>
</table>

*Note: For item 5, students have to choose from two options before they can make further selection from four alternatives under each option.*
APPENDIX VI

THE SCIENTIFIC ATTITUDE INVENTORY: REVISED (SAI II)

These are the position statements and corresponding attitude statements of the SAI II.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>1 Strongly Agree</th>
<th>2 Agree</th>
<th>3 Undecided</th>
<th>4 Disagree</th>
<th>5 Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I would enjoy studying science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Anything we need to know can be found out through science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>It is useless to listen to a new idea unless everybody agrees with it.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Scientists are always interested in better explanations of things.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>If one scientist says an idea is true, all other scientists will believe it.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Only highly trained scientists can understand science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>We can always get answers to our questions by asking a scientist.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Most people are not able to understand science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Electronics are examples of the really valuable products of science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Scientists cannot always find the answers to their questions.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>When scientists have a good explanation, they do not try to make it better.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Most people can understand science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>The search for scientific knowledge would be boring.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Scientific work would be too hard for me.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Scientists discover laws which tell us exactly what is going on in nature.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Scientific ideas can be changed.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Scientific questions are answered by observing things.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Good scientists are willing to change their ideas.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Some questions cannot be answered by science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>A scientist must have a good imagination to create new ideas.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Ideas are the important result of science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>I do not want to be a scientist.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>People must understand science because it affects their lives.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>A major purpose of science is to produce new drugs and save lives.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<tr>
<td>25</td>
<td>Scientists must report exactly what they observe.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>26</td>
<td>If a scientist cannot answer a question, another scientist can.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>27</td>
<td>I would like to work with other scientists to solve scientific problems.</td>
<td>1 2 3 4 5</td>
<td></td>
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</tr>
<tr>
<td>28</td>
<td>Science tries to explain how things happen.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>29</td>
<td>Every citizen should understand science.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>30</td>
<td>I may not make great discoveries, but working in science would be fun.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>A major purpose of science is to help people live better.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>32</td>
<td>Scientists should not criticize each other's work.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>The senses are one of the most important tools a scientist has.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Scientists believe that nothing is known to be true for sure.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Scientific laws have been proven beyond all possible doubt.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>I would like to be a scientist.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Scientists do not have enough time for their families or for fun.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Scientific work is useful only to scientists.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>Scientists have to study too much.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Working in a science laboratory would be fun.</td>
<td>1 2 3 4 5</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
The position statements are labeled with a number and a letter; for example, 1-A. The letter designates whether the position statement is positive (A) or negative (B). The position statements are in pairs, where the pair 1-A and 1-B are intended to be opposite positions regarding the same point of view. The numbers in front of each attitude statement indicates its number in the SAI II.

1-A. The laws and/or theories of science are approximations of truth and are subject to change.
4. Scientists are always interested in better explanations of things.
16. Scientific ideas can be changed.
34. Scientists believe that nothing is known to be true for sure.
16. The laws and/or theories of science represent unchangeable truths discovered through science.
2. Scientists discover laws which tell us exactly what is going on in nature.
35. Scientific laws have been proven beyond all possible doubt.

2-A. Observation of natural phenomena and experimentation is the basis of scientific explanation. Science is limited in that it can only answer questions about natural phenomena and sometimes it is not able to do that.
10. Scientists cannot always find the answers to their questions.
19. Some questions cannot be answered by science.
33. Scientists believe that nothing is known to be true for sure.
2-B. The basis of scientific explanation is in authority. Science deals with all problems and can provide correct answers to all questions.
2. Anything we need to know can be found out through science.
15. When scientists have a good explanation, they do not try to make it better.
26. If a scientist cannot answer a question, another scientist can.
3-A. To operate in a scientific manner, one must display such traits as intellectual honesty, dependence upon objective observation of natural events, and willingness to alter one’s position on the basis of sufficient evidence.
10. Scientists cannot always find the answers to their questions.
25. It is useless to listen to a new idea unless everybody agrees with it.
32. Scientists should not criticize each other’s work.
4-A. Science is an idea-generating activity. It is devoted to providing explanations of natural phenomena. Its value lies in its theoretical aspects.
20. A scientist must have a good imagination to create new ideas.
21. Ideas are the important result of science.
28. Science tries to explain how things happen.
4-B. Science is a technology-developing activity. It is devoted to serving mankind. Its value lies in its practical uses.
9. Electronics are examples of the really valuable products of science.
24. A major purpose of science is to produce new drugs and save lives.
31. A major purpose of science is to help people live better.
5-A. Progress in science requires public support in this age of science; therefore, the public should be made aware of the nature of science and what it attempts to do. The public can understand science and it ultimately benefits from scientific work.
12. Most people can understand science.
23. People must understand science because it affects their lives.
29. Every citizen should understand science.
5-B. Public understanding of science would contribute nothing to the advancement of science or to human welfare; therefore, the public has no need to understand the nature of science. They cannot understand it and it does not affect them.
6. Only highly trained scientists can understand science.
8. Most people are not able to understand science.
38. Scientific work is useful only to scientists.
6-A. Being a scientist or working in a job requiring scientific knowledge and thinking would be a very interesting and rewarding life’s work. I would like to do scientific work.
1. I would enjoy studying science.
27. I would like to work with other scientists to solve scientific problems.
30. I may not make great discoveries, but working in science would be fun.
36. I would like to be a scientist.
40. Working in a science laboratory would be fun.
6-B. Being a scientist or working in a job requiring scientific knowledge and thinking would be dull and uninteresting; it is only for highly intelligent people who are willing to spend most of their time at work. I would not like to do scientific work.
13. The search for scientific knowledge would be boring.
14. Scientific work would be too hard for me.
22. I do not want to be a scientist.
37. Scientists do not have enough time for their families or for fun.
39. Scientists have to study too much.
APPENDIX VII

UNDERSTANDING EVOLUTION SVT ASSESSMENT

Directions: Respond to each phrase below as being either “OLD” or “NEW”. “OLD” phrases are the same or mean the same thing as lesson content from the web site lessons you have read for this study. “NEW” sentences have a different meaning than the content sentences.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>OLD</th>
<th>NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Scientific theories are explanations that are based on lines of evidence, enable valid predictions, and have been tested in many ways.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Evolution is flawed science and is disregarded accordingly by scientists and scholars worldwide.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Moral behavior can be linked to evolution.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Science and religion explain different ideas.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Evolution is the process by which modern organisms have descended from ancient ancestors.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>We can not observe the process of natural selection.</td>
<td></td>
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</tr>
<tr>
<td>7.</td>
<td>Pollen being blown by the wind and people moving to new cities are examples of gene flow.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>An organism's development rarely contains clues about its history and therefore biologists can't use this information to build evolutionary trees.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>A single mutation can have a small effect, but in some cases, evolutionary changes little with the accumulation of many mutations.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>Natural selection is not related to the process of adaptation.</td>
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<td></td>
</tr>
<tr>
<td>11.</td>
<td>It's more accurate to think of natural selection as a process rather than as a guiding hand</td>
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</tr>
<tr>
<td>12.</td>
<td>Modifications in genetic codes impact evolution in short periods of time.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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APPENDIX VIII

LESSON IDEA TEMPLATE

Instructions: Based on your experience and the knowledge you have gained navigating through the tutorials, create a lesson idea related to biological evolution. This lesson idea should target the students you intend to teach. Please complete each part of this template and hold your response to 1 page.

Title of Activity

Grade Level

Content/Subject Area

Lesson Goals:

Description of Lesson Activities:

Assessment Plan:
APPENDIX IX

INSTRUCTION PAGE

Understanding Evolution

SURVEYS

Directions: Complete each of the surveys as instructed. To assure that all of your data is grouped together, you will be asked to provide the SAME last four digits of a phone number for each of the surveys. So PLEASE choose a phone number that you will remember and use the SAME four digits throughout the research project.

Demographics (FIRST SESSION ONLY)

SRA

MATE

CINS

SAI II

LESSONS

Many people do not understand Biological Evolution and the Nature of Science. Teachers may hold misconceptions about these topics, influencing how they think about related concepts and impacting what they teach their students. The objective of this project is to address misconceptions you may have and help you understand more about these topics. Each of the following links will take you to a series of web pages that are intended to increase your knowledge about biological evolution.

Directions: Read through each of these lessons and in one week you will return to the lab, at which time your knowledge of these areas will be assessed again and you will be asked to draft a simple lesson idea that you might teach to your future students related to these topics.

Misconceptions of Evolution

Nature of Science and Evolution

Voyage of The Beagle
ONE MORE SURVEY

SVT (SECOND SESSION ONLY)
APPENDIX X

MISCONCEPTIONS

Misconceptions about Evolution and the Mechanisms of Evolution

Unfortunately, people have misconceptions about evolution. Some are simple misunderstandings; ideas that develop in the course of learning about evolution, possibly from school experiences and/or from the media. Other misconceptions may stem from purposeful attempts to interfere with the teaching of evolution.

As teachers, it is our role to treat all student questions with respect and initially to accept each question as the reflection of a legitimate desire to learn. However, some questions may well be designed to disrupt the learning process. We need to deal with intentionally disruptive questions in ways that are a bit different from legitimate inquiry. And it is important that we learn to distinguish between the two.
Understanding how science works allows one to easily distinguish science from non-science. Thus, to understand biological evolution, or any other science, it is essential to begin with the nature of science.

What is Science?

Science is a particular way of understanding the natural world. It extends the intrinsic curiosity with which we are born. It allows us to connect the past with the present, as with the redwoods depicted here.

Science is based on the premise that our senses, and extensions of those senses through the use of instruments, can give us accurate information about the Universe. Science follows very specific "rules" and its results are always subject to testing and, if necessary, revision. Even with such constraints science does not exclude, and often benefits from, creativity and imagination (with a good bit of logic thrown in).
APPENDIX XII
SITUATIONS OF UNCERTAINTY

Bridging Biological Evolution and Chance

Introduction

The process of evolution are random events. It is a common misconception that some how animals or plant "think" that some sort of trait or mutation would be beneficial and therefore it is selected for. This is not correct. Evolution is a random process with mutations and natural selection occurring in no particular direction but just happening. Over time mutation can give rise to new species, but there is no drive for species to move in one particular direction, it just happens. This is perhaps the greatest misconception of evolution, that somehow there is a deterministic push toward some sort of "super species." This is NOT how evolution functions. Evolution is the result of random events that take place over time that can result in different species. There is NO goal or product to reach.

The following is intended to teach you more about random processes. It is hypothesized that many people do not understand evolution because they do not understand random events, and situations of uncertainty. However, if you gain a greater understanding of random events (situations of uncertain outcome), you are more likely to understand the processes of evolution.

The Random Events of Evolution

Given the random nature of evolution it is perhaps helpful to examine the relationship of species variation and chance occurrence. This is displayed below with an animation to help you imagine the chance occurrence of species variation.

| Distribution of beak pigment – a randomly expressed trait with the majority falling in the center, and then some lighter and darker beaks occurring with less frequency on the sides. Therefore, most birds of this type have tan beaks, but some will be nearly white while others are brown, but these are not as common. | The outcome of a random distribution of possible outcomes. Notice the most likely outcome is in the center. Applying this model to biological traits means that the random variation of traits is most likely to show up in the middle of a distribution. Thus, light and dark beaks or short and long beaks still happen but not as often as tan and medium length beaks. | Beak size – varies based on the expression of a bone morphology protein that all bird have. But because of random variation some birds will randomly express more or less. This is similar to growth hormone in humans resulting in different heights. |

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APPENDIX XIII

Voyage of the Beagle

The Journey

_The Voyage of the Beagle_ is a title commonly given to the book written by Charles Darwin published in 1839 as his _Journal and Remarks_, which brought him considerable fame and respect. The title refers to the second survey expedition of the ship HMS _Beagle_, which set out on 27 December 1831 under the command of captain Robert FitzRoy.

The Expedition

While the expedition was originally planned to last two years, it lasted almost five—the _Beagle_ did not return until 2 October 1836. Darwin spent most of this time exploring on land (three years and three months on land; 18 months at sea).

The map of the voyage of the Beagle.

The book, also known as Darwin's _Journal of Researches_, is a vivid and exciting travel memoir as well as a detailed scientific field journal covering biology, geology, and anthropology that demonstrates Darwin's keen powers of observation, written at a time when Western Europeans were still discovering and exploring much of the rest of the world. Although Darwin revisited some areas during the expedition, for clarity the chapters of the book are ordered by reference to places and locations rather than chronologically. With hindsight, ideas which Darwin would later develop into the theory of evolution are hinted at in the book.

Next -->
NOTICE TO ALL RESEARCHERS:
Please be aware that a protocol violation (e.g., failure to submit a modification for any change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE: November 9, 2006
TO: Dr. Gale Sinatra
FROM: Office for the Protection of Research Subjects
RE: Notification of IRB Action by Dr. J. Michael Stitt, Chair
    Protocol Title: Preservice Teachers’ Understanding of Evolution, The Nature of Science, and Situations of Chance
Protocol #: 0610-2134

This memorandum is notification that the project referenced above has been reviewed by the UNLV Social/Behavioral Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45 CFR 46. The protocol has been reviewed and approved.

The protocol is approved for a period of one year from the date of IRB approval. The expiration date of this protocol is November 8, 2007. Work on the project may begin as soon as you receive written notification from the Office for the Protection of Research Subjects (OPRS).
PLEASE NOTE:
Attached to this approval notice is the official Informed Consent/Assent (IC/IA) Form for this study. The IC/IA contains an official approval stamp. Only copies of this official IC/IA form may be used when obtaining consent. Please keep the original for your records.

Should there be any change to the protocol, it will be necessary to submit a Modification Form through OPRS. No changes may be made to the existing protocol until modifications have been approved by the IRB.

Should the use of human subjects described in this protocol continue beyond 2007, it would be necessary to submit a Continuing Review Request Form 60 days before the expiration date.

If you have questions or require any assistance, please contact the Office for the Protection of Research Subjects at OPRSHumanSubjects@unlv.edu or call 895-2794.
BIBLIOGRAPHY


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