

Differences That Make A Difference:

A Study in Collaborative Learning

by

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A Dissertation Presented in Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

Approved April 2012 by the
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ARIZONA STATE UNIVERSITY

May 2012

ABSTRACT

Collaborative learning is a common teaching strategy in classrooms across age groups and content areas. It is important to measure and understand the cognitive process involved during collaboration to improve teaching methods involving interactive activities. This research attempted to answer the question: why do students learn more in collaborative settings? Using three measurement tools, 142 participants from seven different biology courses at a community college and at a university were tested before and after collaborating about the biological process of natural selection. Three factors were analyzed to measure their effect on learning at the individual level and the group level. The three factors were: difference in prior knowledge, sex and religious beliefs. Gender and religious beliefs both had a significant effect on post-test scores.

To my husband, Jeff Touchman
who has supported me and has acted as advisor, best friend, and love of my life
and to my children, Ivy and Joseph
who continuously give me great happiness and purpose

ACKNOWLEDGMENTS

I wish to thank my committee. All three of them have provided much needed guidance, direction, support, and challenges that have not only created this document, but have shaped me as a professional. Dr. Dale Baker has provided much needed support throughout my time at Arizona State University. Dr. Michael Rosenberg has supported and inspired me for both my Masters degree and now for my PhD degree. Dr. Tirupalavanam Ganesh has supported me through encouragement, great ideas and positive energy.

I would also like to thank all of the students and professors who worked on this project. Without their long hours I would never had been able to complete this dissertation. In particular I would like to thank Hojoon Lee who was always willing and available to brainstorm ideas and also for his generosity in programing scripts for this research; Cheryl Berg for cheering me on EVERY step of the way; Muhsin Menekse, Paula Guerra Lombardi, Krista Adams, Nievita Bueno Watts and Suzanne Cassano for their academic and emotional support throughout this journey. Finally, I want to thank my father and mother, Patrick and Miriam Rogers and my sister, Bonnie Boboia, they have always been a solid foundation for me and encouraged me to dream big!

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Chapter 1

INTRODUCTION

Collaborative learning is an effective learning strategy that is becoming a common part of the curriculum used in classrooms across subjects and age groups. Where students in other settings work at their desks to receive instruction in which most interaction occurs between teacher and student, the key feature of collaborative learning that distinguishes it from other learning settings is the interaction between the students (Roschelle, 1992; Webb, 1982). In the science education literature, when collaborative groups are compared to individuals in a lecture format, the participants in the collaborative groups often outperform their individual counterparts (Doymus, 2008; Diane Ebert-May, Brewer, & Allred, 1997; Fischer & Mandl, 2005; Jensen & Finley, 1996; Roschelle & Teasley, 1994; Stahl, 2000). This result has been presented in several reviews (Johnson, 1981; Sharan, 1980; Slavin, 1977). This is not surprising considering the cognitive benefits that individuals gain from learning interactively (Dolmans & Schmidt, 1996).

The benefits of learning collaboratively are not new. In 1932 John Dewey pioneered the idea of an interactive environment in the classroom when he proposed that education is a social process (Dewey, 1932). Dewey described inquiry as a “reflective transformation of perception, thought, and action” (Roschelle, 1992). Inquiry requires social interaction (Schun, 1979). An individual is able to make sense of information by transforming ideas into a more coherent knowledge structure (or mental model) through inquiry. Lev Vygotsky

was another major influence on social learning with his social constructivist theory. His theory stated that social interaction plays a fundamental role in the process of cognitive development and learning (Vygotsky, 1978). He argued that advanced concepts first appear during social interaction, and only gradually become available to an individual (Roschelle & Goldman, 1992). Furthermore, he described the Zone of Proximal Development (ZPD), which is the difference between what an individual can do without help and what the individual can do with help through interaction with others. In the ZPD an individual can participate slightly above his or her own individual capability (Roschelle & Goldman, 1992). These fundamental theories set a conceptual foundation for collaborative learning benefits.

Despite the numerous studies examining collaboration, there is no explanation as to *why* students are able to learn more effectively in a collaborative setting. The motivation of this dissertation is to answer the following question: What specific factors contribute to the successes gained from collaborative learning? In this research I analyzed students' learning about the biological process of Natural Selection in a collaborative setting. This research had two aims, first to design a sensitive tool to measure learning and second, to identify the factor(s) that contribute towards a positive learning outcome in a collaborative setting.

Aim 1: Measuring Learning

There are numerous science education studies involving the evolutionary topic of Natural Selection. In this dissertation, learning is defined by the difference in scores on assessments. From previous studies, there are three types of assessments that can be used to measure learning. The three types include a multiple-choice test, an essay test or a face-to-face interview between the researcher and the individual students (Anderson, Fisher, & Norman, 2002; Asterhan & Schwarz, 2007; Bishop & Anderson, 1990; Chan, Burtis, & Bereiter, 1997; Coleman, Brown, & Rivkin, 1997; Settlage, 1994). In 2008, Nehm did a qualitative comparison between three of the instruments commonly used in Natural Selection studies. He found that the most accurate measurement tool was an open-ended interview to assess students understanding of the concepts in natural selection (Nehm & Schonfeld, 2008). However, doing an open interview in a large-scale study is not practical.

For this study, I used three assessments to measure learning. Education researchers designed two of the assessments (an essay test and a multiple-choice test)(Coleman, Brown & Rivkin, 1997; Anderson, Fisher & Norman, 2002). I designed the third assessment, a Mental Model Task. The essay test was used to measure learning at the group level (Coleman, Brown & Rivken, 1997) where the multiple-choice test and the Mental Model Task were used to measure learning at the individual level (Anderson et al., 2002). The essay assessment was chosen because it was designed for a collaborative setting. Reliability was not reported and validity was measured using the Content Validity Ratio (CVR) approach

(Lawshe, 1975). This method utilized a group of subject-matter experts (SMEs) who were asked whether or not each item on the assessment was essential (Lawshe, 1975). Lawshe argued that if more than half the panelists indicate that an item is essential, that item has at least some content validity. Basically, greater levels of content validity exist as greater numbers of panelists agree that an item is essential, for this assessment the mean CVR = 1.0. The multiple-choice assessment (CINS) was chosen because it was the most common assessment used in education studies using the topic of evolution. For the CINS, the reported reliability score was $KR_{20} = .58$ for section A and $KR_{20} = .64$ for section B. Despite the authors claim that these reliability scores are moderate, they are low. Because of the lack of high-quality instruments, it was my goal, as a component of this research, to design a more reliable tool to measure learning in the domain-specific area of the evolutionary process of Natural Selection. Therefore, as a third assessment to measure learning, I used my own tool that evaluated the mental model of each student and measured changes at different time-points as the student progressed through the collaborative study.

Ultimately, the goal of this research was to identify which collaborative factors affected learning. Utilizing multiple measurement tools resulted in a clearer picture as to which factors influenced learning.

Aim 2: Identifying collaborative factors

When analyzing collaborative learning, there are observable factors that can contribute towards effective collaboration. These can be divided into three

different categories. First are the input factors which include prior knowledge (Hewson & Hewson, 1983; Schmidt, DeVolder, De Grave, Moust, & Patel, 1989), sex (Baker, 2002; Woolley, Chabris, Pentland, Hashmi, & Malone, 2010) and religious beliefs (Brem, Ranney, & Schindel, 2003; Lombrozo, Shtulman, & Weisberg, 2006). Second, the factors involved during the collaboration. These include activating prior knowledge, help seeking (Webb, Troper, & Fall, 1995), explanation (Chi, Bassok, Lewis, Reimann, & Glaser, 1989), and elaboration (Blankenstein, Dolmans, Vleuten, & Schmidt, 2009). Last are the output factors. These include retention of knowledge (Dolmans & Schmidt, 1996), transfer (Patel, Groen, & Norman, 1991; Schmidt et al., 1996; Tans, Schmidt, Schade-Hoogveen, & Gijsselaers, 1986) and the creation of new original knowledge (Peters & Armstrong, 1998). The research in this dissertation focused on the input factors and their effect on collaborative learning.

When people work together they construct something that did not exist before the collaboration. In other words, the result is something that does not and cannot fully exist in the individual collaborators and can only emerge from a collaborative situation (Peters & Armstrong, 1998). This study attempted at understanding this mechanism by analyzing three input factors and their effects on learning in a collaborative setting. The three factors to be assessed were: difference in prior knowledge, sex and religious beliefs.

Prior knowledge.

There are hints in published work to suggest that when individuals collaborate, the difference in prior knowledge brought to the collaboration contributes to the success of the collaboration. The hints are found in two areas of research: studies about controversy and studies about heterogeneous groups. Johnson and Johnson argued that controversy during collaborative learning leads to increased motivation, creative insight, cognitive development, and learning (Johnson & Johnson, 1979). By controlling the controversy in group collaboration, they promoted conflict, which created cognitive dissonance, which in turn encourages modification of knowledge structures (Johnson & Johnson, 1979). In addition, several researchers have studied heterogeneity of groups. Having a heterogeneous group can lead to controversy within a collaborative group. Heterogeneous groups were superior to homogenous groups in terms of quality of group solution, creativity of group solution and member satisfaction with the solution (Amara, Biran, & Leith, 1969; Jackson et al., 1991; Paul, Seetharaman, Samarah, & Mykytyn, 2004; Schultz-Hardt, Jochims, & Frey, 2002).

In an attempt to explain why collaborative learning is more beneficial than individual learning and more specifically, why heterogeneous groups outperform homogenous groups I captured the knowledge structure (i.e. mental model) of individuals prior to learning about the biological process of Natural Selection collaboratively using the Mental Model Task. Then, I grouped the participants into two different groups: dyads with similar mental models or dyads with

dissimilar mental models. Different combinations for prior-knowledge-similarity within a dyad might lead to different communication and learning processes. One goal of my research was to determine whether group composition in terms of similarity of prior knowledge is related to the collaborative learning process. Heterogeneous pairs should have more to talk about; therefore I theorized that dissimilar prior knowledge between collaborators would result in effective group performance and an increase in individual learning.

Sex.

Gender studies have found that sex composition of collaborative groups can impact the success of the group in regard to how the collaborators communicate with each other (Tucker, Powell, & Meyer, 1995). A study by Woolley found a significant correlation between the numbers of females in a group to the collective intelligence (*c*) of the group. They attributed their finding to social sensitivity, a trait where females scored higher compared to males (Woolley, Chabris, Pentland, Hashmi & Malone, 2010). In Woolley's study, the groups were asked to perform a series of tasks such as puzzle solving, brainstorming, and making collective moral judgments. Several studies examined the role of gender in groups performing various tasks (Lorenzi-Cioldi, Eagly, & Stewart, 1995; Mast, 2001; Woolley et al., 2010). However, sex composition of groups with regard to learning about Evolution Theory needs further examination.

In an attempt to establish the effect of group-composition based on sex in a collaborative learning setting, I grouped students into dyads that varied in

arrangement (male-male, female-female and male-female). I looked at both group performance and individual learning. In this experiment, I predicted that there would be a learning difference depending on the composition of the dyad based on sex. Furthermore, I theorized that dyads composed of females would outperform dyads composed of males.

Religious beliefs.

Research in science education has extensively examined teaching evolutionary theory and the robust misconceptions that students can acquire (Alters & Nelson, 2002; Geraedts & Boersma, 2006; Settlage, 1994). There is also a focus in the literature about pre-existing beliefs and their effects on learning controversial topics (Chambliss, 1994). The literature confirms that the majority of college students do not understand the evolutionary process of natural selection. However, the relationship between understanding evolutionary theory and accepting it as true needs to be examined (Brem, Ranney, & Schindel, 2003; Shtulman, 2006).

This research attempted to examine the relationship between pre-existing religious beliefs and understanding the evolutionary process of Natural Selection. In addition, I examined the impact of group composition. I attempted to answer the question: Will students that have similar religious beliefs or different religious beliefs perform better in a collaborative setting while learning about evolution? Students were categorized based on their pre-existing beliefs and placed into three groups (creationist, evolutionist or blend). Students who believe that human

beings have developed over millions of years from less advanced forms of life without the help of God's guidance were categorized as evolutionists. Students who believe that God created human beings pretty much in their present form were categorized as creationists and students who believe that human beings have developed over millions of years from less advanced forms of life, but God guided this process were categorized as blend. First, I examined if religious beliefs had an affect on individual learning. I predicted that there would be a difference in learning depending on religious beliefs. Specifically, I theorized that students who hold creationist beliefs would be hindered in their ability to understand evolutionary theory. Secondly, I examined if the composition of the dyad based on religious beliefs had an impact on learning at the group level.

Problem Statement

Collaborative learning is becoming a common teaching strategy in classrooms across age groups and content areas. It is important to measure and understand the cognitive process involved during collaboration to improve teaching methods involving interactive activities. This research attempted to answer the question: why do students learn more in collaborative settings? Therefore, the main goal of this dissertation was to build a theory to explain the mechanistic details involved in collaboration.

Research Questions

The purpose of this study was to investigate collaborative learning and to examine the role of prior knowledge, sex and religious beliefs on the effectiveness of learning and collaboration. Four research questions were analyzed:

1. Does the quality of collaboration have an effect on learning concepts about Natural Selection at the individual level and at the group level?
2. In a collaborative setting, does a difference in prior knowledge increase learning concepts about Natural Selection at the individual level and/or at the group level?
3. In a collaborative setting, does sex have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?
4. In a collaborative setting, do religious beliefs have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?

Chapter 2

LITERATURE

Mental Models

Cognitive science is largely based on the idea that the mind operates on an internal representation of knowledge, or mental model (Anderson, 2004). It is what distinguishes it from behaviorism. This idea dates back to 1943, when Craik suggested that the mind constructs “small-scale models” of the world that it uses to predict outcomes (Craik, 1943). Theories in cognitive science pertaining to mental models and their effect on learning have evolved through the years. In 1978, the concept of learning in a cognitive sense was deemed as “vague”, “abstract”, and “lacking a substantive data base” (Shuell, 1986). Earlier theories were based on operational structures that were compared to computer science, such as “the brain is a serial computer” metaphor or “the mind is a computer software system” (Hestenes, 2006). Around 1983, cognitive science changed into theories involving neural network systems and it was widely accepted that thinking involved pattern processing. This is what the majority of the theories are today (Hestenes, 2006). A mental model is used to process patterns about information. During the learning process, mental models are dynamic and are continuously changing and adjusting as individuals interact with the world around them. Cognitive researchers today accept a mental model to be “an internal scale-model representation of an external reality”(Davidson, Dove, & Wertz, 1999). Furthermore, acquiring knowledge and deep level learning can be explained by

the modification of a mental model (Anderson, 1983). It is under this assumption that this dissertation is based.

In the literature, knowledge structures are referred to in different ways, such as: categories (Rosch & Lloyd, 1978), cognitive maps (Axelrod, 1977; Ford & Hegarty, 1984; Neisser, 1976; Weick & Bougon, 1986), belief structures (Fiske & Taylor, 1991), mental models (Johnson-Laird, 1983; Rouse & Morris, 1986), schemas (Anderson & Pichert, 1978; Neisser, 1976; Rumelhart & Norman, 1981) and scripts (Abelson, 1976). Although, there are different terms to describe mental models, from a cognitive perspective, it is accepted that these structures are dynamic and that learning is a result of changes in these structures.

Structure

Mental models deal with how the human mind organizes and uses information about the world (Anderson, 2004). According to Rouse and Morris (1986), it is the role of a representation as a conceptual framework for describing, explaining, and predicting future events, (even if they are incorrect). In other words, mental models are structures that help an individual make sense of their surroundings (Johnson-Laird, 1989). But how are these conceptual frameworks organized? There are a few theories on the structure of mental representations. The most prevalent theory in the literature is the Mental Model Theory first developed by Jean Piaget (1962). He was one of the first researchers to define a mental model and its structure. He argued that there is evidence for two types of mental models, one for imagery called a perception-based knowledge

representations and one for reasoning called a meaning-based knowledge representations (Anderson, 2004; Johnson-Laird, 1989).

Perception-based knowledge deals with the way that visual and verbal information is represented and processed in the *absence* of an external perceptual stimulus. Processing mental perceptual knowledge is called imagery and can involve a very vivid experience. For example, when a person visualizes himself/herself defending a dissertation, they can “see” and “hear” all the details of an imagined experience. Furthermore, it has been long proven that there are separate representations for verbal and visual information that are processed in two different parts of the brain, this is referred to as the dual-code theory (Pavio, 1977). Baker and Santa found that memory is improved when visual and auditory information is used together (1977).

Apart from mentally ‘visualizing’ an idea, the second type of mental representation is the meaning-based representation, which deals with reasoning. Johnson-Laird clarified that manipulation of mental images corresponds to visual representations where the conceptual process of modifying a mental model correspond to reasoning (Johnson-Laird, 1989). A fundamental component of this theory is that one can make inferences about unstated relationships (Johnson-Laird, 1989). Reasoning is a critical part of human thinking. Johnson-Laird, Girotto and Legrenzi argued that individuals possess countless mental models available. They also argued that there are some rules of inferences that are applied when reasoning, depending on which mental model is being used (1998). Each mental model represents a different possibility (Byrne, 2000). This theory of

reasoning was based on deductive reasoning and has been studied and supported extensively by many researchers (Byrne, 2000).

A core assumption for this dissertation study is that knowledge is integrated into an organized coherent framework called a mental model and that learning occurs when the knowledge structure is modified.

Conceptual Learning within the Domain of Natural Selection

Mental models are a representation in the mind that consists of a set of concepts connected by causal links. These structures vary from highly sophisticated to naïve. They may be constructed from formal education but often spontaneously emerge during personal experiences (Schmidt et al., 1989). When learning a new domain-specific concept in the classroom, students come with a mental model of the conception. When students are presented with new information it will either confirm or contradict their mental model. Conceptual change occurs when a learner modifies their knowledge structure to match new information. Conceptual change is part of the learning process (Au et al., 2008; Garvin-Doxas & Klymkowsky, 2008; Roschelle, 1992; Strike & Posner, 1992; Stella Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001).

Conceptual Change

Conceptual change is commonly defined as the restructuring of an existing mental model. Different researchers have defined the mechanism by which conceptual change occurs. For example, Carey and Smith define it as a process of

establishing new conceptual boundaries or collapsing old conceptual boundaries (Carey, 2000; Smith, 2007), where Chi defines it as reassigning concepts into a different ontological category (Chi, 2005), and Vosniadou and Brewer define it as a revision of a framework (Vosniadou & Brewer, 1992). Many studies document conceptual change, usually this involves a transition from a naïve model to a normative model. These studies include topics such as the theory of energy as a substance-based theory to a process-based theory (Slotta & Chi, 2006); the change from a non-spherical model of the earth to a spherical model (Vosniadou & Brewer, 1992); the change from a tactile theory of matter to a particulate theory (Smith, 2007); the change from a behavioral theory of illness to a germ-based theory (Au et al., 2008; Solomon & Cassimatis, 1999); and the change from a directed based theory of evolution to a selection based theory (Bishop & Anderson, 1990; Brumby, 1984; Ferrari & Chi, 1998; Moore et al., 2002).

There is a theoretical disagreement found in the research of conceptual change. In one camp, researchers have argued that knowledge is comprised of a set of coherent theories, similar to scientific theories in their structure and function and that conceptual change involves the restructuring of those theories (Carey, 2000). In the other camp, researchers have argued that student's knowledge is bettered seen as a collection of fragmented ideas grounded in a specific context, better known as "knowledge-in-pieces" (diSessa, 1993). Due to recent findings, extreme positions on either side of the debate are no longer held because students' knowledge consistently show a moderate, yet far from perfect, amount of coherence (diSessa, Gillespie, & Esterly, 2004). Also, although the

“knowledge-in-pieces” view provided an explanation for students inability to transfer knowledge in different contexts, it failed to account for the vast body of knowledge demonstrating domain-specific development of expertise (Spelke & Kinzler, 2007).

Despite the differences between the two theoretical groups, all researchers recognize the significance of misconceptions. Students enter the science classroom with preconceived ideas of science from personal experiences. Some of these preconceived ideas are consistent with the science concepts covered in the classroom and help in understanding the topic (Clement, 1993). However, sometimes the preconceived ideas do not match scientifically accepted theories. These are referred to as misconceptions. Some misconceptions hinder learning because the normative concept does not fit the mental model of the learner. When a student who has not undergone a conceptual change is asked to explain a scientific concept, it is explained consistent with their mental model but is not necessarily the normative explanation (Au et al., 2008; Vosniadou & Brewer, 1992). “Correcting” discrepant information varies depending on the robustness of the misconception. Many interventions have been designed for the goal to rid misconceptions with varying success (Chinn & Brewer, 1993; Shtulman, 2006).

The process of changing a misconception to a normative conception can be classified into three different categories according to their resistance to change (Chi, 2008). The first type is the modification of individual beliefs. A false belief is when there is a contradiction between prior knowledge and new information. Usually, these exist because the learner has not been formally exposed to the

normative information in an educational setting. False beliefs are the least resistant to change and the straightforward technique of refutation will work well in removing this type of misconception (Chi, 2008). The conceptual change literature is saturated with lists of false beliefs (Anderson et al., 2002; Brumby, 1984; Evans, 2000; Geraedts & Boersma, 2006; Hagman, Olander, & Wallin, 2002; A. E. Lawson & Weser, 1990).

The second type of conceptual change involves mental model transformations (Chi, 2008). As previously described, mental models are a representation containing concepts and relationships between those concepts. Mental models are used to predict and describe outcomes about the world (Johnson-Laird, 1989). Misconceptions arise due to a flawed mental model that is coherent but incorrect. Flawed mental models have been found to be fairly resistant to change but with time and exposure to the topic show success in changing (Asterhan & Schwarz, 2007; Catley, 2006; Gregg, Winer, Cottrell, Hedman, & Fournier, 2001; Jacobson & Archodidou, 2000; Jensen & Finley, 1996).

The third and last type of conceptual change involves a categorical shift and is the most resistant to change (Chi, 2008). Part of the learning process involves assigning a new concept to a mental category. Occasionally, a learner will assign a new concept into the wrong mental category. For example, if a child is learning about dolphins and puts that concept into the “fish mental category” then they will incorrectly attribute all the properties of fish to the concept of dolphin. These types of misconceptions are the most robust and resistant to

change (Garvin-Doxas & Klymkowsky, 2008; Moore et al., 2002; Shtulman, 2006).

Regardless of the type of misconception an individual has, the first step in undergoing a conceptual change is recognizing the discrepancy between their naïve concept and the normative concept. This confrontation of concepts is called *cognitive dissonance*. In the education literature, cognitive dissonance is viewed as a catalyst for learning because it promotes the necessary changes in mental models (Chan et al., 1997). Moreover, collaborative settings afford more opportunities for cognitive dissonance due to differences in knowledge between collaborators (Gijlers & Jong, 2005; D.W. Johnson & Johnson, 1979; Linn, 2006).

Natural Selection

Misconceptions occur more frequently when learning difficult content-domains, such as the biological process of Natural Selection. When students have naïve conceptions of natural phenomena which deviate from scientific explanations, students have difficulty understanding the concept (Brumby, 1984). The reason why students have difficulty is because students are unable to relate what they already know (prior knowledge) to the new discrepant information. It is important that students learn the details of Natural Selection as the mechanism of evolution because it is a central concept in biology (Bishop & Anderson, 1990; Brumby, 1984; Ferrari & Chi, 1998; Jensen & Finley, 1996; Nehm & Schonfeld, 2008; Passmore, 2002; Sandoval & Millwood, 2005; Settlage, 1994; Shtulman, 2006). Yet, students do not thoroughly understand the theory even after

instruction because students are hindered due to misconceptions (Brumby, 1984; Settlage, 1994).

Students who possess a scientifically inaccurate mental representation about evolution tend to hold misconceptions about multiple connected concepts. From 49 studies that use Natural Selection as the content-domain, robust misconceptions can be narrowed down to 7 ideas. The first misconception is that individuals with the advantageous variant are the only ones that live and survive to reproduce (Garvin-Doxas & Klymkowsky, 2008; Geraedts & Boersma, 2006; Jacobson & Archodidou, 2000). The second common misconception is that individuals can make themselves evolve out of necessity (Bishop & Anderson, 1990; Ferrari & Chi, 1998; Geraedts & Boersma, 2006; Jacobson & Archodidou, 2000; Jensen & Finley, 1996; Moore et al., 2002; Nehm & Reilly, 2007; Settlage, 1994; Shtulman, 2006). The third common misconception is that the environment causes evolution (Alters & Nelson, 2002; Ferrari & Chi, 1998; Geraedts & Boersma, 2006; Jacobson & Archodidou, 2000; Jensen & Finley, 1996; Nehm & Reilly, 2007). The fourth common misconception is that traits are acquired by an individual during its lifetime are believed to be passed on to the offspring (Bishop & Anderson, 1990; Geraedts & Boersma, 2006; Jacobson & Archodidou, 2000; Jensen & Finley, 1996; Lawson & Thompson, 1988; Settlage, 1994; Shtulman, 2006). The fifth common misconception is that the different proportions of variants are not accounted for, considering every individual in population to be identical and that Natural Selection acts on the population as a whole (Alters & Nelson, 2002; Geraedts & Boersma, 2006; Jacobson & Archodidou, 2000; Nehm

& Reilly, 2007; Shtulman, 2006). Students think that the trait gradually changes, rather than the changing proportion of individuals with discrete traits (Alters & Nelson, 2002). The sixth common misconception is that Natural Selection has a goal (Ferrari & Chi, 1998; Moore et al., 2002). The seventh and final misconception is that the random process of evolution involves traits randomly appearing or disappearing (Garvin-Doxas & Klymkowsky, 2008; Geraedts & Boersma, 2006; Sandoval & Millwood, 2005).

A collaborative learning setting can provide students with the opportunity to discuss alternative conceptions. Discussing conceptions that differ from one's knowledge is a critical part of the learning process because it may reveal individual misconceptions that only become apparent through verbalization (Kneser & Ploetzner, 2001; Vahey, Enyedy, & Gifford, 1999). In this dissertation research, I explored collaborative learning about the biological process of Natural Selection. Theoretically, the collaborative environment induced cognitive dissonance among the collaborators, which facilitated conceptual change.

Collaborative Learning

Collaborative learning, as defined in this dissertation, is the face-to-face interaction between two participants in a coordinated effort to learn new material, (Roschelle & Teasley, 1994). When students are involved in active and interactive instructional strategies, students gain cognitive benefits such as deeper comprehension of ideas and an increase retention of concepts (Dolmans & Schmidt, 1996; D. Ebert-May, Brewer, & Allred, 1997). Collaborative

instructional strategies are considered to be student-centered. There are a variety of implementations, but most focus on the students' exploration and application of the course material. Interactive strategies differ to traditional strategies, which includes the teacher's presentation or explanation of material (Summers, Beretvas, Svinicki, & Gorin, 2005).

Mechanism of Collaboration

Although there is no theory to explain the collaborative mechanism in which students benefit, there are measurable factors involved that have been scrutinized. In an attempt to build a theory to explain the mechanism of collaboration, I used three categories to evaluate the relationship between collaboration and learning. The first category includes the input characteristics. This research included prior knowledge, sex and religious background. The second category includes the interaction characteristics: activating prior knowledge, help seeking, explanation and elaboration. The third category includes the output characteristics, or the collaboration benefits. These are the creation of new and original knowledge, deeper comprehension of ideas, retention of knowledge, transfer, and intrinsic motivation. Although, all three categories are discussed in this chapter, the research in this dissertation will focus mainly on the three input characteristics: prior knowledge, sex and religious background.

Input characteristics

Prior Knowledge and Collaborative Learning. Prior knowledge is defined as the mental model that a learner possesses on a particular topic before learning new material. These mental models represent rules and inferences about how processes, like Natural Selection work. These mental models vary from naïve to highly sophisticated. They may be constructed from formal education but often spontaneously emerge during personal experiences (Schmidt et al., 1989). Learning new concepts involves a process where the student integrates the new information into their existing mental model. Therefore, prior knowledge always plays a role in any learning situation. Learning proceeds primarily from prior knowledge and secondarily from the presented materials (Roschelle, 1992; Roschelle & Goldman, 1992). The classic study by Bransford and Johnson (1972) demonstrated that students with relevant prior knowledge *and* the activation of it promoted learning. Other studies have shown the same effect of prior knowledge on learning (Hewson & Hewson, 1983; P. Johnson & Pearson, 1982; McKeown, Beck, Sinatra, & Loxterman, 1992; Schmidt et al., 1989; Shapiro, 2004).

It is common, during the learning process, for prior knowledge of an individual to conflict with new material. This is known as cognitive dissonance. Cognitive dissonance promotes conceptual change (Strike & Posner, 1992). Collaborative learning can facilitate conceptual change because in an interactive setting it is more likely that the mental model of an individual will be confronted with new ideas due to the differences in the prior knowledge of the individual collaborators. Therefore, different combinations of prior knowledge among

individuals in a collaborative setting might lead to different communication and elicit conceptual change (Baker, Hansen, Joiner, & Traum, 1999; Fijlers & Jong, 2005).

Few studies have measured the differences in prior knowledge of collaborators. Research in learning clearly explains that the acquisition of new knowledge depends heavily on an individual's prior knowledge (Bransford & Johnson, 1972). If differences exist between the mental models of two collaborators, what happens in a collaborative setting? How much do the differences in prior knowledge of the collaborators influence the changes in their individual mental models? This research aims to answer that question. It is my hypothesis that new knowledge is co-constructed during an interactive process due to the differences in the mental models of the participants. Therefore, I predict that if the mental models are measured before collaboration, the more dissimilar they are the bigger the collaborative benefit. Studies about controversy and heterogeneous groups support this prediction.

Controversy during collaboration leads to highly constructive or highly destructive outcomes (Johnson & Johnson, 1979; Schultz-Hardt et al., 2002). Johnson and Johnson (1979) found that managed-controversy in collaborative settings led to increased cognitive development and learning. By controlling the controversy in group collaboration they argued that the conflict promoted cognitive dissonance, which in turn encouraged modification of mental models (Johnson & Johnson, 1979). Also, argumentation (a form of controversy) in collaborative settings has a tendency to have a similar cognitive impact. By

definition, argumentation refers to the process of justifying claims and explanations (Sampson & Clark, 2008). In a sense, argumentation deals with arguing about differences in interpretations, allowing the participants to build on each other's knowledge as well as recognizing and resolving contradictions between their own and other students' knowledge (Azmitia, 1988).

Several researchers have studied heterogeneity of groups. Because heterogeneous groups often result in controversy and argumentation they are superior to homogenous groups in terms of quality of group solution, creativity of group solution and member satisfaction with the solution (Amaria, Biran, & Leith 1969; Jackson et al., 1991; Paul, Seetharaman, Samarah, & Mykytyn, 2004; Schultz-Hardt, Jochims, & Frey, 2002).

An example of success from heterogeneous collaboration is illustrated in a study by Schultz-Hardt (2002). Approximately 200 employees were put into groups of three. Each participant was asked to read an economic case study about a chemical company wanting to expand to either country A or country B. The participants were then allowed to request additional information about either country or both. Based on the requested information, individuals were put into groups designated as homogenous or heterogeneous. The groups were given time to collaborate and request further information if needed. The results suggest that there was more information seeking during the collaboration for the heterogeneous groups compared to the homogeneous groups which explained why the heterogeneous groups came up with the best solution, on average, compared to the homogeneous groups (Schultz-Hardt, Jochims, & Frey, 2002).

This result could be explained by the pooling of different mental models (accessible only to individual members of the group).

In an attempt to explain why collaborative learning is more beneficial than individual learning and more specifically, why heterogeneous groups outperform homogenous groups I will measure the mental models of individuals prior to learning about the biological process of Natural Selection collaboratively in dyads. I will examine if having dissimilar prior knowledge about the content will affect learning. I will be looking at both individual learning and group collaborative problem solving. From this experiment, I predict that dissimilar prior knowledge between collaborators will result in high quality collaboration and an increase in learning.

Sex and Collaborative Learning. Individual characteristics can affect the way a collaborative group succeeds or fails. This applies to sex differences. One reason for this gender-effect is differences in interaction styles for males and females during collaboration (Margrett & Marsiske, 2002). At an early age, males and females interact differently in a social setting based on gender-specific behaviors, such as duration and frequency. These behaviors can impact the outcome of a collaboration (Maccoby, 1990). It is not surprising that sex differences effect collaboration, because a great deal of research has shown differences in communication between males verses females (Carli, 1989; Leaper & Ayres, 2007). Leaper and Smith (2004) did a meta-analysis on gender variations in language use. They confirmed that individuals display gender

differences in conversation style. Girls use more allied speech, where boys use more assertive speech. These differences are seen early in young children. Leman, Ahmed and Ozarow (2005) examined the relationship between sex and children's communication styles in the context of a classroom problem-solving task. The students were given different shapes (circle, triangle and square) and were told that each shape was worth a different value (for example 10, 20 and 50). The students were asked to work with a partner and add shapes together so that they total 100 points. Unknown to both, each student had been told the wrong information about the values associated with the different shapes. This conflict led to a discussion between the students to agree upon a solution. As expected by the researchers, gender-specific communication was seen. Specifically, boys displayed more assertive talk compared to girls. The most notable difference was that boys had a higher frequency of interrupting a girl compared to girls interrupting boys (Leman, Ahmed, & Ozarow, 2005).

What sex composition is optimal for the individual collaborators and the group as a whole? According to Maccoby, (1990) women are at a disadvantage in an interactive setting because she found that women display same-gender behavior characteristics in a mixed-sex group and males are unresponsive to those behaviors. In addition, men are more likely to take a leadership position in a collaborative setting compared to women which tends to underutilize input from the female group members (Kolb, 1997). This is overwhelmingly evident in studies involving females in a predominantly male field (Baker, Krause, Yasar, Roberts, & Robinson Kurpius, 2007; She, 1999; Southerland, Kittleson, Settlege,

& Lanier, 2005). For example, Baker demonstrated in a collaborative study involving graduate level electrical engineering students, that women were marginalized during teamwork activities (Baker et al., 2007).

However, other studies claim the contrary: women are at an advantage in a collaborative setting. For example, a study by Woolley found a significant correlation between the numbers of females in a group to the collective intelligence (*c*) of the group. They attributed their finding to social sensitivity, a trait where females scored higher compared to males (Woolley et al., 2010). In Woolley's study, the groups were asked to perform a series of tasks such as puzzle solving, brainstorming, and making collective moral judgments, and the groups (composed of 2-5 members) containing a majority of females significantly outperformed groups contain a majority of males.

Does group composition based on same-sex versus mixed-sex play a role on the success of individual collaborators or the group as a whole? Science education research suggests that it does (Tucker et al., 1995). A study by Barbieri and Light (1992) found that males tended to be more dominant in same-sex dyads, where females in the same-sex dyads demonstrated more turn taking. Lee and Marks claim that "females benefit more from same-gender learning environments" (Corston & Colman, 1996; Lee & Marks, 1990). In a review on sex differences on group performance, Wood concluded that the *type* of collaborative task determines who will be at an advantage (Wood, 1987). For instance, interaction styles of women appeared to drive tasks that involve social activity and group consensus, where men appeared to drive tasks that require a

correct solution (Wood, 1987). Variations in the effects of sex in different contexts are profoundly relevant in a collaborative setting (Leman, 2010). However, it would be minimalistic to view gender-specific communication styles as universal, or that one sex will inevitably succeed compared to the other. A theory called *contextual interactive model* suggests that gender communication differences are at their greatest when a common goal is not shared between the collaborators. In other words, there is less differentiation seen when two individuals are connected with a shared goal or conversation focus (Deaux & Major, 1983).

This dissertation research aims at exploring the relationship between sex-differences and learning in a collaborative setting. Learning is defined as a difference in scores on an individual assessment and a group assessment. In an attempt to examine this relationship I analyzed collaborative groups with different compositions based on sex. I measured any observable learning difference between males and females along with group performance based on group composition. It was predicted that there would be a difference in learning through collaboration. Furthermore, I hypothesized that groups composed of females would result in a more effective collaboration at the group level and that females would have an increase in learning compared to their male counterparts.

Religious Beliefs and Collaborative Learning. The majority of college students do not understand evolutionary theory (Lawson & Thompson, 1988). Most studies claim that misconceptions arise due to the complexity of the topic

and that it is the misconceptions that prevent students from fully understanding the theory (Demastes, Settlage, & Good, 1995; Geraedts & Boersma, 2006; Hagman, Olander, & Wallin, 2002; Jacobson & Archodidou, 2000). The research clearly demonstrates that understanding the biological process of evolution requires more than a few lessons in biology. It also requires lessons in the nature of science and the philosophy in science. In other words, an individual first has to understand what constitutes a scientific theory before they can appreciate and comprehend the concept of evolutionary theory (Dagher & BouJaoude, 1997; Lombrozo, Shtulman, & Weisberg, 2006; Lombrozo, Thanukos, & Weisberg, 2008).

Some researchers claim that if a student understands the nature of science then they are more likely to *accept* the theory of evolution, despite contradictory religious beliefs (Dagher & BouJaoude, 1997). Overall, few studies have looked at the relationship between understanding evolutionary theory and believing it to be true.

Some people accept evolutionary theory to various degrees where others reject it. Environmental influences might play a role in the acceptance of evolution, as suggested by Brem, Ranney, and Schindel (2003). She found that students who accept evolutionary theory were exposed to antievolution messages as often as creationists, however students who accept evolutionary theory were exposed to pro-evolution messages more than creationists. Also, students who accept evolutionary theory were more likely to believe that evolution had no social consequences compared to students who didn't accept evolutionary theory

(Brem, Ranney, & Schinel, 2003). What effect does the acceptance or rejection of evolution have on learning complex content pertaining to the process of Natural Selection? A more interesting question that has yet to be examined is: Do the differences or similarities in religious beliefs of the collaborators have an effect on learning, in a collaborative setting. It is the goal of this dissertation research to analyze the effects of group composition based on religious beliefs on learning about the biological process of Natural Selection.

Interaction characteristics

Collaboration, as a learning process, can also be examined by observing interaction characteristics. These characteristics involve observable traits that play out during a discussion between collaborators. The first characteristic is the activation of prior knowledge. The kind of prior knowledge a learner possesses greatly influences their ability to learn new information. But having the right prior knowledge isn't enough; it must be evoked for learning to occur. Schmidt (1989) illustrated this in a study where participants in an experimental group studied a content-relevant text before collaborating on a problem. During the collaboration, the participants in the experimental group that discussed the information in the text (activating prior knowledge) outperformed students in the control group. In a more recent study by Barron (2000), she demonstrated the importance of the activation of prior knowledge. She qualitatively observed small groups to determine which factors were more associated with effective collaborative problem solving. The characteristics she looked at were conversation length, the

induction of prior knowledge and the number of ideas that were not related to the problem. She reported that the induction of prior knowledge was the only factor that was directly correlated to individual performance on a post test (Barron, 2000).

The second interactive characteristic involved in collaboration is giving and receiving help. Help seeking behaviors have a positive relationship to learning (Webb & Mastergeorge, 2003). These are exploration behaviors where the learner has the opportunity to discover new information. However, just participating in these types of behaviors doesn't guarantee that learning will occur. For example, just seeking and hearing an explanation does not correlate with learning, as demonstrated in the tutor research. Roscoe and Chi (2007) observed that tutors spend the majority of a tutoring session explaining concepts to a tutee. This behavior does not correlate to the tutee learning. Despite this, Vedder (1985) proposed that help seeking behaviors are only effective if the student uses the new information. For example, effective help seeking behavior could include a student practicing solving a problem using someone else's explanation. This allows the participant to make and reveal mistakes while attempting to solve a problem. Webb & Mastergeorge (2003) analyzed the behaviors of individuals seeking and receiving help. They found that students that used the help to practice solving a problem had higher scores compared to students just saying "I get it" (Webb & Mastergeorge, 2003). Both the giver and receiver of help should be in a position to benefit because receiving help is an act

of exploration and giving help allows a participant to explain and elaborate (Webb & Mastergeorge, 2003).

Explanation is the third collaborative characteristic that has been shown to be productive in the learning process. Explanations are statements that articulate information with the goal of making some idea clear and comprehensible (Roscoe & Chi, 2007). During collaborative learning, participants use verbal explanations to express key ideas, principles and relationships (Slavin, 1996). These explanations may involve a range of elements such as summarizing main ideas, using examples, and using analogies. They can be used to share known information or to make sense of new information (Chi et al., 1989; Roscoe & Chi, 2007). Collaboration affords a setting for explanation. Explaining allows the learner to actively construct and modify mental models, which facilitate the processing and understanding of new information (Dolmans & Schmidt, 1996; Mayer, 1984; Webb, 1989). During collaborative learning, the explanations used can be embedded into scaffolding interactions, where the participants interact over successive turns to incrementally develop the knowledge of each other. Furthermore, when explaining while solving a problem collaboratively students are forced to think about the salient features of a problem, which is essential for developing problem-solving strategies (Cooper, 1999).

Elaboration is the fourth collaborative characteristic. Elaboration can take different forms, which include discussion, note-taking or answering questions. These activities help the learners to reflect on what he or she understands but it also helps to construct rich cognitive models about the information that is being

learned (Schmidt, 1993). From a cognitive perspective, elaboration is thought of as a form of higher-order thinking in which new ideas are generated by connecting new information with knowledge already present (Blankenstein et al., 2009). The act of elaborating encourages the learner to recognize misconceptions and reorganized mental models (King, 1994). Not surprisingly, the richness of elaboration has led many to hypothesize that it contributes towards learning (Bargh & Schul, 1980; King, 1994)

Output characteristics

Collaboration is often utilized as a learning strategy in science classrooms. The collaboration output characteristics can be defined as the benefits of this learning strategy. The output characteristics include: deeper comprehension of ideas, transfer, retention of knowledge, and the creation of new and original knowledge (Doymus, 2008; Ebert-May, Brewer, & Allred, 1997; Fischer & Mandl, 2005; Jensen & Finley, 1996; Mastropieri, Scruggs, & Graetz, 2003; Peters & Armstrong, 1998; Roschelle & Teasley, 1994; Stahl, 2000).

First, deeper comprehension of concepts and retention of knowledge is a common result of collaborative learning. Ebert-May (1997) compared the biological literary outcome of a class that used cooperative groups to a class that used a traditional lecture format. The hypothesis of the study was that “students would learn science better by becoming engaged in the process of science” (Ebert-May, Brewer & Allred, 1997, pg. 602). Concept maps were given to the experimental group showing the relationships between ideas, to provide a visual

road map. Following this, students were asked to work on three problems in small groups. When comparing learning gains from a pre and post-tests, the collaborative opportunity in the experimental class provided students with the chance to learn and retain more of the science content when compared to the students in the traditional lecture format (Ebert-May, Brewer & Allred, 1997).

In addition to deeper comprehension and retention of knowledge, collaborative learning has been successful at promoting transfer of new knowledge. Tans, Schmidt, Schade-Hoogevann, and Gijsselaers (1986) did a study on medical students where they randomly assigned each participant to either a problem-based or a lecture-based version of a course in muscle physiology. He used a test of core knowledge to measure learning and a test with real world problems to measure transfer. These assessments were given after six months of taking the course. Students from the problem-based group scored up to five times higher on both tests compared to the control group (Tans et al., 1986).

Thirdly, the co-construction of knowledge can be determined as an output trait of collaborative learning. New and original knowledge isn't simply the sum of the individual knowledge from the individual collaborators. It is both more than and different than the individual knowledge parts (Peters & Armstrong, 1998). "The group learning experience is more than the sum of individual experiences because of the interactive nature of the knowledge construction process" (Peters & Armstrong, 1998). Webb and Palinscar (1996) examined four collaborative factors. The four factors were: resolution of conflict and controversy, giving and receiving explanations, providing emotional and

motivational support and the co-construction of new ideas. Of the four measures, co-construction had the highest correlation to learning (Webb & Palinscar, 1996). In other words, an effective collaboration has to involve creating new and original knowledge that did not exist in any of the individuals before the collaboration. In sum, collaboration means that people work together in order to construct something that did not exist before the collaboration, something that does not and cannot fully exist in the lives of individual collaborators (Peters & Armstrong, 1998; Stahl & Hesse, 2009).

In this chapter, I discussed the research and theoretical frameworks of collaboration and the relationship of collaboration to student learning. In the education literature, when collaborative groups are compared to individual learning, the participants in the collaborative groups often outperform their individual counterparts (Dolmans & Schmidt, 1996). This result is not surprising considering the collaboration benefits that individuals gain from learning interactively (Dolmans & Schmidt, 1996). The benefits include deeper comprehension of ideas, retention of knowledge, transfer and the creation of new and original knowledge (Doymus, 2008; Diane Ebert-May et al., 1997; Fischer & Mandl, 2005; Jensen & Finley, 1996; Mastropieri et al., 2003; Peters & Armstrong, 1998; Roschelle & Teasley, 1994; Stahl, 2000). Collaborative learning activities are frequently used in science classrooms. However, knowledge about how to group students for optimal learning is still an emerging area of research. As always, there is a need to understand the mechanism behind

collaborative learning to utilize it in terms of grouping students for effective collaboration.

CHAPTER 3 METHODS

This research involved analyzing collaborative learning about the biological process of Natural Selection. Numerous studies in science education make a case that students who participate in collaborative learning generally outperform students who learn alone (Doymus, 2008; Ebert-May, Brewer, & Allred., 1997 ; Fischer & Mandl, 2005; Jensen & Finley, 1996; Roschelle & Teasley, 1994; Stahl, 2000). This dissertation had two aims; the first aim was to design a sensitive tool to measure learning. Learning was defined as the difference between test scores. The second aim was to measure the effects of three factors on learning in a collaborative setting. I first validated that a high quality collaborative-learning session resulted in learning then analyzed the three factors. The first factor was prior knowledge similarity (similar or dissimilar) between collaborators. The second factor was sex, male or female. The third factor was religious belief with regard to human evolution. There were three categories: creationist, evolutionist or a blend. Students who believe that human beings have developed over millions of years from less advanced forms of life without the help of God's guidance were categorized as evolutionists. Students who believe that God created human beings in their present form were categorized as creationists and students that believe that human beings developed over millions of years from less advanced forms of life, but God guided this process were categorized as blend. Three dependent variables were used to measure learning at two levels. The two levels were the individual level and the group level. The learning gains at the individual level were calculated from two assessments: the

CINS developed by Anderson (2002) and a Mental Model Task developed by me. To measure at the group level, each dyad was asked to complete a problem-solving task collaboratively.

Chapter three presents a description of the research design and methods selected for this study, including details of the sample, a description of the materials used and the procedure of the data collection. All data sources are detailed in the appendix (Appendix D-J). Finally, I will explain how the data was analyzed to answer the following research questions.

Research Questions

1. Does the quality of collaboration have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?
2. In a collaborative setting, does the difference in prior knowledge increase learning concepts about Natural Selection at the individual level and/or at the group level?
3. In a collaborative setting, does sex have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?
4. In a collaborative setting, do religious beliefs have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?

Research Design and Sample Description

Description of Research Design

This research was designed to achieve two goals: 1) to design a reliable and valid instrument to measure learning in the domain of evolution and 2) to investigate the quality of collaboration and the effect of three collaborative factors on learning about the biological process of Natural Selection. The three factors were prior knowledge similarity, sex, and religious beliefs. The study design was quantitative. The design of the Mental Model Task utilized a Pearson correlation model; analyzing the effects of collaborative factors utilized a Univariate Analysis of Covariance (ANCOVA) model. I performed four ANCOVAs for each of the following factors: quality of collaboration with two levels (effective or ineffective), prior knowledge similarity with two levels (similar or dissimilar), sex with two levels (male or female) and religious beliefs with three levels (creationist, evolutionist, blend).

Procedure

The study took place on three separate days in seven different classrooms (Appendix A). I conducted the study (IRB #1010005648).

Day 1. Students were introduced to the study and informed that the purpose of the study is to investigate the mechanism of collaborative learning in a scientific domain. As an incentive to participate, all students who agreed to participate and

completed all three days were entered in a drawing for a \$50 American Express gift card, which was issued to one student at the end of the semester. If consented, each participant was assigned a number and was informed that they would never be identified as a participant in the study (Appendix B). Each participant individually completed a demographic survey (Appendix D), followed by taking the CINS pre-test (Appendix F), and lastly, they completed the Mental Model Task (Appendix E). This took approximately one hour.

Day 2. Participants, individually, read the text materials on Natural Section (Appendix C) and then completed the Mental Model Task. This took approximately one hour. The data from the Mental Model Task was used to assign dyads into two groups: similar mental models and dissimilar mental models. At the end of Day 2, I met with each instructor to explain how to observe the collaborations and went over the instructions and the observation sheet (Appendix E). The meeting with each instructor ranged from 20 min to 45 min.

Day 3. Participants were put into their assigned dyads and worked on the collaborative problem-solving task where each dyad solved three problems (Appendix H). Two problems were near transfer problems and the third was a far transfer problem. The researcher and the instructor wrote down observations for each dyad while the participants collaborated. After collaborating, each individual completed an evaluation on the collaboration (Appendix J), the CINS posttest and the Mental Model Task. This took between 1 and 1.5 hours. After the participants

left the room, the instructor and I discussed each collaborative dyad and compared notes to come to a consensus about the quality of each dyad. This meeting lasted between 20 to 30 min for the community college classes because of the smaller number of dyads (7-10 dyads) and approximately 45 min for the ASU class, which had 22 dyads.

Sample

The study was conducted in Phoenix, Arizona with a convenience sample of 142 students who were enrolled at either GateWay Community College or Arizona State University. Participants were recruited from the following four classes at GateWay Community College: BIO205 Microbiology, BIO105 Environmental Biology, BIO156 Introductory Biology for Allied Health or BIO202 Human Anatomy and Physiology II, and one class at Arizona State University: BIO440 Functional Genomics. The sample of students was comprised of 53 males and 89 females across a range of ages (18-63) and ethnic groups (Table 3.1). There was a large range in biological knowledge of the participants due to the diversity of the classes from which participants were recruited. The majority of the students had been exposed to some Natural Selection concepts prior to the study.

TABLE 3.1: Student Demographics

Factor	Level	<i>n</i>
Sex	Male	53
	Female	89
Ethnicity	Caucasian	74
	Latino	35
	African American	20
	Asian	9
	Native American	4

Sample size determination. A power analysis was performed to determine what sample size was required to have a reasonable chance of detecting a difference when a true difference existed. The power analysis suggested a minimum sample of 33 dyads in each group. This *a-priori* sample size calculation was derived using the alpha level of .05, one predictor, the anticipated effect size of .7 and the desired statistical power level of .80 (Nakagawa & Cuthill, 2007). Data was collected on three separate days. There were 205 students enrolled in the study on Day 1, however 53 participants failed to complete all the requirements. Ultimately, there were complete data sets for 142 participants (71 dyads) that were used in the final analysis.

Materials and Data Sources

Natural Selection Text

The Natural Selection text (Appendix C) was prepared to summarize the four main principles presented in the theory of evolution through natural selection and to provide a well-studied example that applies the tenets of the theory to

explain a living population. I collaborated with two biologists to identify the four basic principles in the biological process of natural selection and to choose a text based on these principles. The principles are presented in Table 3.2.

TABLE 3.2: The four principles of Natural Selection

1. Variation	Within a species, individuals show considerable variation in their physical characteristics. The variations are produced randomly. Only inherited variations are important in evolution.
2. Hereditary transmission of variation	The surviving and successfully reproducing individuals will give rise to the next generation, and in this way the “successful” variations are transmitted to the next generation.
3. Struggle for survival	Since a larger number of individuals are born than can survive, there is a struggle for survival, a competition for food and space, or a struggle to survive unfavorable environmental conditions.
4. Selective advantage	Those organisms with variations that better equip them to survive in a given environment will be favored over other organisms that are less well adapted.

There were five data sources used to provide the data for this study and all participants completed the same activities. The data sources are described below.

Demographic Survey

The first data source was a demographic survey (Appendix D) created by the researcher to identify the participant’s age, sex, major, ethnic group, amount of prior exposure to biology content and religious beliefs regarding human evolution. This data source was used to collect demographic information as well as group dyads into groups based on sex and religious beliefs.

Mental Model Task

The second data source was the Mental Model Task (Appendix E), which was used to elicit and capture the mental models of the participants. This technique is similar to the grouping task done in a study by Boekaert (2002). The information captured from this tool served two purposes. First, it was used to measure learning by comparing the participant model to an expert model on each day of the procedure. Second, it was used to determine domain-specific prior knowledge of the participants before undergoing the collaborative activity for the purpose of grouping participants into two groups: similar dyads and dissimilar dyads. The expert mental model in the domain of Natural Selection was established with the help of an evolutionary biologist from Arizona State University, Dr. Michael Rosenberg, to determine the list of 22 terms and the appropriate relationship between the terms. To elicit the mental models of the participants, they were given a list of pairs where each pair represents a different combination of two terms from the total 22 terms (231 pairs). Individually, each participant was asked to circle each pair in which the two terms have a relationship. From this, a 22x22 matrix was created and a '1' was placed in the cell corresponding to each circled pair. Correlation between two matrices was computed to the expert to measure learning and to one another to group dyads into similar and dissimilar dyads. I was able to measure the degree of similarity within domain-specific prior knowledge between collaborators. It allowed me to group participants according to the p-values into the two groups: dyads with similar

mental models were significantly correlated ($p < 0.05$) and dyads with dissimilar mental models were not significantly correlated ($p > 0.05$). Correlation was calculated using the Mantel Test (Mantel, 1967), which is a statistical test to determine the correlation between two matrices.

Validity and Reliability of the Mental Model Task

Content validity of any instrument refers to the ability of that instrument to measure what it is intended to measure, where the reliability of any instrument refers to the sensitivity of the instrument to be able to measure the content consistently. The Mental Model Task was designed to represent the domain-specific knowledge structure (or mental model) for each participant with regard to Natural Selection. To test for validity, three individuals with varying knowledge about natural selection (a nonscientist, a novice and an expert) performed the Mental Model Task. Compared to the previously established expert model, the results showed that the nonscientist had the lowest correlation ($r = 0.015$, $p = 0.38$), the novice had a correlation between the non-scientist and the expert ($r = 0.251$, $p = 0.00$) and the expert had the highest correlation ($r = 0.669$, $p = 0.00$) (Table 3.3). These results validate the instrument.

TABLE 3.3: Calculated Correlation of Mental Model Task for three individuals with varying knowledge about natural selection (a nonscientist, a novice and an expert) to determine the validity of the Mental Model Task

		Correlation (r)	p-value
Non-scientist	High-school Spanish teacher	0.015	0.38872
Novice	High-school biology teacher	0.251	0.00105
Expert	University evolutionary biology graduate student	0.669	0.00088

To test for reliability, a stability test was performed using data from a pilot study in a Spring 2011 Microbiology BIO205 class at GateWay Community College. Students ($n = 18$) were asked to do the Mental Model Task at two different time points one week apart. Using the Mantel Test to measure correlation (r), 8 of the 18 had an $r > 0.80$, where 9 of the 18 had an $r = 1.0$ (Table 3.4). In addition, a Cronbach's alpha test was performed on my sample. The Mental Model Task was found to be reliable (231 items; $\alpha = .86$).

TABLE 3.4: Calculated Correlation of Mental Model Task for each participant when taken at two time points to determine the reliability of the Mental Model Task

Week 1	Week2	Correlation (r)
11101-1	11101-2	1
111010-1	111010-2	1
111011-1	111011-2	0.97014
111012-1	111012-2	1
111013-1	111013-2	0.88649
111014-1	111014-2	1
111015-1	111015-2	1
111016-1	111016-2	1
111017-1	111017-2	0.96334
111018-1	111018-2	1
11102-1	11102-2	0.96969
11103-1	11103-2	1
11104-1	11104-2	0.94192
11105-1	11105-2	0.97507
11106-1	11106-2	1
11107-1	11107-2	0.95928
11108-1	11108-2	0.98687
11109-1	11109-2	0.83633

Natural Selection Assessment

The third data source was the Conceptual Inventory of Natural Selection (CINS) developed by Anderson, Fisher and Norman (2002) (D. L. Anderson et

al., 2002)(Appendix F). It is a diagnostic test to assess student's understanding of Natural Selection. The items on the test were developed based on actual scientific studies of natural selection opposed to using imaginary examples, giving the test authenticity. It is a 20-item multiple-choice test that uses common misconceptions as distracters. The CINS assesses the following 10 main ideas: biotic potential, carrying capacity, resources are limited, limited survival, genetic variation, origin of variation, variation is inherited, differential survival, change in population and origin of species. In addition to assessing these ideas, the following topics appear in the test: competition, randomness, beneficial traits, neutral traits, harmful traits, fitness, reproductive success, descent with modification, evolution, change in gene pool over time, population, adaptation and species. The CINS was used as both the pre- and post-test taken on Day 1 and Day 3 to measure learning.

Validity and Reliability of the Natural Selection Assessment

The current version of the CINS has been used in multiple studies (Dagher & BouJaoude, 2005; Ingram & Nelson, 2005; Kelemen & Rosset, 2009; Klymkowsky, Garvin-Doxas, & Zeilik, 2003; Knight & Wood, 2005; Nehm & Reilly, 2007). The CINS was the most common assessment used for studies that used Natural Selection as the subject domain. For this reason, I chose it for my dissertation research. When the CINS was developed, it was field-tested with 206 students in a nonmajors' general biology course (Anderson, Fisher & Norman, 2002). To determine the validity for each item on the CINS, 2 university and 2 community college biology professors were asked to choose the correct answers

for each question. By choosing the intended answer on each question, the test was validated. The reliability of a test measures the consistency of responses. To ensure the general internal consistency, they used the Kuder-Richardson 20 (KR₂₀). This method considers all possible ways of splitting the test. The KR₂₀ for the test was 0.58 for Section A and 0.64 for section B (Anderson, Fisher & Norman, 2002). This reliability is low by most standards. However, when I ran a Cronbach's alpha reliability test on my sample it was higher (20 items; $\alpha = .78$).

Quality of Collaborations

The fourth data source was the determination of the quality for each collaborative dyad. Each dyad was assessed and placed into two groups: effective collaborators or ineffective collaborators. The criteria for effective collaborations were established *a-priori*. Three criteria were used to determine the effectiveness for each collaborative dyad to triangulate the observations. Effective collaborators required all three of the following criteria. First, the amount of collaboration time, for a dyad to qualify to be effective collaborators the collaboration needed to be a minimum of 20 minutes (Coleman et al., 1997). Second, both participants in each dyad answered an evaluation survey regarding the quality of the collaboration (Appendix J). In the survey, it asked if both collaborators contributed equally regarding time and content. The participants in each dyad must have determined that both collaborators contributed equally to be considered an effective collaboration. Third, both the instructor and the researcher observed the collaborations as they took place. Careful notes were taken to capture the

presence of two external criteria: equal contribution from both participants and presence of collaboration discourse (Appendix G). Both external observations needed to be present to meet the third criteria.

On Day 1, each instructor was given written instructions on how to observe the dyads (Appendix G). On Day 2, each instructor met with the researcher independently for a face-to-face explanation on how to observe and score students. This meeting ranged between 20 to 45 min for the three instructors. The intention of this meeting was to go over the observation criteria and to address any questions the instructors had. The first observation criterion was equal contribution during collaboration. This was based on reciprocity, in other words, if students conversed back and forth regarding the content (Woolley et al., 2010). The second observation criterion was the presence of effective collaboration discourse. Collaboration discourse included acknowledgements, repetitions or restatements (Clark & Wilkes-Gibbs, 1986). Discourse that reflected collaborative skill show that participants acknowledge the other partners contributions and maintain attention to the task. This was broken down to three types of utterances that could be observed. The utterances were *acknowledgements* (“ok” or “yeah” responses), *repetitions* (repeating back the previous statement), and *restatements* (rephrasing the previous statement). Each of these type of utterances has been shown to positively influence collaboration by “establishing the common ground necessary to achieve joint goals” (Clark & Wilkes-Gibbs, 1986, pg.). See Table 3.5 for example statements indicative of each type of collaborative discourse. Immediately after collaborations were completed,

the instructor and researcher went through each dyad to confer observations. All discrepancies were resolved in a face-to-face discussion and observations were revised accordingly.

TABLE 3.5: Examples of Statements for Collaborative Discourse

<i>Collaborative Discourse</i>		<i>Example</i>
Acknowledgements	BergA Dyad 2	They could be camouflaged in the snow. Mm-hmm
Repetitions	JTouchman Dyad 2	Wings are a valuable trait. Yeah, wings are valuable.
Restatements	JTouchman Dyad18	Brown or black bears are at a disadvantage because of the environment. Yes, because they don't blend into the snow.

Overall, the following three criteria needed to be met for a dyad to be placed into the “effective collaboration” group: 1) at least 20 minutes of collaboration; 2) both collaborators agree on equal contribution in time and content and 3) equal contribution and presence of collaboration discourse observed by the instructor and researcher.

Collaborative Problem Solving Task

The fifth data source was a collaborative task that consisted of three problems. This problem-solving task was used to measure learning by determining whether students were able to transfer their understanding of the

general concepts of the biological process of Natural Selection to unfamiliar scenarios (Appendix H). The three questions for this task came from a study by Coleman, Brown and Rivkin (1997). The questions differ in their difficulty level and the extent in which inferences are required to solve them. The first two problems were designed to be near transfer tasks. The first question asks participants to use the Theory of Natural Selection to explain how polar bears came to be white. Structurally, this problem is very similar to the example that was used in the text given on Day 2. The second problem is slightly more difficult because it requires the participants to switch from one subject matter to another. Instead of thinking about animals evolving visible characteristics, they had to switch domains to bacteria evolving greater resistance to antibiotics. To solve both of the near transfer problems, participants had to identify an environmental pressure, indicate a selective advantage, and refer to the transmission of heredity. The explanations were scored for the presence of the following four major principles: 1) random variation, 2) struggle for survival, 3) selective advantage and 4) hereditary transmission of variation (Coleman, Brown and Rivkin, 1997). For scoring the two near-transfer problem solutions, all four principles needed to be present. For each principle, a 0 was given if the principle was not mentioned, a score of 1 was given if the principle was alluded to and a score of 2 was given if the principle was mentioned clearly. For each near-transfer solution, the total score will range from 0 to 8 (see Appendix I for rubric).

The third problem was a far transfer task because it required the participants to infer and apply the four principles presented in the text to a novel

task. Participants were asked to explain why evolutionary biologists would be concerned about how birds could have developed wings and about what could have been the value of earlier intermediate structures (i.e. stubs). To solve this problem, participants had to first recognize the existence of the conundrum. The conundrum being that it is very difficult to explain how birds developed wings solely through concepts of selective advantage and natural selection, because having a partial wing (or a stub) does not show an obvious advantage. To be successful on this problem, they needed to infer some advantage of an intermediate structure. Scoring this problem used a separate coding scheme. Using the rating scale developed by Coleman, each solution was scored between 0 and 3. A score of 0 was given if the participant did not know the answer or if there was no mention of any idea. A score of 1 was given if the solution contained a reference to the necessity, purpose or usefulness of birds having wings, or if it included the impact of the environment in relation to a wing-like structure. A score of 2 was given if the solution contained a reference to the wing-like structures having a selective advantage but no mention of the conundrum and a score of 3 was given if the solution identified the conundrum and gave a possible advantage to the intermediate structure (Appendix I). From this collaborative task, a total of 19 points were possible. The collaborative solutions were scored by the researcher and a biology professor and the average of the two scores were used.

Validity and Reliability of the Problem Solving Task

Content validity for this instrument was assessed using the Content Validity Ratio (CVR), an approach described by Lawshe (1975). Content validity is where test items reflect the knowledge required for a given topic area (e.g., evolution). The CVR method is a widely used method for gauging agreement among raters, or judges, regarding how essential each item is. This method utilized a group of subject-matter experts (SMEs) who were asked whether or not each item on the assessment is essential (Lawshe, 1975). Each panel member was asked: “Is the skill or knowledge measured by this item ‘essential’, ‘useful, but not essential’, or ‘not necessary to the performance of the construct’?” Lawshe argues that if more than half the panelists indicate that an item is essential, that item has at least some content validity. Basically, greater levels of content validity exist as greater numbers of panelists agree that an item is essential. The CVR for each item in the measurement instrument is calculated as follows:

$$\text{CVR} = (N_e - N/2)/(N/2)$$

Where:

CVR= content validity ratio

N_e = number of subject matter expert panelists indicating “essential”

N = total number of SME panelists

Values from this formula range from +1 to -1; positive values indicate that at least half the subject matter experts rated the item as essential. The mean CVR across the three questions may then be used as an indicator of overall test content validity. The minimum value of the CVR is to make sure that agreement is unlikely to be due to chance is 0.99 for five panelists. For this study, a panel of

five biology professors from the Math and Science department at GateWay Community College established a content validity of this assessment with an overall mean CVR of 1.0. Reliability has not yet been established for this instrument.

Research Questions

The purpose of this study was two-fold. The first goal was to develop a valid and reliable instrument to measure learning in the specific domain of the biological process of Natural Selection. The second goal was to examine the role of prior knowledge, gender and religious beliefs on the effectiveness of learning and collaboration. Four research questions were analyzed:

1. Does the quality of collaboration have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?
2. In a collaborative setting, does the difference in prior knowledge increase learning concepts about Natural Selection at the individual level and/or at the group level?
3. In a collaborative setting, does sex have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?
4. In a collaborative setting, do religious beliefs have an effect on learning concepts about Natural Selection at the individual level and/or at the group level?

Data Analysis

In this dissertation, learning was defined by a difference of scores on assessments. Each research question was examined at two levels, learning at the individual level and the group level. The individual level was measured using two assessments. The first assessment was the CINS, developed by a science education researcher and used in many education studies (Anderson, Fisher & Norman, 2002). I developed the second assessment, the Mental Model Task, and it was also used to measure individual learning. The reason I used two assessments was to compare my new assessment, the Mental Model Task, against a tool that has already been established. Group learning is also measured for each research question. This was measured using a collaborative task. Coleman, Brown & Rivkin developed the collaborative task (1997).

Before analyzing the three collaborative input factors (prior knowledge, gender and religious beliefs), I wanted to validate the theoretical framework for this research by confirming that students that participate in collaborative learning will learn more than students that do not collaborate. To test this, I compared students that participated in high quality collaboration versus students that participated in low quality collaboration. To validate the theory, I grouped dyads into two groups: effective collaborators and ineffective collaborators. Using an ANOVA model, I was able to compare the two groups to answer the first research question: Does the quality of collaboration have an effect on learning concepts about Natural Selection at the individual level and/or at the group level? To detect a difference in learning between the two groups at the individual level, I

performed an ANCOVA using the scores from the CINS and the Mental Model Task, using the pretests for the covariate. In addition, I created a Mental Model Profile by graphing the mean scores from the Mental Model Task from the three days. This profile allowed me to observe the pattern of how the participant's mental models changed while undergoing the intervention. Then I performed an ANOVA on the scores from the collaborative problem to detect a difference in learning between effective collaborators versus ineffective collaborators at the group level.

The theoretical framework for this dissertation was based on the theory that collaboration evokes learning. The goal of this research is to identify which factor(s) is(are) responsible for enhancing learning. To answer research questions 2, 3 and 4, I attempted to analyze the relationship between three collaborative factors and learning in a collaborative setting, at the individual level as well as the group level.

Question 2 pertained to prior knowledge. Specifically, the question was: Does the difference in prior knowledge increase learning concepts about Natural Selection at the individual level and/or at the group level? The prediction for this question was based on theories constructed from research pertaining to heterogeneous groups and the beneficial effects of controversy and/or argumentation during learning. The prediction was that dyads with dissimilar prior knowledge would perform better on the assessments. To analyze the relationship between prior knowledge and collaborative learning, each dyad was placed into one of the two groups, either a similar prior knowledge group or a

dissimilar prior knowledge group. I used an ANCOVA model to detect any learning differences based on prior knowledge differences. For the ANCOVA, I used the scores from the CINS and the Mental Model Task, using the pre-test scores as the covariate. Also, I created a Mental Model Profile by graphing the mean scores from the Mental Model Task from the three days to observe the pattern of mental model change. Lastly, to detect any learning differences at the group level, I performed an ANOVA using the collaborative problem scores.

The third research question pertained to gender differences. The question was: In a collaborative setting, does gender have an effect on learning concepts about Natural Selection at the individual level and/or at the group level? From the literature, it was difficult to predict the outcome. In Woolley's study (2010), groups with females outperformed groups with males. She attributed this to the theory that females were more socially sensitive. However, other studies, such as Baker's study, groups with males outperformed groups with females. Baker attributed this to a disadvantage to females when in a predominantly male field (2007). To answer this question I used an ANCOVA model to compare females and males. To detect if there was a difference in learning at the individual level, I used the scores from posttest on the CINS and the Mental Model Task, with the scores on the pretest for the covariate. I also created a Mental Model Profile by graphing the mean scores from the Mental Model Task from the three days. This profile allowed me to observe the pattern of how the participant's mental models changed while undergoing the intervention. To detect if there was a difference in

learning at the group level, I used the scores from the collaborative problem-solving task.

The last research question pertained to religious beliefs of the collaborators. The question was: In a collaborative setting, do religious beliefs have an effect on learning concepts about Natural Selection at the individual level and/or at the group level? At the individual level I specifically analyzed the effect of the acceptance or rejection of evolution on learning complex content pertaining to the process of Natural Selection. To do this, I performed an ANCOVA using the scores from the CINS and the Mental Model Task, with the pretests as the covariate. In addition, I created a Mental Model Profile by graphing the mean scores from the Mental Model Task from the three days. This profile allowed me to observe the pattern of how the participant's mental models changed while undergoing the intervention. Finally, to analyze the effect of religious beliefs on group composition, I grouped participants into different combinations based on their religious beliefs. To analyze the effect of differences or similarities in religious beliefs in a collaborative setting, I performed an ANOVA using the scores from the collaborative problem-solving task to detect any differences between the groups.

CHAPTER 4 RESULTS AND CONCLUSIONS

This chapter presents the quantitative analysis of the study in an attempt to examine the relationship between collaborative factors and learning the biological process of Natural Selection in a collaborative setting. In my study, learning is defined by a difference in scores on assessments. The measurement strategies and experimental approach to answer the research questions were described in Chapter 3. This chapter will focus on presenting the data. This dissertation is based on the theory that students who learn interactively have an advantage compared to students who learn alone. To verify this assumption, the first analysis was an analysis on the quality of collaboration. Following this, I analyzed three different collaborative factors (prior knowledge, gender and religious beliefs) to measure if they had a positive effect on learning. Each analysis investigated learning at two levels, the individual level and at the group level. The Statistical Package for the Social Sciences (SPSS) was used to do the data analysis. The assessment at the individual level was performed using two measurement tools, a Conceptual Inventory of Natural Selection (CINS) developed by (Anderson et al., 2002) and a Mental Model Task developed by me. The assessment at the group level was performed using a problem-solving task developed by (Coleman et al., 1997). Chapter 5 will analyze the meaning of these findings for the broader study in collaborative learning in science education.

Quality of Collaboration and Collaborative Learning

Individual Level

A one-way analysis of covariance (ANCOVA) was conducted to evaluate the relationship between the quality of collaboration and individual learning. The independent variable, the quality of collaboration, included two levels: effective and ineffective. Each dyad was placed into one of the two groups. Dyads were placed into the effective group based on the following three criteria: 1) they had to collaborate for at least 20 min, 2) both collaborators had to agree that both contributed equally to the content of the problem and 3) the dyad had to display equal contribution and collaborative discourse, observed by the instructor and the researcher. The dependent variable was the post-test score on the CINS and the covariate was the pre-test score on the CINS. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,138) = 1.69$, $MSE = 128.73$, $p = .195$, partial $n^2 = .012$. The ANCOVA was not-significant, $F(1,139) = 2.35$, $MSE = 129.37$, $p = .128$ (Figure 4.1). Sample size, as well as means and standard deviations are reported in Table 4.1.

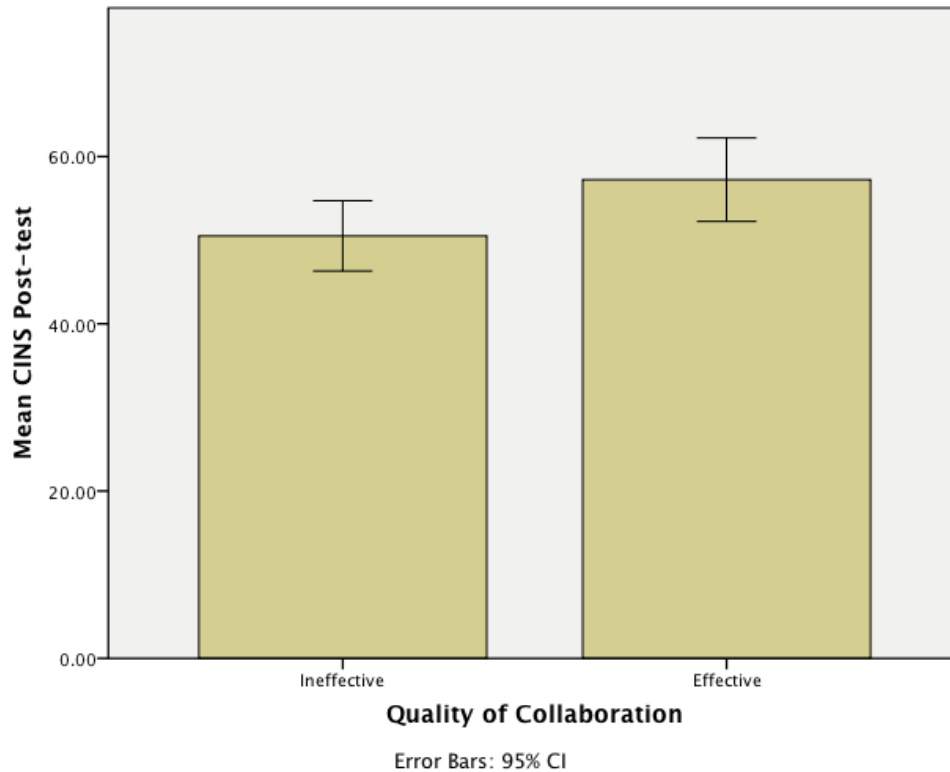


Figure 4.1. Mean Post Test scores on CINS for ineffective and effective dyads.

Table 4.1

Descriptive Statistics for the scores on the CINS for the two groups

Group	N	Mean	SD
Effective	73	57.22	21.52
Ineffective	69	50.51	17.36

In a second analysis at the individual level, an ANCOVA was performed to evaluate the results from the Mental Model Task. In this case the dependent variable was the Mental Model Task z -score taken on the last day of the experiment. This score was calculated by computing the Pearson's correlation (r) between each individual mental model aligned with the expert mental model. The sampling distribution of Pearson's r is not normally distributed; therefore the statistic was transformed to Fisher's z . This converts Pearson's r to the normally

distributed variable z . The covariate was the z -scores calculated from the Mental Model Task taken on the first day of the experiment. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,138) = .154$, $MSE = .027$, $p = .695$, partial $\eta^2 = .001$. Similar to the CINS results, the ANCOVA was not-significant, $F(1,139) = 2.97$, $MSE = .027$, $p = .087$ (Figure 4.2). Sample sizes, as well as means and standard deviations are reported in Table 4.2.

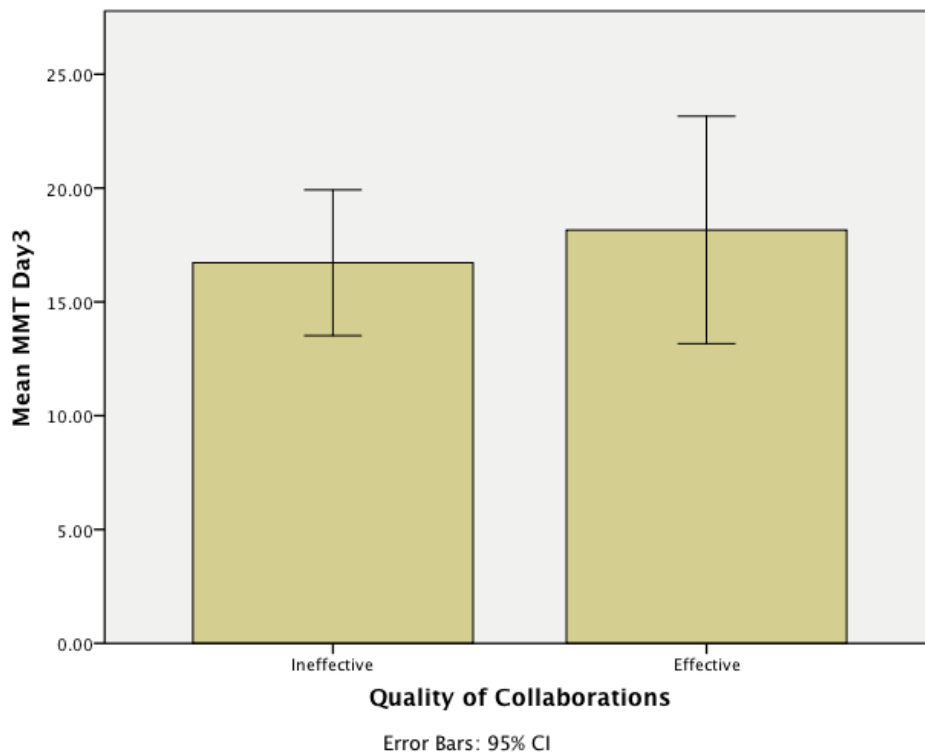


Figure 4.2. Mean Test scores on the Mental Model Task for ineffective and effective dyads.

Table 4.2

Descriptive Statistics for scores on the Mental Model Task for the two groups

Group	N	Mean	SD
Effective	73	18.16	20.63
Ineffective	69	16.72	13.81

A Mental Model Profile was created to analyze the data from the Mental Model Task. Of specific interest was the pattern of learning determined by the changes in the mental model of the participants. Data points were taken on three separate days to track changes in mental models as students participated in the intervention. Correlations (r) were calculated between each participant mental model to an expert mental model. To normalize the data, the statistic r was transformed into a Fisher's z . To create the profile, mean z scores were graphed for both groups (effective collaborators and ineffective collaborators) for Day1, Day2, and Day3 (Figure 4.3). For Day 1, the total mean for z scores was 14.77 with a standard deviation of 8.5. For Day 2, $M = 14.02$ and $SD = 8.7$. For Day 3, $M = 17.40$ and $SD = 17.3$.

To compare groups, the slope (m) was calculated for each group to represent the learning trend between each time point. Specifically, slopes represent the change in correlation between the participant mental models compared to the expert mental model. Between Day1 and Day2, the trend for the effective group ($m = -0.87$) and the ineffective group ($m = -0.64$) had a decrease in learning. Between Day2 and Day3, both groups had an increase in the learning trend. Although not significant, the effective group trended higher ($m = 4.46$) compared to the ineffective group ($m = 2.19$).

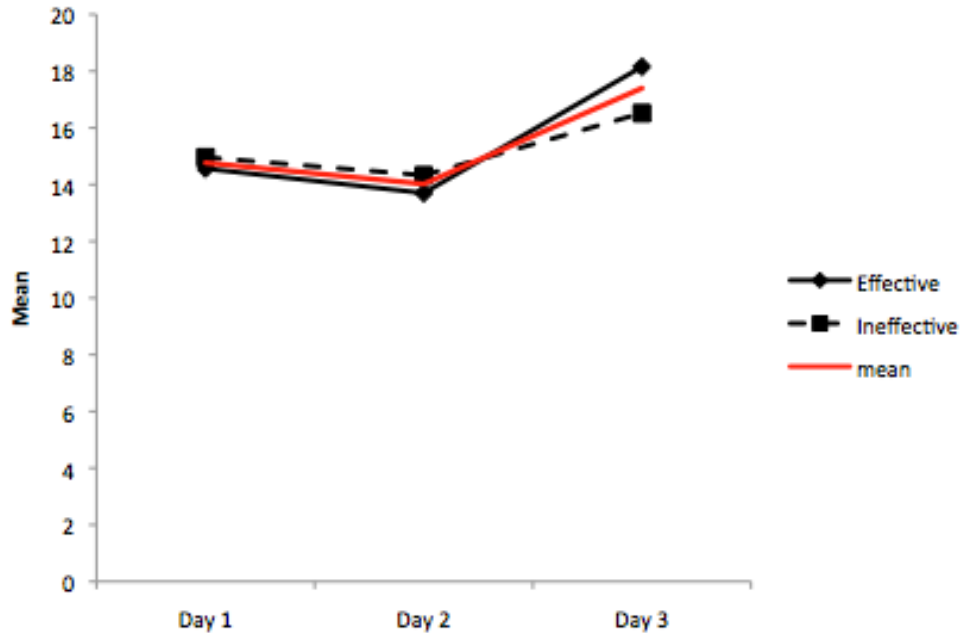


Figure 3.3. Mental Model Profile was created using the mean z scores for Day1, Day2 and Day 3 from the Mental Model Task for ineffective and effective dyads.

Group Level

A one-way analysis of variance (ANOVA) was conducted to evaluate the relationship between the quality of collaboration and learning at the group level. The independent variable, the quality of collaboration, included two levels: effective and ineffective. The dependent variable was the score from the problem-solving task collaboratively performed by each dyad. The ANOVA was significant, $F(1,140) = 37.5$, $MSE = 391.44$, $p = .000$, (Figure 4.4). The strength of relationship between the quality of collaboration and the score on the collaborative task, assessed by η^2 , was strong, with the quality of collaboration accounting for 21% of the variance of the dependent variable. Sample sizes, means and standard deviations are reported in Table 4.3.

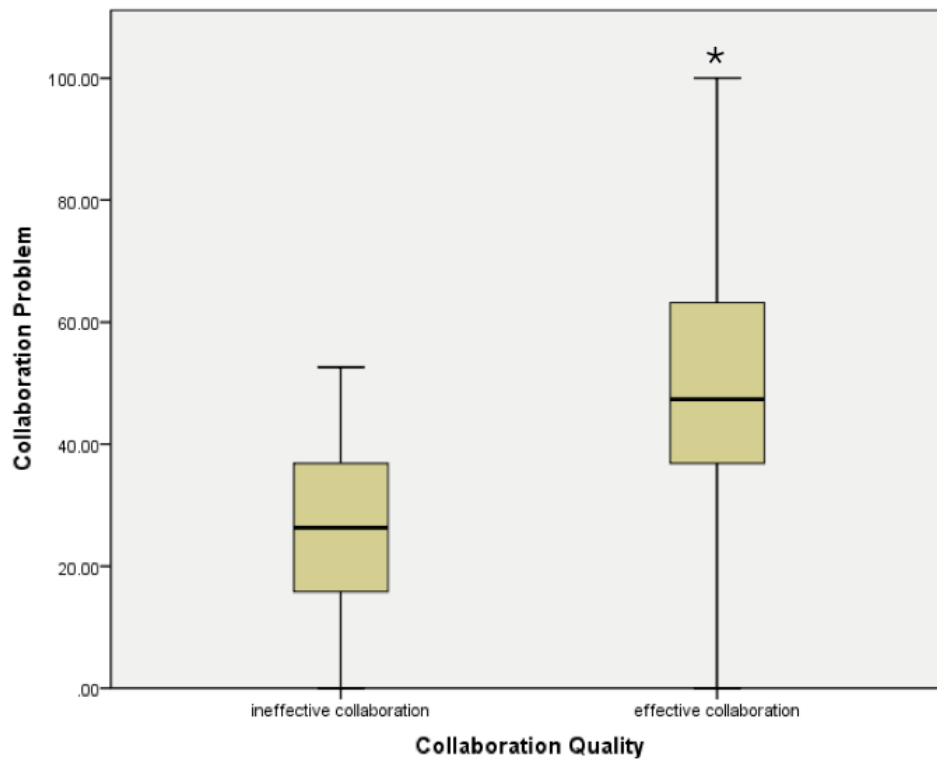


Figure 4.4. Collaborative problem scores between ineffective groups versus effective groups.

Table 4.3

Descriptive Statistics for the scores on the Group Learning Assessment for the two groups

Group	N	Mean	SD
Effective	73	48.95	20.95
Ineffective	69	28.60	15.75

In conclusion, individual learning is unaffected by the quality of collaboration. However, the quality of collaboration does affect the learning outcome at the group level. In other words, if the collaboration is effective then the group outcome is increased.

Prior Knowledge and Collaborative Learning

Individual Level

An ANCOVA was conducted to evaluate the relationship between the similarity in prior knowledge between collaborators and their individual learning. The independent variable, prior knowledge similarity, included two levels: similar mental models between collaborators or dissimilar mental models between collaborators. The similarity in prior knowledge between collaborators was determined by using the information from the Mental Model Task on Day 2. I was able to correlate mental models between participants to determine if a dyad contained significantly correlated mental models putting them into the similar prior knowledge group or if a dyad contained non-significantly correlated mental models, putting them into the dissimilar prior knowledge group. The dependent variable was the post-test score on the CINS with the covariate being the pre-test score on the CINS. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,138) = 1.01$, $MSE = 131.24$, $p = .315$, partial $n^2 = .007$. The ANCOVA was not-significant, $F(1,139) = .319$, $MSE = 131.25$, $p = .573$, partial $n^2 = .002$ (Figure 4.5). The descriptive statistics are reported in Table 4.4.

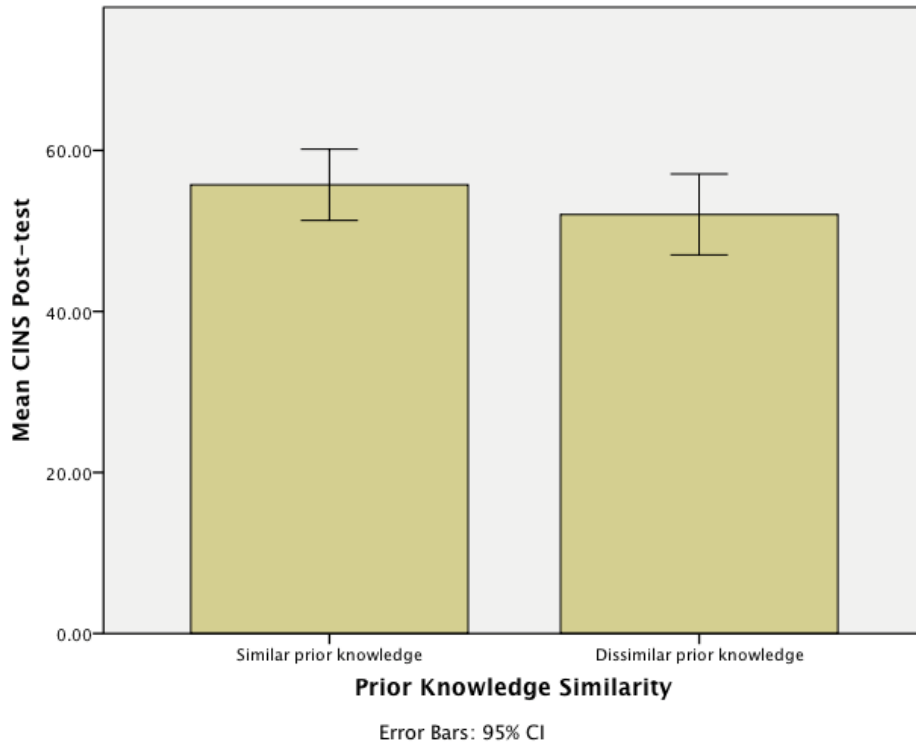


Figure 4.5. Mean Post Test scores on CINS for participants in a dyad with similar prior knowledge and participants in a dyad with dissimilar prior knowledge.

Table 4.4

Descriptive Statistics for the scores on the CINS for the two groups

Group	N	Mean	SD
Similar Prior Knowledge	76	55.72	19.33
Dissimilar Prior Knowledge	66	52.04	20.41

In a second analysis at the individual level, an ANCOVA was performed to evaluate the results from the Mental Model Task. In this case the dependent variable was the Mental Model Task z -score taken on the last day of the experiment. This score was calculated by computing the Pearson's correlation (r) between each individual mental model aligned with the expert mental model. Then, transforming the Pearson's r to the normally distributed variable z . The covariate was the z -score calculated from the Mental Model Task taken on the

first day of the experiment. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,138) = .007$, $MSE = .028$, $p = .933$, partial $n^2 = .001$. Similar to the CINS results, the ANCOVA was not-significant, $F(1,139) = .047$, $MSE = .028$, $p = .829$, partial $n^2 = .00$ (Figure 4.6). Sample sizes, as well as means and standard deviations are reported in Table 4.5.

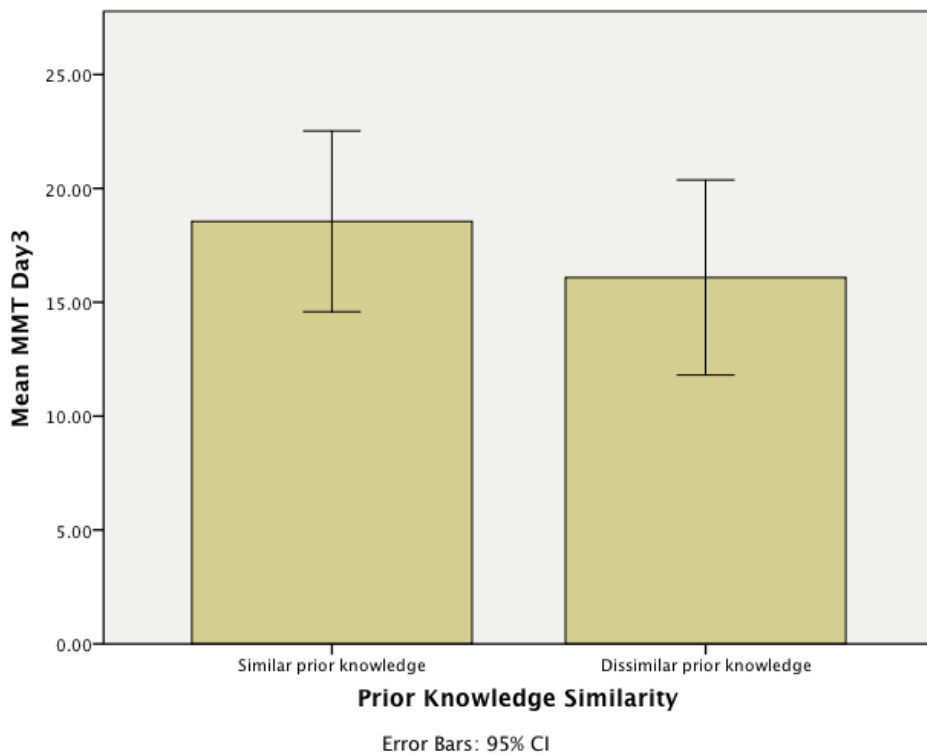


Figure 4.6. Mean z scores from the Mental Model Task for participants in a dyad with similar prior knowledge and participants in a dyad with dissimilar prior knowledge.

Table 4.5

Descriptive Statistics for the scores on the Mental Model Task for the two groups

Group	N	Mean	SD
Similar Prior Knowledge	76	18.55	16.91
Dissimilar Prior Knowledge	66	16.08	17.12

A Mental Model Profile was created to analyze the data from the Mental Model Task. Of specific interest was the pattern of learning determined by the changes in the mental model of the participants. Data points were taken on three separate days to track changes in mental models as students participated in the intervention. Correlations (r) were calculated between each participant mental model to an expert mental model. To normalize the data, the statistic r was transformed into a Fisher's z . To create the profile, mean z scores were graphed for both groups (similar prior knowledge and dissimilar prior knowledge) for Day1, Day2, and Day3 (Figure 4.7). For Day 1, the total mean for z scores was 14.77 with a standard deviation of 8.5. For Day 2, $M = 14.02$ and $SD = 8.7$. For Day 3, $M = 17.40$ and $SD = 17.3$.

To compare groups, the slope (m) was calculated for each group to represent the learning trend between each time point. Specifically, slopes represent the change in correlation between the participant mental models compared to the expert mental model. Between Day1 and Day2, the trend for the similar prior knowledge group ($m = 0.13$) slightly increased where the dissimilar prior knowledge group ($m = -1.74$) decreased. Between Day2 and Day3, both groups had an increase in the learning trend, although not significant. The dissimilar group had the larger slope ($m = 5.18$) and the similar group had the smaller slope ($m = 1.81$).

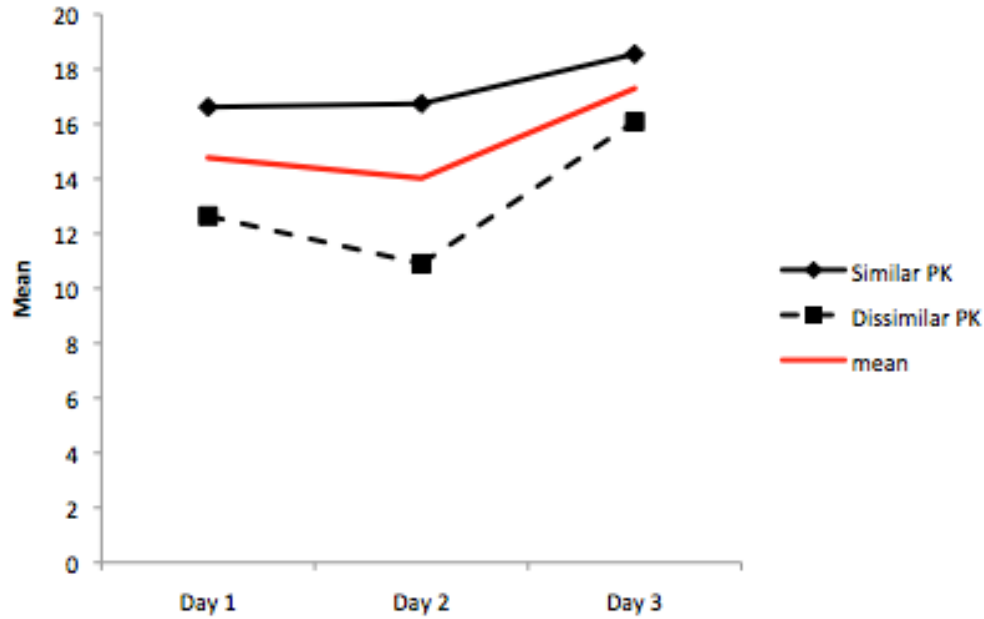


Figure 4.7. Mean z scores from the Mental Model Task for collaborators with similar prior knowledge and dissimilar prior knowledge.

Group Level

An ANOVA was conducted to evaluate the relationship between similarity in prior knowledge and learning at the group level. The independent variable, prior knowledge similarity, included two levels: similar mental models and dissimilar mental models. The dependent variable was the score from the problem-solving task collaboratively performed by each dyad. The ANOVA was not significant, $F(1,140) = .188$, $MSE = 495.7$, $p = .66$, partial $n^2 = .001$ (Figure 4.8). Sample sizes, means and standard deviations are reported in Table 4.6.

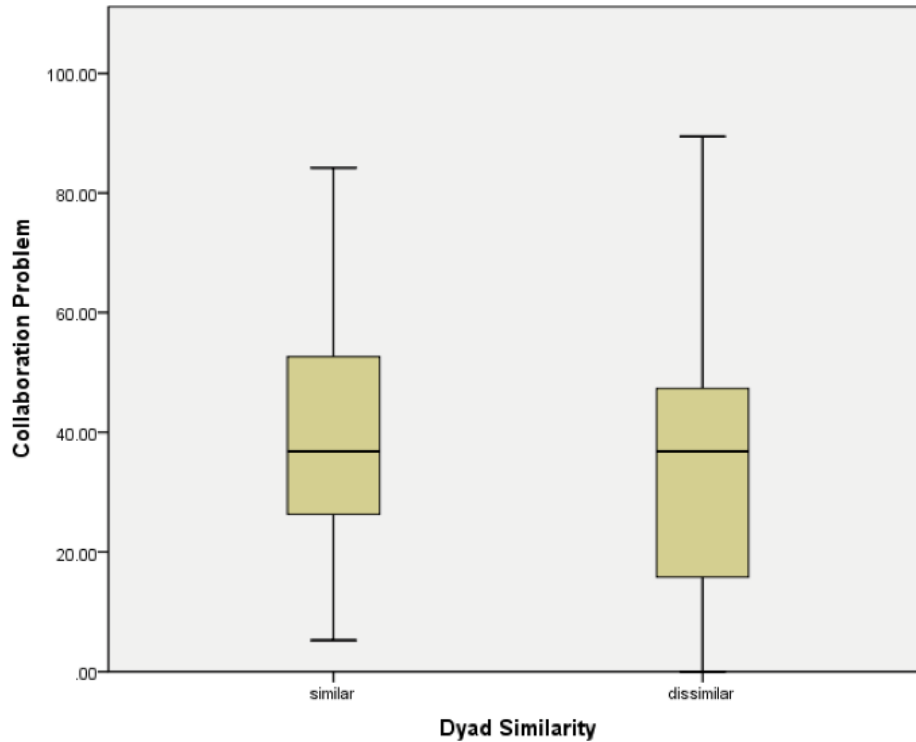


Figure 4.8. Collaborative problem scores for dyads with similar prior knowledge and dyads with dissimilar knowledge.

Table 4.6

Descriptive Statistics for the scores on the Group Learning Assessment for the two groups

Group	N	Mean	SD
Similar Prior Knowledge	76	39.82	20.01
Dissimilar Prior Knowledge	66	38.19	24.60

In conclusion, similarity in prior knowledge does not play a role in learning at the individual level or at the group level. Therefore, we can conclude that grouping students based on prior knowledge similarity will not have an effect on learning.

Sex and Collaborative Learning

There was a higher proportion of males in the upper division course, 26 of the total 53 that participated (49%), and only 16 of the total 89 females in the study (18%), (Figure 3.7). The other six lower-division courses combined contained 51% of the males and 82% of the females (Figure 3.8).

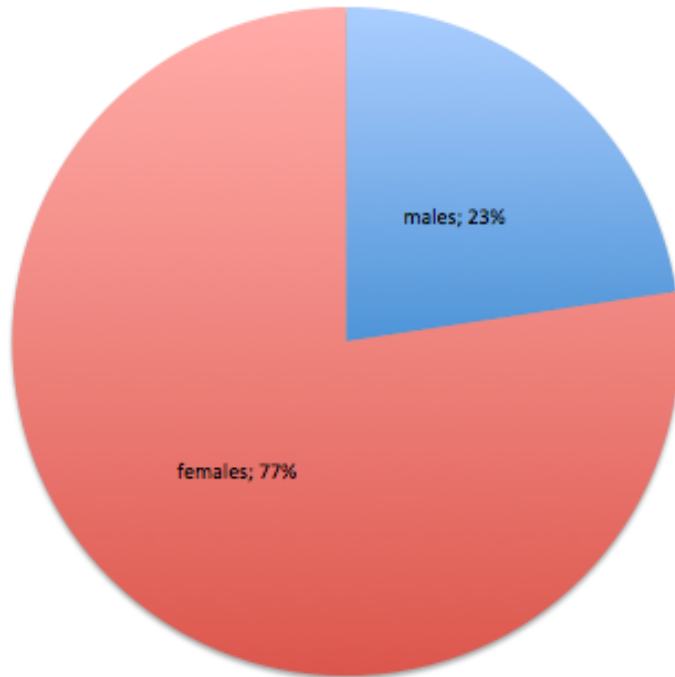


Figure 4.9 Male/Female ratio for pre-nursing courses: BIO156, BIO202 and BIO205

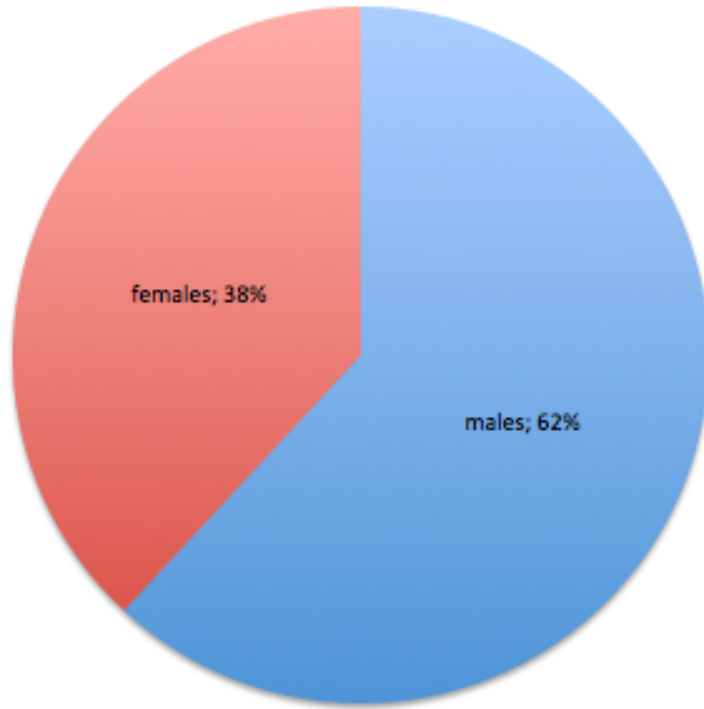


Figure 4.10 Male/Female ratio for upper division biology course: BIO440

Individual Level

An ANCOVA was conducted to evaluate the relationship between sex and individual learning. The independent variable, sex, included two levels: male and female. The dependent variable was the post-test score on the CINS and the covariate was the pre-test score on the CINS. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,138) = .019$, $MSE = 128.49$, $p = .891$, partial $n^2 = .001$. The ANCOVA was significant, $F(1,139) = 4.33$, $MSE = 127.58$, $p = .039$, partial $n^2 = .03$ (Figure 4.11). Males had the larger mean compared to females; the descriptive statistics are reported in Table 3.7.

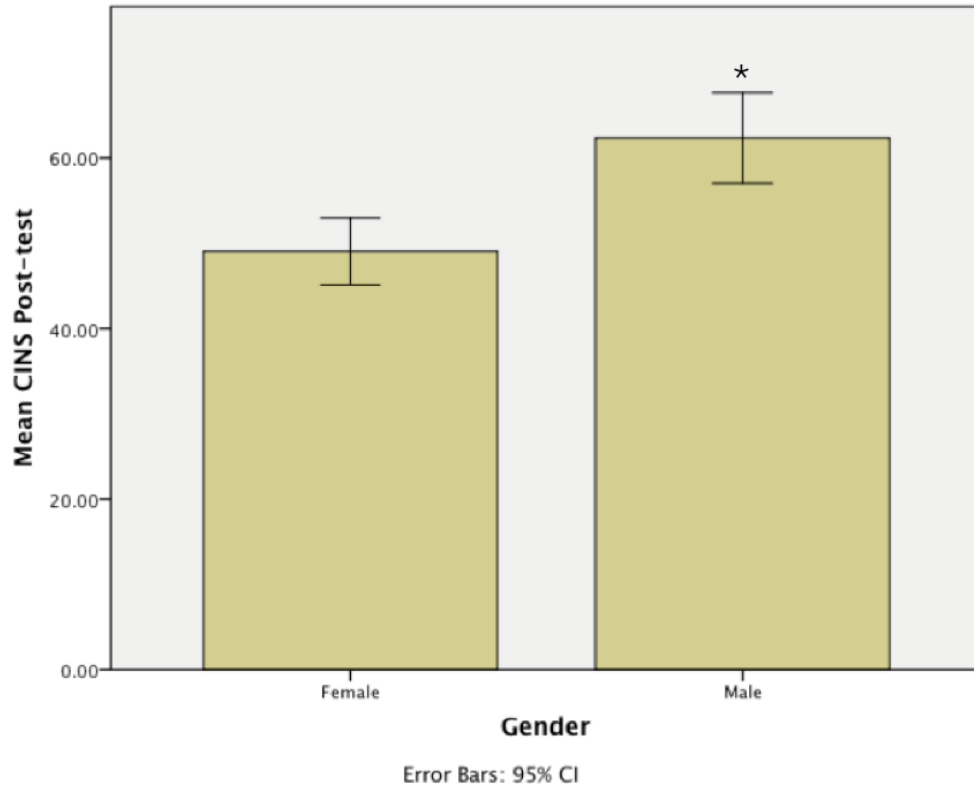


Figure 4.11. Mean Pre and Post Test scores on CINS for females and males.

Table 4.7

Descriptive Statistics for scores on the CINS for the two groups

Group	N	Mean	SD
Males	53	62.36	19.23
Females	89	49.04	18.61

In a second analysis at the individual level, an ANCOVA was performed to evaluate the results from the Mental Model Task. In this case the dependent variable was the Mental Model Task z -score taken on the last day of the experiment. This score was calculated by transforming the Pearson's correlation (r) to Fisher's z . The covariate was the z -score calculated from the Mental Model Task taken on the first day of the experiment. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the

covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(1,138) = .002$, $MSE = .028$, $p = .968$, partial $n^2 = .001$. This analysis differed from the CINS results, the ANCOVA was not-significant, $F(1,139) = .043$, $MSE = .028$, $p = .836$, partial $n^2 = .001$ (Figure 4.12). The means on the last day were the same for males and female. Sample sizes, as well as means and standard deviations are reported in Table 4.8.

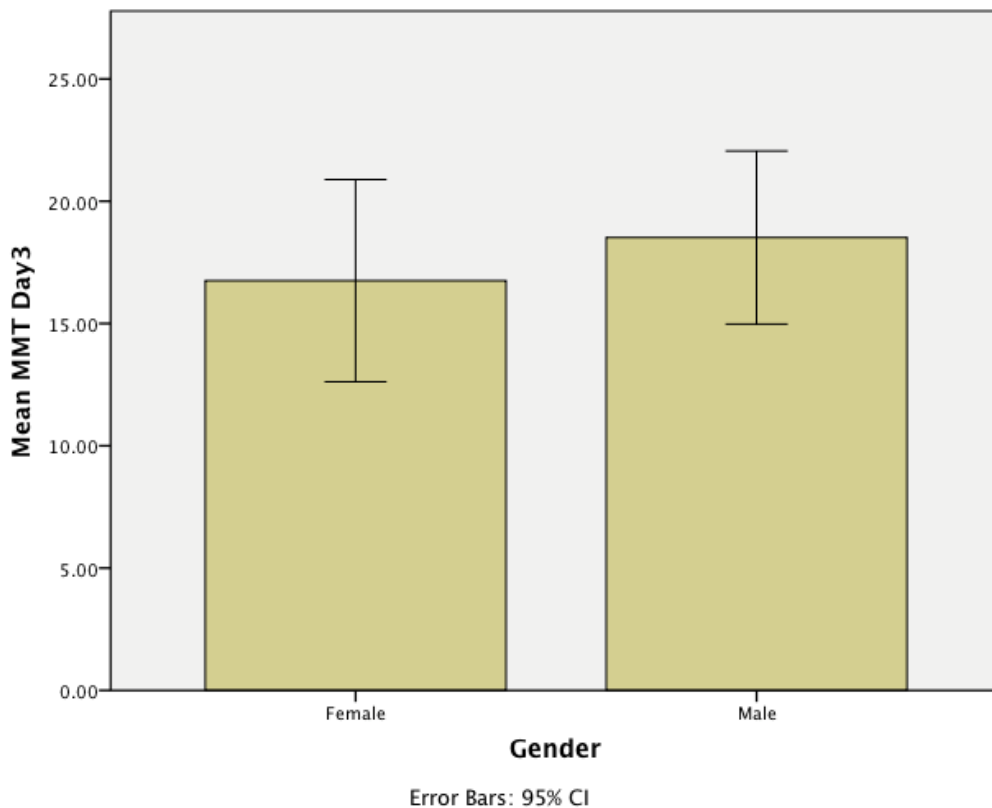


Figure 4.12. Mean z scores from the Mental Model Task for sex.

Table 4.8

Descriptive Statistics for the scores on the Mental Model Task for the two groups

Group	N	Mean	SD
Males	53	18.51	15.40
Females	89	16.74	18.21

A Mental Model Profile was created to analyze the data from the Mental Model Task. Of specific interest was the pattern of learning determined by the changes in the mental model of the participants. Data points were taken on three separate days to track changes in mental models as students participated in the intervention. Correlations (r) were calculated between each participant mental model to an expert mental model. To normalize the data, the statistic r was transformed into a Fisher's z . To create the profile, mean z scores were graphed for both groups (males and females) for Day1, Day2, and Day3 (Figure 4.13). For Day 1, the total mean for z scores was 14.77 with a standard deviation of 8.5. For Day 2, $M = 14.02$ and $SD = 8.7$. For Day 3, $M = 17.40$ and $SD = 17.3$.

To compare groups, the slope (m) was calculated for each group to represent the learning trend between each time point. Specifically, slopes represent the change in correlation between the participant mental models compared to the expert mental model. Between Day1 and Day2, the trend for the males ($m = -0.35$), and the females ($m = -0.97$) had a slight decrease in learning. Between Day2 and Day3, all both groups had an increase in the learning trend. Although not significant, females had the larger slope ($m = 3.88$) and males had

the smaller slope ($m = 2.53$).

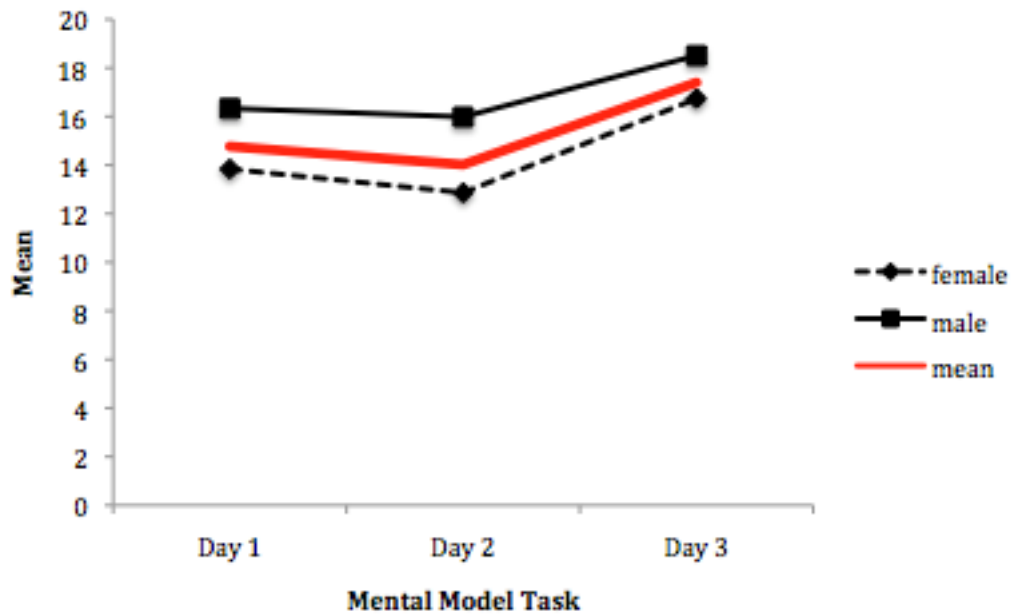


Figure 4.13. Mean z scores from the Mental Model Task for females and males.

Group Level

An ANOVA was conducted to evaluate the relationship between group composition based on gender and learning at the group level. The independent variable, group composition, included three levels: male-male, female-female and male-female. The dependent variable was the score from the problem-solving task collaboratively performed by each dyad. The ANOVA was not significant, $F(1,149) = .1.79$, $MSE = 487.36$, $p = .170$, partial $\eta^2 = .025$ (Figure 4.14). Sample sizes, means and standard deviations are reported in Table 4.9.

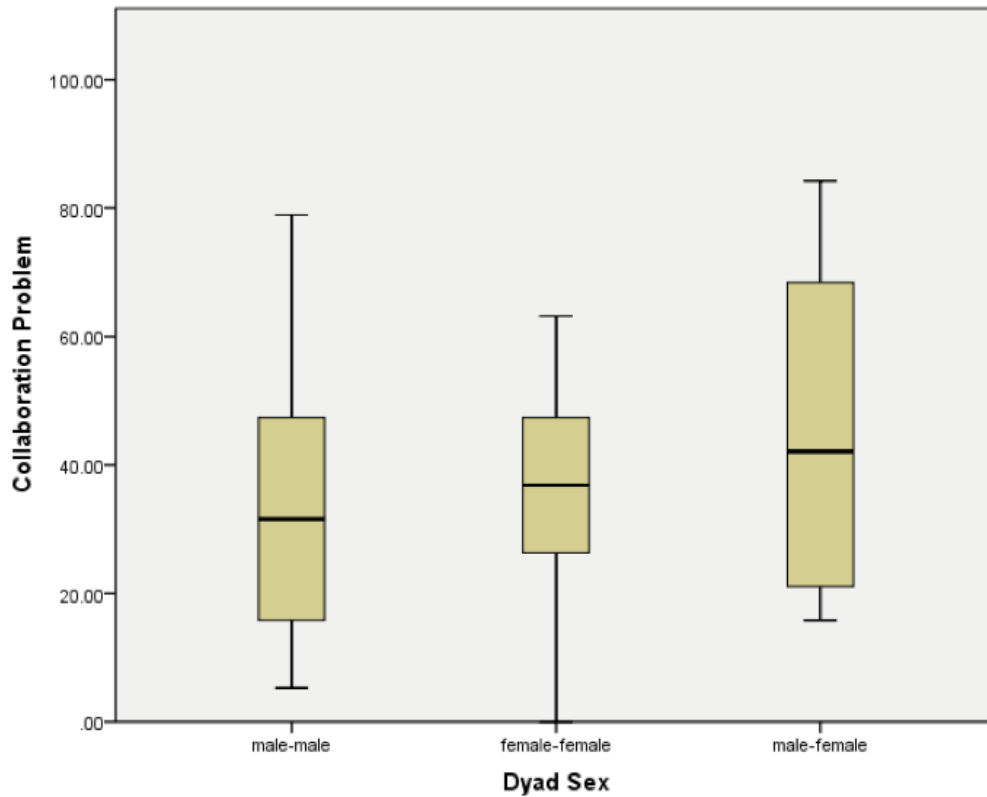


Figure 4.14 Collaborative problem scores for male-male dyads, female-female dyads and male-female dyads.

Table 4.9

Descriptive Statistics for the scores for the Group Learning Assessment for the three groups

Group	N	Mean	SD
Male-Male	20	35.28	19.36
Female-Female	68	40.09	23.57
Male-Female	54	45.79	23.66

From this analysis, it is difficult to assess the effect of sex on learning at the individual level because the two individual assessments concluded with different results. The CINS resulted in a significant difference between males and females, with males outperforming the females. The Mental Model Task resulted

with males and females performing similarly but females showing a larger learning slope according to the Mental Model Profile. At the group level, there was no significant difference between the groups; therefore it is difficult to determine any advantage to the group composition based on sex.

Religious Beliefs and Collaborative Learning

Individual Level

An ANCOVA was conducted to evaluate the relationship between religious beliefs and individual learning. The independent variable, religious beliefs, included three levels: evolutionist, creationist and blend. Participants who believe that human beings have developed over millions of years from less advanced forms of life without the help of God's guidance were categorized as evolutionists. Students who believe that God created human beings pretty much in their present form were categorized as creationists and students that believe that human beings have developed over millions of years from less advanced forms of life, but God guided this process were categorized as blend. All participants were randomly assigned to dyads. There were six possible combinations of dyads based on individual religious beliefs. The dependent variable was the post-test score on the CINS and the covariate was the pre-test score on the CINS. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(2,136) = .247$, $MSE = 128.3$, $p = .782$, partial $n^2 = .004$. The ANCOVA was significant, $F(2,138) =$

3.038, $MSE = 126.9$, $p = .05$, partial $n^2 = .042$ (Figure 4.15). The evolutionists had the largest mean compared to the blend group and the creationist group. Post hoc analyses to the ANCOVA for the CINS scores consisted of conducting pairwise comparisons to find which belief affected learning most strongly. The evolutionist group produced significantly higher scores on the CINS in comparison with either of the other two groups. The creationist and the blend group were not significantly different from each other. The descriptive statistics are reported in Table 4.10.

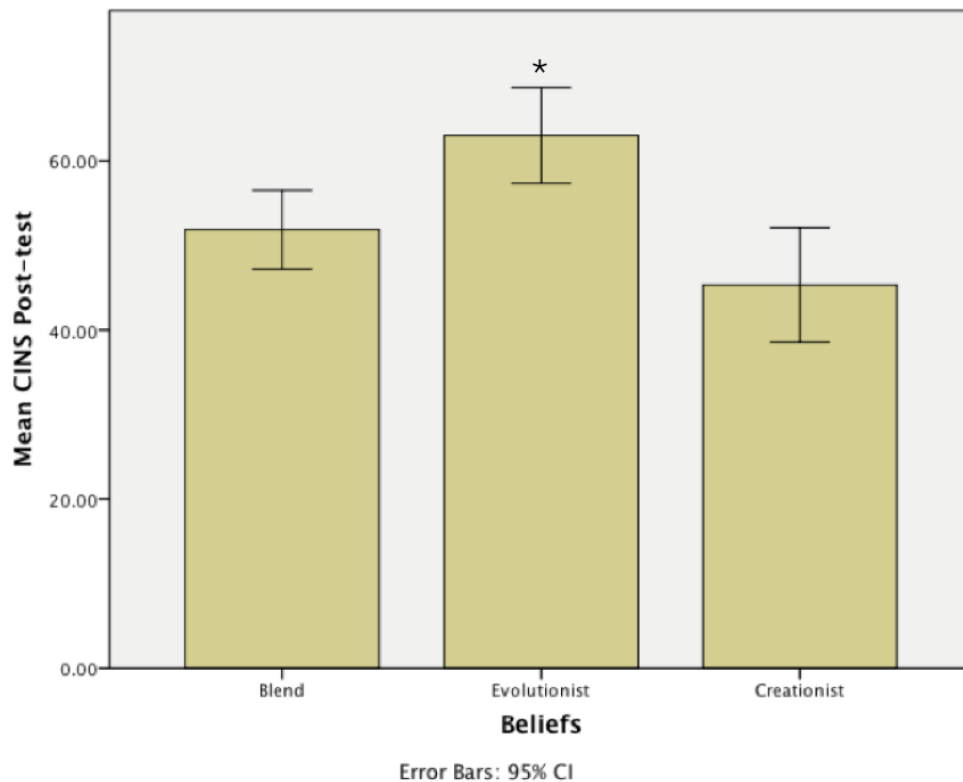


Figure 4.15. Mean Post Test scores on CINS for participants with evolutionist, creationist and blend beliefs.

Table 4.10

Descriptive Statistics for the scores on the CINS for the three groups

Group	N	Mean	SD
Blend beliefs	67	51.86	19.16
Evolutionist beliefs	45	63.00	18.84
Creationist beliefs	30	45.33	18.14

In a second analysis at the individual level, an ANCOVA was performed to evaluate the results from the Mental Model Task. In this case the dependent variable was the Mental Model Task z -score taken on the last day of the experiment. This score was calculated by computing the Pearson's correlation (r) between each individual mental model aligned with the expert mental model. Pearson's r was transformed to the normally distributed variable z . The covariate was the z -score calculated from the Mental Model Task taken on the first day of the experiment. A preliminary analysis evaluating the homogeneity-of-slopes assumption indicated that the relationship between the covariate and the dependent variable did not differ significantly as a function of the independent variable, $F(2,136) = .060$, $MSE = .028$, $p = .942$, partial $n^2 = .001$. Unlike the CINS results, the ANCOVA was not-significant, $F(2,138) = 1.88$, $MSE = .027$, $p = .156$, partial $n^2 = .027$ (Figure 4.16). Post hoc analyses to the ANCOVA for the scores from the Mental Model Task consisted of conducting pairwise comparisons to find which belief affected learning most strongly. The evolutionist group produced significantly higher scores on the Mental Model Task in comparison with either of the other two groups. The creationist and the blend group were not

significantly different from each other. Sample sizes, as well as means and standard deviations are reported in Table 4.11

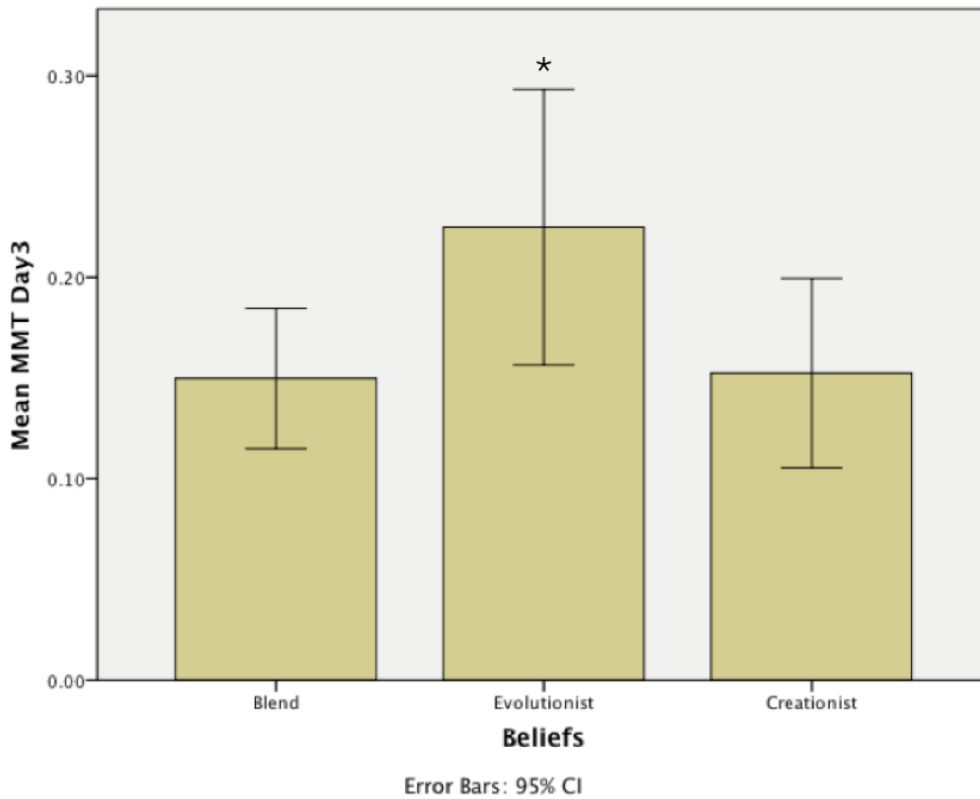


Figure 4.16. Mean z scores from the Mental Model Task for participants with evolutionist, creationist and blend beliefs.

Table 4.11

Descriptive Statistics for the scores on the Mental Model Task for the three groups

Group	N	Mean	SD
Blend beliefs	67	14.97	14.22
Evolutionist beliefs	45	22.48	22.71
Creationist beliefs	30	15.23	12.50

A Mental Model Profile was created to analyze the data from the Mental Model Task. Of specific interest was the pattern of learning determined by the changes in the mental model of the participants. Data points were taken on three

separate days to track changes in mental models as students participated in the intervention. Correlations (r) were calculated between each participant mental model to an expert mental model. To normalize the data, the statistic r was transformed into a Fisher's z . To create the profile, mean z scores were graphed for each group (evolutionists, creationist and the blend group) for Day1, Day2, and Day3 (Figure 4.17). For Day 1, the total mean for z scores was 14.77 with a standard deviation of 8.5. For Day 2, $M = 14.02$ and $SD = 8.7$. For Day 3, $M = 17.40$ and $SD = 17.3$.

To compare groups, the slope (m) was calculated for each group to represent the learning trend between each time point. Specifically, slopes represent the change in correlation between the participant mental models compared to the expert mental model. Between Day1 and Day2, the trend for the blend group ($m = -1.03$), the evolutionist group ($m = -0.52$) and the creationist group ($m = -0.43$) showed no change in mental models. Between Day2 and Day3, all three groups had an increase in the learning trend. Evolutionist had the largest slope ($m = 6.4$), creationists had a smaller slope ($m = 3.45$), and the blend group had the smallest slope ($m = 1.32$). As reported in the previous section, the evolutionists performed significantly higher compared than the creationist and the blend group. The effect size d of .30 indicates a medium effect.

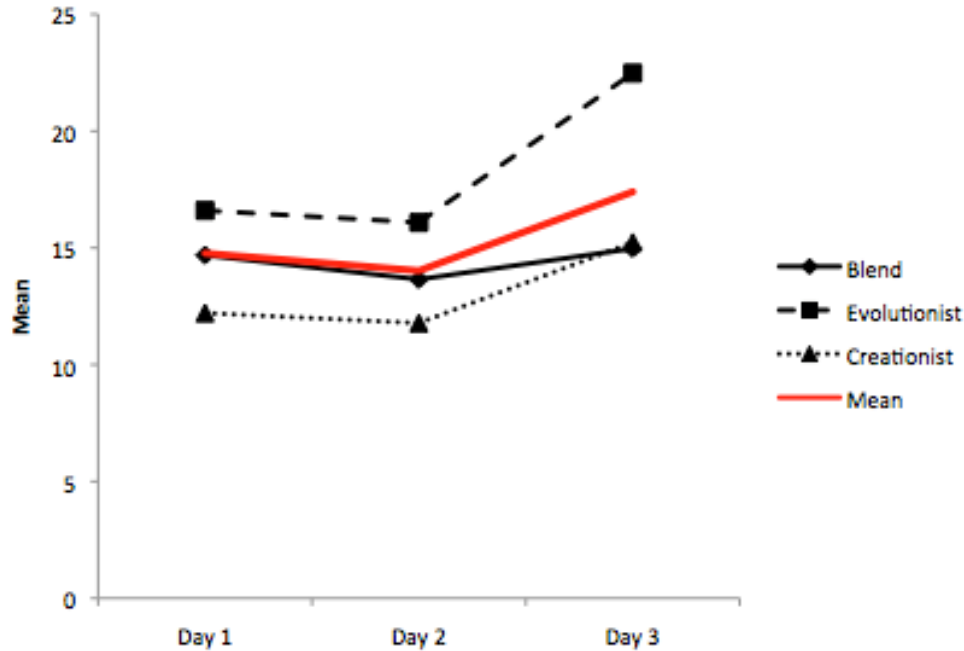


Figure 4.17. Mean z scores from the Mental Model Task for participants with evolutionist, creationist and blend beliefs.

Group Level

An ANOVA was conducted to evaluate the relationship between religious beliefs and learning at the group level, more specifically, the impact of the combination of collaborator's beliefs on collaboration. The independent variable, the combination of religious beliefs, included six levels: evolutionist-evolutionist, creationist-creationist, blend-blend, blend-evolutionist, blend-creationist and evolutionist-creationist. The dependent variable was the score from the problem-solving task collaboratively performed by each dyad. The ANOVA was not significant, $F(5,136) = .620$, $MSE = 499.58$, $p = .685$, partial $n^2 = .022$ (Figure 4.18). Sample sizes, means and standard deviations are reported in Table 4.12.

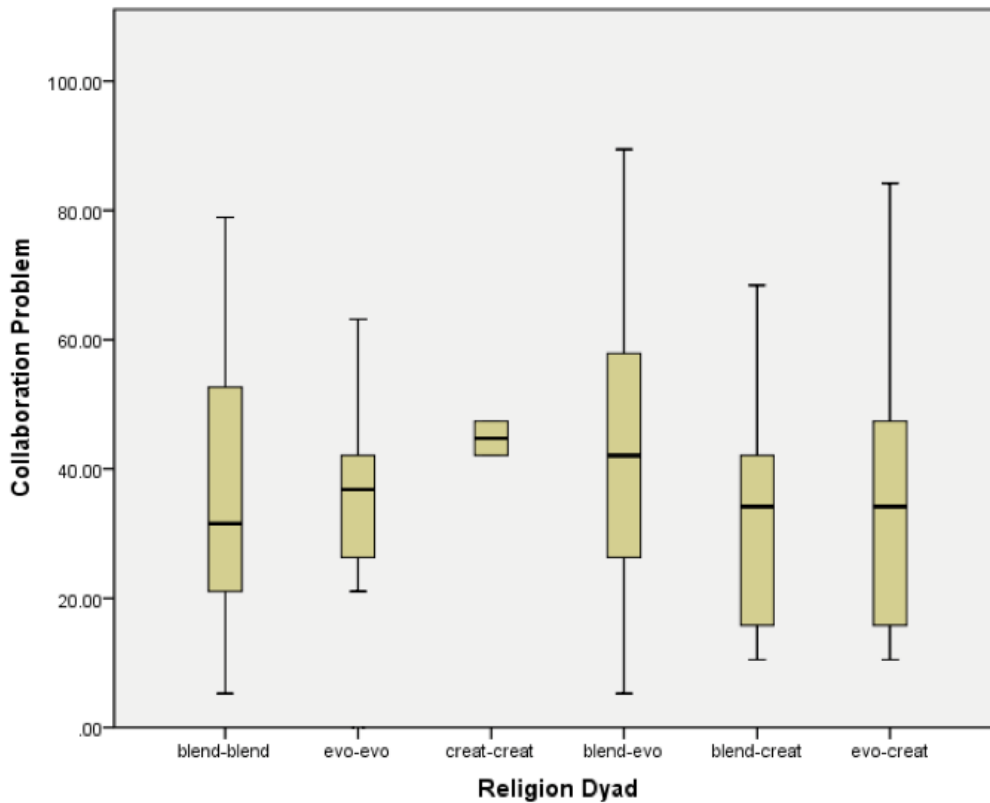


Figure 4.18. Collaborative problem scores for dyads with different combinations of religious beliefs.

Table 4.12

Descriptive Statistics for the scores on the Group Learning Assessment for the six groups

Group	N	Mean	SD
Evolutionist-Evolutionist	18	39.18	25.28
Creationist-Creationist	4	44.75	3.0
Blend-Blend	42	37.84	19.70
Blend-Evolutionist	26	44.12	24.40
Blend-Creationist	24	33.77	16.71
Evolutionist-Creationist	28	39.84	27.08

The sample sizes for the groups were too small so an additional analysis was necessary. An ANOVA was conducted. The independent variable was the

similarity or dissimilarity in religious beliefs and the dependent variable was the score from the problem-solving task. The ANOVA was not significant, $F(1,140) = .040$, $MSE = 496.2$, $p = .841$, partial $n^2 = .00$ (Figure 4.19). Sample sizes, means and standard deviations are reported in Table 4.13.

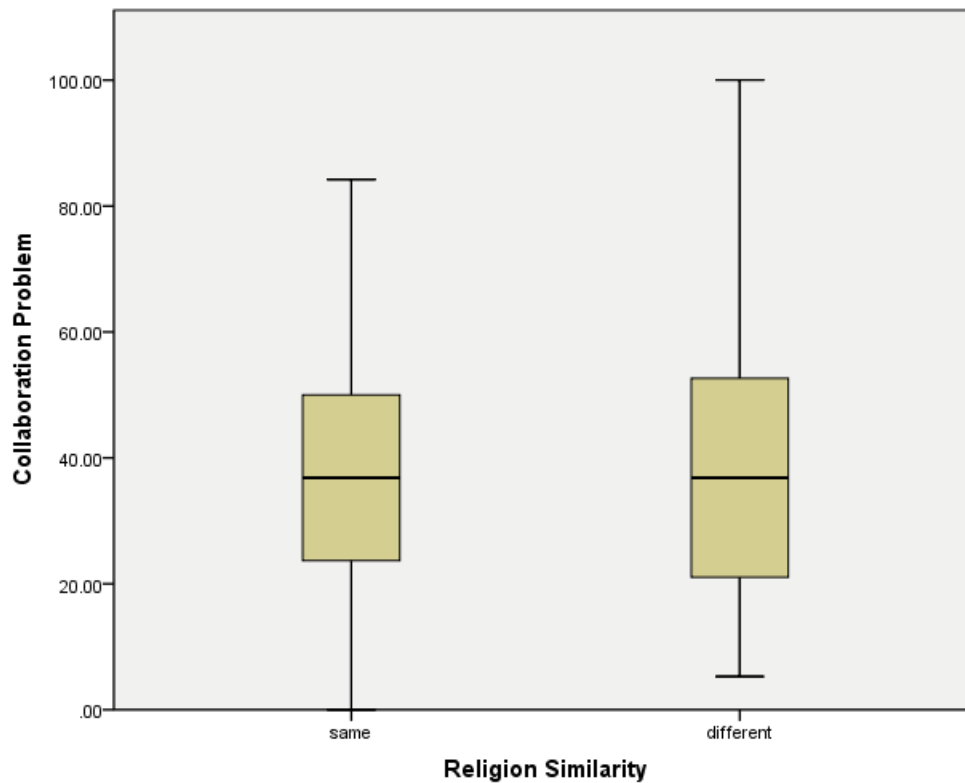


Figure 4.19. Collaborative problem scores for dyads with the same beliefs and dyads with different beliefs.

Table 4.13

Descriptive Statistics for the scores on the Group Learning Assessment for the two groups

Group	N	Mean	SD
Similar Religious Beliefs	64	38.65	20.69
Dissimilar Religious Beliefs	78	39.40	23.48

In conclusion, at the individual level, religious beliefs have an influence on learning about the biological process of Natural Selection as measured by the

CINS. There was a significant difference between students that were categorized as evolutionists compared to creationist and students with a blended belief. The students that were categorized as evolutionists outperformed the other two groups. Further studies are necessary to understand the relationship between religious beliefs and learning about evolution. Furthermore, on the Mental Model task, there was a trend. The evolutionists did better with a higher learning slope, although it was not significant. Lastly, at the group level, there was no significant difference between the groups. Therefore it is difficult to determine any advantage to the group composition based on religious beliefs

CHAPTER 5 DISCUSSION AND IMPLICATIONS

The research in this dissertation was based on the theory that students learn more in a collaborative setting. This theory was tested and validated by numerous studies presented in the education literature (Dolmans & Schmidt, 1996; Ebert-May et al., 1997). However, the analysis in my study suggested that a collaborative setting only benefits students if assessed at the group level. The analysis revealed that on the individual level, students in a high-quality collaboration had similar assessment scores compared to students who participated in a low quality collaboration.

There are researchers who argued that some students do not benefit from participating in a collaborative setting because of a phenomenon called Collaborative Inhibition (Steiner, 1966). These arguments could explain why participants in my study involved with high quality collaboration didn't outperform participants in low quality collaboration on the individual assessments. Firstly, unstructured collaboration does not guarantee improved learning (Dillenbourg, 2002). The theory of Cognitive Overhead of Coordination could cause the inhibition of successful collaboration (Steiner, 1972). In this coordination, collaborators must keep track of multiple pieces of information, including both their partners' ideas and strategies for solving a problem as well as their own. In addition, the collaborators must keep track of turn taking, monitoring and incorporating contributions, which together can use too much cognitive resources inhibiting solving a problem.

Another theory called the Retrieval Strategy Disruption Theory can also explain why collaboration can be non-beneficial (Basden, Basden, Bryner, & Thomas, 1997). This theory posits that each individual learner has his or her own strategy of information retrieval. When working with another, differences in retrieval strategies could be disruptive (Basden, Basden, Bryner, & Thomas, 1997). Lastly, there are two social factors that could negatively influence collaborative success. Williams (1981) described social loafing as a social factor that could hinder successful collaboration. He termed this the Free Rider Hypothesis. This is where individuals contribute less because there are others that can do the work (Nokes, Meade, & Morrow, in review; Williams, 1981). The second social factor that can affect collaborative learning is a difference in power/status. If a collaborator felt superior or inferior, this would affect the amount and type of contributions (Edmondson, 1999).

Relationship between Prior knowledge and Collaborative Learning

Prior knowledge has an effect on collaborative learning (Gijlers & Jong, 2005). Does grouping students based on the differences or similarities in prior knowledge effect collaborative learning? I predicted that students with differing prior knowledge would collaborate longer, and thus, potentially learn more. According to my analysis, this is not the case. The results revealed that similarity or dissimilarity in prior knowledge had no effect on learning when students were in a collaborative setting. Furthermore, there was no correlation between differences in prior knowledge and the length of time in collaboration. This

suggests that differing knowledge does not necessarily lead to more discussion. Therefore, grouping students based on similarity in prior knowledge will most likely not have an effect on student collaborative learning.

Additionally, the results from the Mental Model Profile revealed an interesting pattern (Figure 3.7). For all three days, participants involved in collaboration where they had similar prior knowledge scored above the mean and participants with dissimilar prior knowledge scored below the mean. However, the pattern of learning was different between the two groups. The slope between Day2 and Day3 for the dissimilar group ($n = 5.18$) trended higher, although not significant, than the similar group ($n = 1.81$).

Relationship between Sex and Collaborative Learning

In this dissertation research males were compared to females. Learning was measured as a difference in scores at the individual level as well as the group level. At the individual level, there was a significant difference found between males and females in favor of males, but *only* on the multiple-choice Conceptual Inventory of Natural Selection (CINS) test. This result was not seen on the Mental Model Task. This result can be interpreted one of two ways. The first interpretation is that the males did learn more about natural selection compared to the females and the Mental Model Task was not sensitive enough to detect the difference. This is a logical explanation because of the male/female ratio in the seven courses involved in the study. Of the seven courses, six courses were a lower-division biology courses taught at a community college where one was an

upper-division university biology course. There was a higher proportion of males in the upper division course, 26 of the total 53 that participated (49%), and only 16 of the total 89 females in the study (18%), (Figure 4.9). The other six lower-division courses combined contained 51% of the males and 82% of the females (Figure 4.10). Students in the upper division biology course typically perform higher compared to the lower division courses. This uneven distribution may account for why males outperformed females overall.

Furthermore, this uneven distribution highlights another known phenomenon, that males and females are still separated into male or female dominated fields (Murphy, Steele, & Gross, 2007). Of the six community college courses used in this study, five of them were pre-requisites for a nursing program. In these courses, the majority of the students were females, reflecting that nursing is a female dominated field. The upper division biology course had more males than females; this outcome supports the idea that more males are preparing for a career in science, historically dominated by males (see Figures 5.2 and 5.3). Among many explanations of the unequal distributions of males and females in math and science fields, one is that females are socialized, directly and indirectly, to avoid studies and jobs typically pursued by males (Baker, 1998; Murphy et al., 2007).

Another common sex bias seen in education is that, on average, males score higher on multiple-choice assessments (Murphy, 2011; Walstad & Robson, 1997). For example, on the ACT and SAT, the oldest and most widely used college entrance exams, a gap exists with males outperforming females. This

persists across all other demographic factors, including socio economic status, parental education, grade point average, rank in class, and size of high school (Walstad & Robson, 1997). This is the second interpretation of the result that males scored significantly higher on the CINS and not the Mental Model Task. The Mental Model Task was a format unfamiliar to all participants so it eliminated the assessment advantages that can exist on multiple-choice tests.

Relationship between Religious Beliefs and Collaborative Learning

An interesting finding was the significant difference in scores, on the CINS and the Mental Model Task, with the evolutionist group scoring higher when compared to both the blend group (students who think evolution occurred with God's help) and the creationist group. Because of the contradictions to Christian beliefs, teaching evolution in American schools has become controversial (Lawson & Worsnop, 1992). It is important for students to learn the details of Evolution Theory because the concept sets a foundation for understanding all emergent processes. The question I was trying to answer was: Can students that reject evolution because of Christian beliefs still learn about the biological process of Natural Selection? In the analysis, particularly from the Mental Model Task data, the answer is: yes, students with Christian beliefs can still learn the concept of the evolutionary process of Natural Selection. This is evident from the Mental Model Profile (Figure 3.15), because the creationist group had a positive slope from Day2 to Day3 (Table 5.1). However, the interesting finding is that the evolutionist group started out higher than the two

groups on Day 1 and had the highest slope between Day 2 and Day 3, with a significantly higher mean on Day3. The learning pattern seen in the Mental Model Profile was different compared to the gender profile and the prior knowledge profile. With the gender and prior knowledge groups, the profile pattern was that the group starting below the mean on Day1 had a higher slope between Day2 and Day3.

Table 5.1
Slopes on the Mental Model Profile for the three groups

Group	<i>n</i> (Day1 to Day2)	<i>n</i> (Day2 to Day3)
Blend beliefs	-1.03	1.32
Evolutionist beliefs	-0.52	6.40
Creationist beliefs	-0.43	3.45

This pattern suggests that students that believe that evolution occurred without God’s guidance will enhance comprehension of the difficult topic of the biological mechanism of Natural Selection. A study by Brem and her colleagues provide an explanation (Brem et al., 2003), that evolutionists and creationists differed in their prior exposure to pro- and antievolution sources of information. She concluded that people seek out messages that align with their beliefs. For example, “evolutionists seek out classes, TV shows, internet sites and other outlets that feature proevolution messages, while creationists should do the same for antievolution messages” (Brem, Ranney & Schindel, 2003, pg. 182). This behavior would explain why evolutionists have a more developed mental model pertaining to the topic of evolution. Their prior knowledge will aid in learning more in the classroom.

This study provides the groundwork for further research investigating the role of prior knowledge, gender and religious beliefs as mediators for changes in mental models and comprehension about the biological process of Natural Selection. The long-term goal is to develop a model of the collaboration mechanism that informs both cognitive learning theory and educational practice. Future research involves looking at collaborations in more detail with a qualitative analysis.

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APPENDIX A
DATA COLLECTION TIMELINE

Date	Class	Instructor	Day	Assessments
5-Feb	BIO 205	S. Touchman	1	Survey, Pre-Test and Mental Model Task
5-Feb	BIO 202	J. Ware		
7-Feb	BIO202	J. Ware		
8-Feb	BIO 105	C. Berg		
8-Feb	BIO 156	C. Berg		
8-Feb	BIO 440	J. Touchman		
11-Feb	BIO 156	C. Berg		
12-Feb	BIO205	S. Touchman	2	Read Text and Mental Model Task
12-Feb	BIO 202	J. Ware		
14-Feb	BIO202	J. Ware		
22-Feb	BIO 105	C. Berg		
22-Feb	BIO 156	C. Berg		
15-Feb	BIO 440	J. Touchman		
25-Feb	BIO 156	C. Berg		
5-Mar	BIO 205	S. Touchman	3	Collaborative Task, Posttest and Mental Model Task
5-Mar	BIO 202	J. Ware		
7-Mar	BIO202	J. Ware		
8-Mar	BIO 105	C. Berg		
8-Mar	BIO 156	C. Berg		
8-Mar	BIO 440	J. Touchman		
11-Mar	BIO 156	C. Berg		

APPENDIX B
CONSENT FORM

February 2011

ARIZONA STATE UNIVERSITY

Arizona State University
Department of Education
Tempe, AZ 85282

You are being asked permission to use class materials for research that involves examining how people learn in collaborative situations. We are investigating the topic of collaborative learning in order to further our understanding of its benefits. Your participation in the research study is completely voluntary. Please read the following information carefully. Feel free to ask questions if you do not understand something.

If you participate in this study, you will be asked to solve a problem with another participant. Part of participating in this study will involve you taking a pre and post-test and learning about Natural Selection. The total participation time will be approximately 3 hours of class time. The material and activities involved in this study is not part of the class curriculum and if you agree to participate then the survey, pretest, posttest and collaborative problem will be used as data and will be analyzed. In addition to the opportunity to learn about biological process of Natural Selection you will be entered into a lottery to possibly win a Visa card worth \$50.00.

Any and all information obtained from you during the study will be confidential. Your privacy will be protected at all times. You will not be identified individually in any way as a result of your participation in this research. You will be assigned a random identification number that you will put on the survey and all the assessments. The data collected however, may be used as part of publications and papers related to learning. You must be at least 18 years old to participate.

Your participation in this study is entirely voluntary. You may refuse to participate in this research. Such refusal will not have any effect on your class grade. If you begin to participate in the research, you may at any time, for any reason, discontinue your participation without any negative consequences. Please feel free to ask any questions about anything that seems unclear to you and to consider this research and consent form carefully before you sign.

Participant's signature _____

Name (please print) _____

Date _____

If you have further questions about this research project, please contact the principal investigator, Stephanie Touchman at stephanie.touchman@asu.edu or faculty supervisor Dale Baker at dale.baker@asu.edu. If you have questions about your rights as a research participant or if you have a research related complaint please contact the Arizona State University Office of Research Integrity and Assurance at (480) 965-6788.

APPENDIX C
NATURAL SELECTION TEXT

Evolution by Natural Selection

What is evolution? It is a pattern that emerges through time. And what is the mechanism that produces the pattern we call evolution?

This chapter introduces the mechanism, natural selection, which Darwin declared produces the pattern.

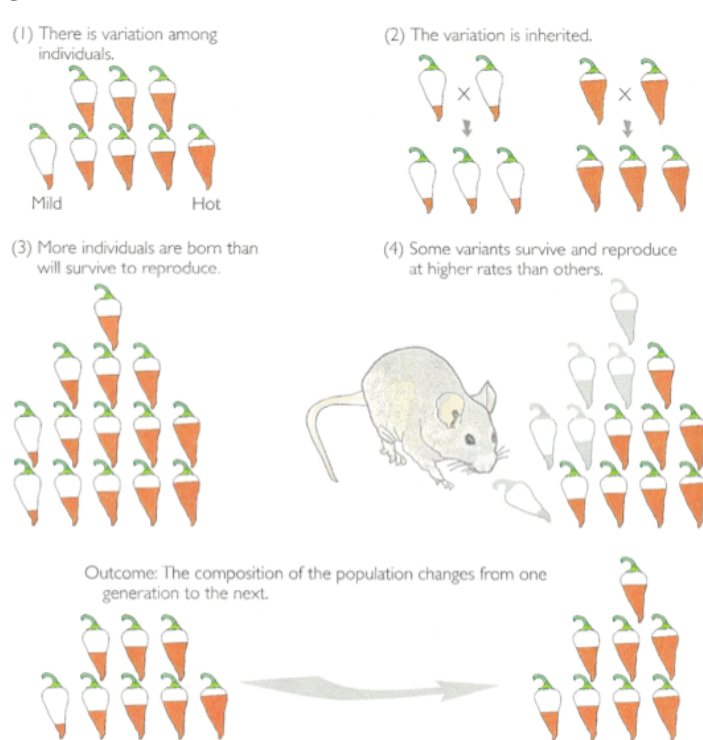
Darwin's Theory of Evolution by Natural Selection states that evolution (descent with modification) is the logical outcome of four principles.

They are:

1. Individuals within populations are variable.
2. The variations among individuals are, at least in part, passed from parents to offspring.
3. In every generation, some individuals are more successful at surviving and reproducing than others, (in other words, some individuals have a higher fitness).
4. The survival and reproduction of individuals are not random; instead they are tied to the variation among individuals. The individuals with the most favorable variations, those who are better at surviving and reproducing, are naturally selected.

If these four principles are true, then the composition of the population changes from one generation to the next. In the figure below it shows how Darwin's theory might play out in a population of chilies eaten by packrats.

Figure 3.1



The logic is straightforward: If there are differences among the individuals in a population that can be passed on to offspring, and if there is differential success among those individuals in surviving and/or reproducing, then some traits will be passed on more frequently than others. As a result, the characteristics of the population will change slightly with each succeeding generation. This is

Darwinian evolution: gradual change in the proportions of groups in a population over time.

Note that while the logic is straightforward it contains a subtlety that can cause confusion. To understand how natural selection works, we have to think statistically. The selection itself -the surviving and reproducing- happens to individuals, but what changes is populations. In the chilies example, Because of the differences in the taste (mild to hot), individuals within the same population varied in their chances of being eaten by a mouse. The hot ones were less likely to be eaten, therefore reproduces more successfully. When they reproduced, they passed their hotness mutation to their offspring. In the next generation, then, there are a higher proportion of chilies carrying the hotness mutation compared to the generation before it. This change in the population is evolution by natural selection.

Darwin referred to the individuals who are better at surviving and reproducing, and whose offspring make up a greater percentage of the population in the next generation, as more fit. In so doing he gave the everyday English words *fit* and *fitness* a new meaning. Darwinian *fitness* is the ability of an individual to survive and reproduce in its environment.

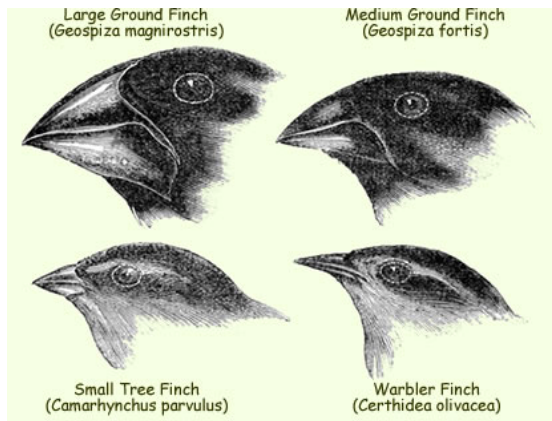
An important aspect of fitness is its relative nature. Fitness refers to how well an individual survives and how many offspring it produces compared to other individuals of its species. Biologists use the word *adaptation* to refer to a trait or characteristic of an organism, like the hotness of the chilies, that increases its fitness relative to individuals without the trait.

In the next section, we examine natural selection by reviewing the evolution of the beaks of the Galapagos finches, a result of a ***change in their environment.***

The Evolution of Beak Shape in Galapagos Finches

Peter Grant and Rosemary Grant have been studying finches in the Galapagos Archipelago since 1973. Collectively, they are called Darwin's finches; the birds are derived from a small flock that invaded the archipelago from Central America some 2.3 million years ago. The descendents of this flock today comprise 13 different species that live in the Galapagos, plus a 14th that lives on Cocos Island. As you can see from the figure below, the finches are similar in size and coloration, however they show remarkable variation in the size and shape of their beaks.

Figure 3.2



The beak is the primary tool used by the birds in feeding, and the enormous range of beak shape of the Galapagos finches reflects the diversity of the foods they eat. The warbler finches feed on insects, spiders, and nectar; woodpecker and mangrove finches use twigs or cactus spines as tools to pry insect larvae or termites from dead wood; several ground finches in the genus *Geospiza* pluck ticks from iguanas and iguanas and tortoises in addition to eating seeds; the vegetarian finch eats leaves and fruits.

The Grants' team focused their observations on the medium ground finches on a little island called Daphne Major. The climate on this island is seasonal even though the location is equatorial. A warmer, wetter season from January through May alternates with a cooler, drier season from June through December. The vegetation consists of dry forest and scrub, with several species of cactus. Few finches migrate onto or off of the island and the population is small enough to study. In an average year, there are about 1,200 individual finches on the island. Medium ground finches live up to 16 years and their generation time is 4.5 years.

Medium ground finches are primarily seed eaters. The birds crack seeds by grasping them at the base of the bill and they applying force. The beak size is directly correlated to the size of seeds that the birds eat, birds with bigger beaks eat larger seeds and birds with smaller beaks eat smaller seeds. There is variation in the beak depth in the medium ground finch population, ranging from 6 mm as the smallest to 14 mm as the largest with an average of 9.5 mm. In 1977, there was a terrible drought. Instead of the normal 130 mm of rainfall during the wet season, the island only got 24 mm. Because of the drought, the plants made fewer flowers and fewer seeds. Over the course of 20 months, 84% of the medium ground finches died of starvation.

As the drought wore on, not only the number, but also the types of seeds available changed dramatically. Before the drought, the seeds available to the finches had a range from small and soft seeds to large and hard seeds. The finches preferred the small and soft seeds. However, after the drought, there were only large and hard seeds that survived allowing only the birds with deeper beaks to eat and reproduce. The environment changed and this led to a change in the population. After the drought, the average beak size was 10.2 mm (9.5 mm before the drought), and the smallest size being 7 mm and the largest size being 11.5 mm.

From this research, and others similar to it, we are able to observe natural selection in progress. From this example we observed that there is a variation in beak size and shape, in addition to the fact that the characteristics of the beaks are heritable. Because of a change in the environment there was a selection pressure that effected which finches would survive and reproduce. As a result, the proportions of each beak size within the population changed.

1. In the first example, what type of chili would the mouse most likely eat first?

2. What environmental event occurred during 1977 that affected the finches?

APPENDIX D
DEMOGRAPHIC SURVEY

Survey

Participation number (Please remember this number!):

Gender:

Age:

What program are you in?

What biology courses have you taken?

What is your ethnicity?

What language do you speak at home?

Which of the following statements comes closest to your views on the origin and development of human beings:

_____ 1) Human beings have developed over millions of years from less advanced forms of life, but God guided this process.

_____ 2) Human beings have developed over millions of years from less advanced forms of life, but God had no part in this process.

_____ 3) God created human beings pretty much in their present form at one time within the last 10,000 years or so.

APPENDIX E
MENTAL MODEL TASK

Mental Model Task
Test- Version C
Arizona State University

DIRECTIONS: The following three pages contain a list with pairs of terms pertaining to the biological process of Natural Selection. Circle each pair of terms that have a strong relationship to each other. There is no right or wrong answer; this is based on *your* knowledge.

EXAMPLE:

1. Dog Cat
2. Dog Bird
3. Dog Fish
4. Cat Bird
5. Cat Fish
6. Bird Fish

Explanation:

“Dog Cat” was circled because both animals are mammals and “Bird Fish” were circled because they are both non-mammals.

	Number: _____		
		41	Allele Variation
		42	Disadvantage Environment
1	Advantage Allele	43	Disadvantage Fitness
2	Advantage Disadvantage	44	Disadvantage Generation
3	Advantage Environment	45	Disadvantage Genes
4	Advantage Fitness	46	Disadvantage Heredity
5	Advantage Generation	47	Disadvantage Mutation
6	Advantage Genes	48	Disadvantage Neutral
7	Advantage Heredity	49	Disadvantage Non-random
8	Advantage Mutation	50	Disadvantage Offspring
9	Advantage Neutral	51	Disadvantage Phenotype
10	Advantage Non-random	52	Disadvantage Predators
11	Advantage Offspring	53	Disadvantage Prey
12	Advantage Phenotype	54	Disadvantage Reproduction
13	Advantage Predators	55	Disadvantage Resources
14	Advantage Prey	56	Disadvantage Selection Pressure
15	Advantage Reproduction	57	Disadvantage Size of Population
16	Advantage Resources	58	Disadvantage Survival
17	Advantage Selection Pressure	59	Disadvantage Traits
18	Advantage Size of Population	60	Disadvantage Variation
19	Advantage Survival	61	Environment Fitness
20	Advantage Traits	62	Environment Generation
21	Advantage Variation	63	Environment Genes
22	Allele Disadvantage	64	Environment Heredity
23	Allele Environment	65	Environment Mutation
24	Allele Fitness	66	Environment Neutral
25	Allele Generation	67	Environment Non-random
26	Allele Genes	68	Environment Offspring
27	Allele Heredity	69	Environment Phenotype
28	Allele Mutation	70	Environment Predators
29	Allele Neutral	71	Environment Prey
30	Allele Non-random	72	Environment Reproduction
31	Allele Offspring	73	Environment Resources
32	Allele Phenotype	74	Environment Selection Pressure
33	Allele Predators	75	Environment Size of Population
34	Allele Prey	76	Environment Survival
35	Allele Reproduction	77	Environment Traits
36	Allele Resources	78	Environment Variation
37	Allele Selection Pressure	79	Fitness Generation
38	Allele Size of Population	80	Fitness Genes
39	Allele Survival		
40	Allele Traits		

81	Fitness	Heredity	21	Genes	Resources
82	Fitness	Mutation	22	Genes	Selection Pressure
83	Fitness	Neutral	23	Genes	Size of Population
84	Fitness	Non-random	24	Genes	Survival
85	Fitness	Offspring	25	Genes	Traits
86	Fitness	Phenotype	26	Genes	Variation
87	Fitness	Predators	27	Heredity	Mutation
88	Fitness	Prey	28	Heredity	Neutral
89	Fitness	Reproduction	29	Heredity	Non-random
90	Fitness	Resources	30	Heredity	Offspring
91	Fitness	Selection Pressure	31	Heredity	Phenotype
92	Fitness	Size of Population	32	Heredity	Predators
93	Fitness	Survival	33	Heredity	Prey
94	Fitness	Traits	34	Heredity	Reproduction
95	Fitness	Variation	35	Heredity	Resources
96	Generation	Genes	36	Heredity	Selection Pressure
97	Generation	Heredity	37	Heredity	Size of Population
98	Generation	Mutation	38	Heredity	Survival
99	Generation	Neutral	39	Heredity	Traits
100	Generation	Non-random	40	Heredity	Variation
101	Generation	Offspring	41	Mutation	Neutral
102	Generation	Phenotype	42	Mutation	Non-random
103	Generation	Predators	43	Mutation	Offspring
104	Generation	Prey	44	Mutation	Phenotype
105	Generation	Reproduction	45	Mutation	Predators
106	Generation	Resources	46	Mutation	Prey
107	Generation	Selection Pressure	47	Mutation	Reproduction
108	Generation	Size of Population	48	Mutation	Resources
109	Generation	Survival	49	Mutation	Selection Pressure
110	Generation	Traits	50	Mutation	Size of Population
111	Generation	Variation	51	Mutation	Survival
112	Genes	Heredity	52	Mutation	Traits
113	Genes	Mutation	53	Mutation	Variation
114	Genes	Neutral	54	Neutral	Non-random
115	Genes	Non-random	55	Neutral	Offspring
116	Genes	Offspring	56	Neutral	Phenotype
117	Genes	Phenotype	57	Neutral	Predators
118	Genes	Predators	58	Neutral	Prey
119	Genes	Prey	59	Neutral	Reproduction
120	Genes	Reproduction	60	Neutral	Resources

161	Neutral	Selection Pressure			
162	Neutral	Size of Population	201		
163	Neutral	Survival	202	Predators	Survival
164	Neutral	Traits	203	Predators	Traits
165	Neutral	Variation	204	Predators	Variation
166	Non-random	Offspring	205	Prey	Reproduction
167	Non-random	Phenotype	206	Prey	Resources
168	Non-random	Predators	207	Prey	Selection Pressure
169	Non-random	Prey	208	Prey	Size of Population
170	Non-random	Reproduction	209	Prey	Survival
171	Non-random	Resources	210	Prey	Traits
172	Non-random	Selection Pressure	211	Prey	Variation
173	Non-random	Size of Population	212	Reproduction	Resources
174	Non-random	Survival	213	Reproduction	Selection Pressure
175	Non-random	Traits	214	Reproduction	Size of Population
176	Non-random	Variation	215	Reproduction	Survival
177	Offspring	Phenotype	216	Reproduction	Traits
178	Offspring	Predators	217	Reproduction	Variation
179	Offspring	Prey	218	Resources	Selection Pressure
180	Offspring	Reproduction	219	Resources	Size of Population
181	Offspring	Resources	220	Resources	Survival
182	Offspring	Selection Pressure	221	Resources	Traits
183	Offspring	Size of Population	222	Resources	Variation
184	Offspring	Survival	223	Selection Pressure	Size of Population
185	Offspring	Traits	224	Selection Pressure	Survival
186	Offspring	Variation	225	Selection Pressure	Traits
187	Phenotype	Predators	226	Selection Pressure	Variation
188	Phenotype	Prey	227	Size of Population	Survival
189	Phenotype	Reproduction	228	Size of Population	Traits
190	Phenotype	Resources	229	Size of Population	Variation
191	Phenotype	Selection Pressure	230	Survival	Traits
192	Phenotype	Size of Population	231	Survival	Variation
193	Phenotype	Survival		Traits	Variation
194	Phenotype	Traits			
195	Phenotype	Variation			
196	Predators	Prey			
197	Predators	Reproduction			
198	Predators	Resources			
199	Predators	Selection Pressure			
200	Predators	Size of Population			

APPENDIX F
CONCEPTUAL INVENTORY OF NATURAL SELECTION

Conceptual Inventory of Natural Selection

Your answers to these questions will assess your understanding of the Theory of Natural Selection. Please choose the answer that best reflects how a biologist would think about each question.



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, 1999). 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?**
- The traits of each finch within a population gradually change.
 - The proportions of finches having different traits within a population change.
 - Successful behaviors learned by finches are passed on to offspring.
 - 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 dark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?**
- Most of the finches on an island cooperate to find food and share what they find.
 - Many of the finches on an island fight with one another and the physically strongest ones win.
 - There is more than enough food to meet all the finches' needs so they don't need to compete for food.
 - 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?**
- 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.
 - 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.
 - The changes in the finches' beaks occurred because the environment induced the desired genetic changes.
 - 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?**
- Any behaviors that were learned during a finch's lifetime.
 - Only characteristics that were beneficial during a finch's lifetime.
 - All characteristics that are genetically determined.
 - 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?**
- The finches were quite variable, and those whose features were best suited to the available food supply on each island reproduced most successfully.
 - All finches are essentially alike and there are not really fourteen different species.
 - Different foods are available on different islands and for that reason, individual finches on each island gradually developed the beaks they needed.
 - 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 the 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 pattern.

- 13 In guppy populations, what are the primary changes that occur gradually over time?
- The traits of each individual guppy within a population gradually change.
 - The proportions of guppies having different traits within a population change.
 - Successful behaviors learned by certain guppies are passed on to offspring.
 - 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 (Thorpe & Brown, 1989). Because of this, scientists assume that the lizards traveled from Africa to the Canary Islands by floating on tree trunks washed out to sea.

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?
- Finding food is not a problem since food is always in abundant supply.
 - Since lizards can eat a variety of foods, there is likely to be enough food for all of the lizards at all time.
 - Lizards can get by on very little food, so the food supply does not matter.
 - 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 a certain species when the food supply is limited?
- The lizards cooperate to find food and share what they find.
 - The lizards fight for the available food and the strongest lizards kill the weaker ones.
 - Genetic changes that would allow lizards to eat new food sources are likely to be induced.
 - 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?
- All lizards in the population are likely to be nearly identical.
 - 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.
 - All lizards in the populations share many similarities, but there are differences in features like body size and claw length.
 - 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?**
- Lizards that learn to catch a particular type of insect will pass the new ability to offspring.
 - Lizards that are able to hear, but have no survival advantage because of hearing, will eventually stop passing on the "hearing" trait.
 - Lizards with stronger claws that allow for catching certain insects have offspring whose claws gradually get even stronger during their lifetime.
 - 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. Which lizard might a biologist consider to be the "most fit"?**

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

- Lizard A
 - Lizard B
 - Lizard C
 - 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?**
- The lizards needed to change in order to survive, so beneficial new traits developed.
 - The lizards wanted to become different in size, so beneficial new traits gradually appeared in the population.
 - Random genetic changes and sexual recombination both created new variations.
 - The island environment caused genetic changes in the lizards.
- 20 What could cause one species to change into three species over time?**
- Groups of lizards encountered different island environments so the lizards needed to become new species with different traits in order to survive.
 - Groups of lizards must have been geographically isolated from other groups and random genetic changes must have accumulated in these lizard populations over time.
 - There may be minor variations, but all lizards are essentially alike and all are members of a single species.
 - 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 G
COLLABORATION SCORE SHEET

Class _____

Observer _____

Instructions:

While observing the student collaborations, there will be two categories to score.

Equal Contribution Category

First, you will be looking for equal contribution from both students in each dyad. When listening to the dialogue if you observe both participants contribute in regard to the content then they will be scored as a “yes” in this category, if you only hear contributions from one participant and the other is only listening and/or agreeing then they will be scored as a “no” in this category.

Effective Collaboration Discourse Category

Second, you will be looking for supportive language within each collaborative dyad. This is broken down to three types of utterances that can be observed. The utterances are *acknowledgements* (“ok” or “yeah” responses), *repetitions* (repeating back the previous statement), and *restatements* (rephrasing the previous statement). If you hear any of these utterances they will be scored a “yes” in this category, if none are observed then they will be scored a “no” in this category

Dyad			Equal contribution (yes/no)	Acknowledgements, repetitions or restatements (yes/no)
1	12118	12119		

Observations:

APPENDIX H
COLLABORATION PROBLEM SOLVING TASK

Numbers: _____

Instructions: Please answer the following three questions together with your partner. After collaborating and agreeing, write the solution in the space provided below the question.

Polar bears, bacteria and birds

1. Using the theory of evolution through natural selection, please invent an explanation for how polar bears came to be white.

2. Using the theory of evolution through natural selection, please invent an explanation for why certain antibiotics that used to be able to kill off certain bacteria can stop being effective after a period of time.

Hints:

- An antibiotic rarely kills all the bacteria it is intended to.
- The reproductive cycle of the bacteria is very short. Bacteria can progress through an immense number of generations in a short time.

3. Evolutionary biologists have been concerned about how certain structures such as wings have evolved. These biologists are concerned about what could have been the value of earlier wing-like structures. Why is this a matter of concern?

APPENDIX I
RUBRIC FOR SCORING COLLABORATION PROBLEM SOLVING TASK

Rubric for Collaboration Task

Class: _____

Dyad: _____

Numbers: _____

Question	Requirement	Points	Score
1	Random Variation	0,1,2	
1	Struggle for Survival	0,1,2	
1	Selective Advantage	0,1,2	
1	Heredity	0,1,2	
2	Random Variation	0,1,2	
2	Struggle for Survival	0,1,2	
2	Selective Advantage	0,1,2	
2	Heredity	0,1,2	
3	Doesn't know	0	
3	Birds need wings	1	
3	Wings have an advantage	2	
3	Mentions the conundrum	3	
Total		19	

APPENDIX J
COLLABORATION EVALUATION SURVEY

Collaboration Evaluation Survey

Participant number _____

1. Regarding the time, did you feel that both collaborators participated in the collaboration equally? Or was it one sided?

2. Regarding the content, did you feel that both collaborators participated in the collaboration equally? Or was it one sided?

3. Did you learn anything new that you didn't know before the collaboration regarding the concept of Natural Selection?

BIOGRAPHICAL SKETCH

Stephanie Touchman was born on September 15, 1975 in Tucson, Arizona. She completed her Bachelor of Science in Biology in 1998 from the University of Arizona. From 1998 to 2003 she worked as a laboratory technician first at a Biotech company, Scios Inc. in Mountain View, California and then at Stanford University on the Human Genome Project. She returned to Arizona and from 2003-2005, she completed a Masters Degree in Computational Biology at Arizona State University. From 2005-2007, she pursued a PhD in Molecular Biology but found that her passion was in Education so she switched programs to the College of Education to complete a PhD in Science Education.