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RELATIONSHIP OF BELIEFS, EPISTEMOLOGY, AND ALTERNATE CONCEPTIONS TO COLLEGE STUDENT UNDERSTANDING OF EVOLUTION AND COMMON DESCENT

DISSERATION

Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Graduate School of The Ohio State University

By

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* * * * *

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1999

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ABSTRACT

Quantitative and qualitative methodologies were combined to explore the relationships between an understanding of evolution and 4 epistemology factors: (a) control of learning, (b) speed of learning, (c) stability of knowledge, and (d) belief in evolution/creationism. A 17-item instrument was developed that reliably measured a belief in creationism and subtle differences between this belief and an acceptance of evolution.

The subjects were 45 students enrolled in a biology course at a 2-year community college. Evolution was taught in a traditional format, and common descent was taught in an inquiry-based laboratory session consisting of: (a) a comparison of hemoglobin DNA sequences of the human, chimpanzee, and gorilla; and (b) a comparison of 8 primate skull casts, including the modern human, chimpanzee, gorilla, and five prehistoric fossils.

Prior to instruction the students completed an epistemology questionnaire and a knowledge test about evolution. Five weeks after instruction, the students completed a posttest. A t-test revealed no differences between the pretest and the posttest. However, the group of students that scored higher on the posttest than on the pretest was found to have a stronger belief in the uncertainty of knowledge.

Pearson r was computed to check for relationships between the 4 epistemological factors and the understanding of evolution. There was a significant relationship between a
belief in creationism and a lessor understanding of evolution as measured on both the pretest and the posttest (p < .05). The relationship between gender and test scores was also examined with men demonstrating statistically significantly higher scores on the common descent component than women did.

Narrative data included interviews and branching/grouping activities. Four alternate conceptions about common descent were identified. Even after instruction, 16 out of 39 students thought humans evolved from the chimpanzee. Additionally, students grouped the 8 primate skulls into just 2 categories: human and animals. Other misconceptions included a nonevolutionary use of the term, related, and the use of naïve organizers leading to incorrect conclusions about the relatedness of certain organisms, such as a connection between fish and whales. These organizers included: (a) similarity of traits, (b) environment, (c) relative size, (d) function, and (e) complexity.
Dedicated to Jack, who has brought me much joy,

and to Mom, who has given me strength
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PUBLICATIONS


FIELDS OF STUDY

Major Field: Education
TABLE OF CONTENTS

Abstract ..................................................................................................................................... ii
Dedication ................................................................................................................................... iv
Acknowledgments ..................................................................................................................... v
Vita .............................................................................................................................................. vi
List of Tables ............................................................................................................................. xi
List of Figures ............................................................................................................................ xii

Chapters:

1. Introduction ........................................................................................................................... 1

   Problem statement and focus questions ............................................................ 4
   Definitions ......................................................................................................... 5
   Need for the study ............................................................................................. 8
   A worthwhile goal .................................................................................. 8
   Barriers to learning evolution ........................................................................... 8
   Inquiry-based laboratory sessions ............................................................... 12
   Theoretical rationale ............................................................................ 13
   Epistemology ........................................................................................... 13
   Inquiry-based laboratory experiences ...................................................... 18
   Research questions with hypotheses .............................................................. 20
   Research question 1 ................................................................................ 20
   Research question 2 with hypotheses ....................................................... 20
   Research question 3 with hypotheses ..................................................... 22
   Research question 4 ................................................................................. 23
   Significance .............................................................................................. 23

2. Review of the literature ............................................................................................ 26

   Biological evolutionary theory ........................................................................ 26
Evolutionary theory in the scientific community ........................................ 26
Evolutionary theory and the general public .............................................. 29
Evolutionary theory in education ............................................................. 30
Educational goals .................................................................................... 35
Creationism as a competing ideology ..................................................... 37
Epistemology .......................................................................................... 38
Perry’s epistemology model ................................................................. 38
Schommer’s epistemology model ........................................................... 39
Beliefs ..................................................................................................... 40
Role of epistemology in science education .......................................... 41
Role of epistemology in evolution education ...................................... 42
Laboratory investigations .................................................................. 45
History .................................................................................................... 45
Theoretical base .................................................................................... 46
Deductive investigations ...................................................................... 46
Effectiveness of laboratory sessions ................................................... 47
Laboratory sessions for teaching evolution ........................................ 48

3. Methods and procedures .................................................................................................. 50

Research design .................................................................................... 50
Site ......................................................................................................... 52
Subjects .................................................................................................. 53
Instrumentation ..................................................................................... 54
  Epistemology survey ......................................................................... 54
  Knowledge of evolutionary theory test ........................................... 57
Laboratory worksheets .......................................................................... 58
Student interview protocol ................................................................. 59
Instructional strategy .......................................................................... 59
Procedures for collecting data ............................................................ 60
Methods of analysis of data ................................................................. 61
Pilot study ............................................................................................ 62
Limitations ........................................................................................... 63
Assumptions ......................................................................................... 65

4. Results ........................................................................................................... 66

Presentation and analysis of quantitative data ..................................... 66
  Summary of the statistics of the demographic data ......................... 68
  Summary of the statistics of the epistemology factors .................... 71
  Summary of the statistics of the evolution knowledge test ............ 88
Relationships between epistemological factors and knowledge of evolution ............................................... 95
Relationships between categorical demographic data and scores on knowledge of evolution tests .......... 107
Relationships between interval demographic data and scores on knowledge of evolution tests ........................................109
Summary of quantitative data analysis .................................................111
Presentation and analysis of qualitative data ...................................................113
  Interviews ............................................................................................113
Evidence of understanding of human evolution..................................131
Summary of the qualitative analysis.....................................................163

5. Discussion, summary, and recommendations ...........................................................166

  Discussion of the results ....................................................................................166
    Discussion of the results addressing research question 1 ..................166
    Discussion of the results addressing research question 2 .............173
    Discussion of the results addressing research question 3 ...........180
    Discussion of the results addressing research question 4 .........182
    Discussion of the data analysis at the student level......................187
  Summary and recommendations.................................................................191
    Recommendations for instruction .........................................................193
    Suggestions for future research ...........................................................196
    Conclusion .............................................................................................198

Glossary...........................................................................................................199

Appendices.............................................................................................................203

  Appendix A.............................................................................................203
  Appendix B.............................................................................................209
  Appendix C.............................................................................................216
  Appendix D.............................................................................................224
  Appendix E.............................................................................................234

List of references....................................................................................................237
LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assignment of items to epistemology factors</td>
<td>76</td>
</tr>
<tr>
<td>2. Reliabilities, means, and standard deviations for the epistemology factor</td>
<td>79</td>
</tr>
<tr>
<td>3. Means and standard deviations for the knowledge test</td>
<td>93</td>
</tr>
<tr>
<td>4. Means and standard deviations for epistemology factors and knowledge is certain subscale by groups of students based on differences in posttest and pretest scores</td>
<td>95</td>
</tr>
<tr>
<td>5. Pearson correlations for the relationship between epistemology factor scores and knowledge test scores</td>
<td>96</td>
</tr>
<tr>
<td>6. Means, standard deviations, and ( t )-test values of the knowledge tests by gender</td>
<td>107</td>
</tr>
<tr>
<td>7. Correlations between demographic variables and knowledge test scores</td>
<td>109</td>
</tr>
<tr>
<td>8. Distribution of demographic variables of total sample and interviewed sample</td>
<td>115</td>
</tr>
<tr>
<td>9. Mean scores for the epistemology factors and the knowledge tests of total sample and interviewed sample</td>
<td>116</td>
</tr>
<tr>
<td>10. Student responses to knowledge tests</td>
<td>212</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Distribution of students by years of college</td>
<td>70</td>
</tr>
<tr>
<td>2. Distribution of students by number of high school biology courses</td>
<td>72</td>
</tr>
<tr>
<td>3. Distribution of students by number of college biology courses</td>
<td>72</td>
</tr>
<tr>
<td>4. Distribution of students by grade point average</td>
<td>73</td>
</tr>
<tr>
<td>5. Distribution of student scores on the belief in evolution/creationism epistemology factor</td>
<td>80</td>
</tr>
<tr>
<td>6. Distribution of student scores on the belief in the stability of knowledge epistemology factor</td>
<td>80</td>
</tr>
<tr>
<td>7. Distribution of student scores on the belief in the speed of learning epistemology factor</td>
<td>82</td>
</tr>
<tr>
<td>8. Distribution of student scores on the belief in the control of learning epistemology factor</td>
<td>82</td>
</tr>
<tr>
<td>9. Distribution of students by percentage of opinion of evolution due to religious beliefs</td>
<td>87</td>
</tr>
<tr>
<td>10. Correlation of belief in evolution/creationism scores to knowledge pretest total scores</td>
<td>98</td>
</tr>
<tr>
<td>11. Correlation of belief in evolution/creationism scores to knowledge posttest total scores</td>
<td>99</td>
</tr>
<tr>
<td>12. Correlation of belief in evolution/creationism scores to knowledge posttest common descent component scores</td>
<td>100</td>
</tr>
<tr>
<td>13. Sample time lines</td>
<td>218</td>
</tr>
<tr>
<td>14. Kelly’s time line</td>
<td>219</td>
</tr>
</tbody>
</table>
15. Terry’s time line ................................................................. 220
16. Cindy’s time line .............................................................. 221
17. Sample time line of pictures ............................................. 222
18. Four diagrams of representative time lines ..................... 223
19. Student 23’s laboratory worksheets ................................. 225
20. Student 25’s laboratory worksheets ................................. 228
21. Student 36’s laboratory worksheets ................................. 231
22. Possible evolutionary relationships of hominids (Day, 1984) 235
Many students enter college and complete their formal education without a basic understanding of biological evolution. This lack of understanding persists even after students have been exposed to the topic within a science curriculum. Yet, it is the theory of evolution that unifies and illuminates the science of biology. Understanding evolution is key to interpreting observations made of the natural world and life’s processes. Both educators and scientists alike recognize that effective teaching strategies are needed to span the divide between current student understanding and the desired goal of an informed, scientifically correct understanding (American Association for the Advancement of Science, 1993; National Academy of Sciences, 1998; National Research Council, 1996). In order for more effective instructional practices to be developed, there is a need to explore both the aspects that facilitate student learning of evolution and the barriers that inhibit it.

Research has already identified several contributing factors to college students’ inadequate understanding of evolution. These factors can be classified into two broad categories: (a) difficulties in student understanding of evolutionary theory, and (b) controversies regarding the teaching of evolution.
First of all, some of the identified learning difficulties stem from evolution being a complex topic consisting of several different theories, including the theories of natural selection and common descent. Both of these theories were considered by Darwin to be the keystone of his writings (Mayr, 1991). The difficulties with evolution's complexities go beyond secondary schooling and persist into the postsecondary experience in that college students often do not demonstrate an understanding of evolutionary theory. (Bishop & Anderson, 1990; Jensen & Finley, 1995). Research has revealed that the lack of understanding may be due to misconceptions about evolution and its processes (Brumby, 1984; Dagher & BouJaoude, 1997). Another contributing factor to conceptualization difficulties is that many students think that evolution cannot be observed in one's lifetime (Keown, 1988).

As previously mentioned, the second category of factors involved in inadequate learning is that evolution is viewed by the general public to be a controversial topic, most often because of its perceived opposition to religious beliefs. The controversial nature of evolutionary theory affects the way it is taught in secondary schools. In a survey of 343 high school biology teachers in Iowa, Huang (1995) found that 15% did not think evolution should be taught in public schools. Shankar and Skoog (1993) conducted a similar survey of 307 Texas high school biology teachers and found 14% of the teachers did not support the teaching of evolution. Should a secondary teacher include evolution in the curriculum, the topic may be covered only briefly. For example, in Shankar and Skoog's study, in spite of most of the teachers claiming to support the teaching of evolution, in actuality, they were not covering it comprehensively in content or in time. In
particular, human evolution was basically ignored by Texas secondary teachers. Overall, many teachers across the United States avoid controversy, especially one with religious overtones, and they compromise by not emphasizing evolution's unifying status in the biological sciences (Bradley, 1989), but instead give evolution only superficial coverage as a separate unit.

In spite of the cursory treatment evolution often receives, this theory remains an important concept that should be part of the curriculum. Evolutionary theory is included in the recommended content of secondary-level science education by such organizations as the National Research Council (1996), the National Science Teachers Association (1996), and the Ohio Department of Education (1994). These scientific and educational groups advocate that evolutionary theory should be taught using both a lecture format that addresses naïve conceptions and hands-on activities. However, these recommendations are not always practiced in the classroom. A vast majority of suggested activities available in the literature are nothing more than paper-and-pencil activities, computer simulations, and analogies that use household items (Demastes, Good & Peebles, 1995; Gauld, 1992; Kurvink, 1995; McComas & Alters, 1994;). Less frequent are examples of activities that use evidence and observations of the real world to explore and confirm evolutionary theory in a manner similar to the way scientists practice scientific inquiry (Nickels, 1987; Offner, 1994a, 1994b).

Effective teaching strategies must be developed that facilitate correct understandings and address college students' misconceptions of evolutionary theory. One strategy that has been found to be effective for other content areas is the use of laboratory
sessions which require students to apply scientific theory by conducting student-designed experiments in a guided-inquiry environment (Tien & Stacey, 1996). The application of this strategy to the teaching of evolution may provide an appropriate environment in which to study college students' understanding as they evaluate the strengths and weaknesses of evolutionary theory in explaining various sources of evidence.

This study evaluated student understanding within the context of both traditional instruction and student-designed experiments that encouraged students to test evolutionary theory using their interpretations of real data. When students have an opportunity to see evidence of evolution and are encouraged to test the theory, their understanding of this difficult, complex topic may be facilitated. This study explored factors that may be involved with student understanding of evolutionary theory.

Problem Statement and Focus Questions

Many college students demonstrate an inadequate understanding of evolutionary theory in spite of instruction. Some of this lack of understanding is due to conceptual difficulties, including misconceptions. Some of the problem is due to a less-than-adequate instructional treatment in secondary school. In particular, the theory of common descent as it applies to human evolution is often ignored. Also, many students think that evolution cannot be directly observed. Within this present context, there are several questions that deserve attention.

What student characteristics, such as various epistemologies, are associated with a lack of understanding of evolution? Do some college students have objections to evolution and the theory of common descent based on a religious perspective? Do
students with these objections demonstrate less understanding than other students demonstrate? Do college students who accept evolution have a better understanding of evolution and common descent? Are there variables, such as number of biology courses taken, year in college, or gender, that are associated with student understanding of evolutionary theory and common descent? What are the alternate conceptions that students have about common descent?

Definitions

Terms used in this study are defined below:

**Epistemology** - The approach one has toward knowledge and learning; the filter by which new information is perceived and the belief system one has towards one’s own learning and educational experience.

**Stability of knowledge score** - score obtained on a subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers knowledge to: (a) depend on authority, such as instructors, texts, and experts; (b) consist of single answers; and (c) be certain.

**Structure of knowledge score** - score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers knowledge in one field of study to be connected to another field of study and to the practical aspects of life.

**Control of learning score** - score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers learning to be an innate ability versus an acquired ability.
**Speed of learning score** - score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers learning to be: (a) easy versus difficult, and (b) quick or not at all versus the belief that learning comes after the second or more efforts.

**Belief in evolution/creationism score** – score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student believes in creation, a supernatural creator, and a creator as the designer of different species versus the level to which a student accepts evolution. An acceptance of evolution includes an acceptance of the modern scientific explanation of biological change over time, the theory that different species share a common ancestor, and the theory of natural selection working on genetic variation as the mechanism by which populations change over time.

**Creationism** - a perspective based on a biblical account, rather than a scientific one, which explains the origin of species as coming from the creator who designed and created each species as a separate, definite entity, each with its own essence.

**Common descent** - the evolutionary theory that explains that modern species have descended from other species that may or may not be extinct. Related species share phenotypic and genotypic similarities, resulting from either sharing a more recent ancestor (in terms of geological time), or being a direct descendent (or ancestor) of each other.

**Speciation** - the process by which one or more new species develop from another existing species, resulting in separate populations that can no longer interbreed.
Acceptance of evolutionary theory - the belief that evolutionary theory is a valid and sufficient explanation of biological change over time.

Applying evolutionary theory - the willingness and ability to use evolutionary theory to explain and predict scientific observations, data, and evidence.

Understanding of evolutionary theory - the demonstration of a conceptualization of the scientifically acceptable definition, explanation, and/or application of evolutionary theory.

Alternate conceptions - include the following: (a) misunderstandings of evolutionary theory; (b) naïve conceptions, especially when applied to mechanisms and processes of evolution; and (c) alternate conceptions of natural selection and the origin of species, such as those ideas that are part of creationist ideology.

Theory of biological evolution - the explanation of observed changes in populations of living organisms over time. Evolution encompasses several facets, including related species having descended from a shared ancestor and natural selection of genetic variation as the mechanism by which populations change over time.

Natural selection - the process by which factors in the environment and inherent in an individual affect the varying success rates that individuals with phenotypic variations have in reproduction, eventually resulting in populational changes in species.

Guided-inquiry student-designed experiment - a laboratory experiment in which students are given a theory to test and a list of materials available with which to test the given theory. The students design their own laboratory procedures, either individually, or in groups. The students then perform their procedures, testing the theory in a deductivist
manner. This type of laboratory session differs from many other inquiry laboratories in that it is not an inductive experience, but a deductive experiment. It also differs from most other laboratory sessions, in that the procedures are not stated in a step-by-step manner. The guided-inquiry component refers to the fact that the instructor acts as a coach and facilitator, guiding activity in a general direction, rather than dictating activity in a specific direction.

Need for the Study

A Worthwhile Goal

The *National Science Education Standards* published by the National Research Council (1996) stated that, "As a result of their activities in grades 9-12, all students should develop understanding of . . . biological evolution" (p. 190). This worthwhile goal has not yet been realized, even at the college level. A special 1994 issue of the *Journal of Research in College Teaching* was devoted to the recent progress in teaching and learning evolution. Cummins, Demastes, and Hafner (1994) summarized the present state, "Much work still needs to be done both in science education research and in curriculum development to produce materials and methods that effectively convey to students the complexity and elegance of evolutionary theory" (p. 446).

Barriers to Learning Evolution

The need for more effective teaching and learning also exists at the college level. Sinclair, Pendarvis, and Baldwin (1997) reported a study of 218 college zoology students in which only 21% comprehended Darwin's theory prior to instruction. This figure increased to only 34% after college-level instruction. These researchers also reported that,
in spite of being lectured specifically about the theory of common descent as applied to primate evolution, college students "... tenaciously held to misconceptions regarding the ancestral relationships between humans and other primates" (p. 124). Lord and Marino (1993) found that after instruction at the college level, only 7% of 392 college students selected the correct interpretation of the modern theory of evolution on a multiple-choice question.

Another common barrier to student understanding of evolution is that many students inaccurately apply everyday meanings of common terms, such as "adapt," without fully understanding the scientific meaning of such terms. In the study reported by Lord and Marino (1993), 42% of 392 college students held a teleological naïve view of evolution, in which they perceived organisms to purposefully strive toward higher forms. Naïve conceptions such as this one can potentially interfere with college students acquiring a more scientifically acceptable understanding of evolution.

The lack of success in college student understanding of evolution can be traced to originate when these students were in high school. Surveys of secondary biology teachers show that teachers have often avoided teaching evolution due to its controversial nature (Tatina, 1989; Zimmerman, 1987). These same surveys show that even those teachers who do include evolution in the curriculum may not possess a correct understanding of the topic. Zimmerman reported that in a study of Ohio high school biology teachers, only 12% of the teachers chose the best answer on a question asking for the definition of evolution. In a study replicating Zimmerman's, Tatina reported that figure to be only 7% for South Dakota high school teachers.
Historically, the teaching of evolution has been enmeshed in controversy, perhaps best characterized by the 1925 trial of John Scopes. In Caudill's (1986) analysis of the reporting of the trial in the press, he contended that there was not only a legal conflict, but also an additional conflict of two ways of knowing: observation versus revelation. Today, this conflict continues in the controversy surrounding evolution that often provokes debate and the formation of opinions of either acceptance or rejection of evolutionary theory (Nickels, Nelson, & Beard, 1996). Two studies have evaluated the association between rejection of evolution and understanding evolution. Bishop and Anderson (1990) studied 110 college students and found that belief in the truthfulness of evolutionary theory was not significantly related to posttest performance of the cognitive domain. Demastes, Settlage, and Good (1995) studied 192 college students and found that students' acceptance of evolution was not a contributing factor in students' usage of scientifically correct conceptions. However, neither of these studies investigated directly a correlation between a conceptual understanding of evolution and a belief in creationist ideology.

Do religious beliefs add an additional hurdle for many students in learning evolutionary theory? Sinclair et al. (1997) found that 26% of 218 college zoology students believed that there was a dichotomous choice between creationist religious beliefs and evolution. Further, these beliefs interfered with acceptance of evolutionary theory. In a Lebanese study, Dagher and BouJaoude (1997) found that those college seniors majoring in biology who rejected evolution did so on the basis of religious arguments against the theories of common descent and populational speciation. However,
the researchers did not attempt to correlate students' creationist beliefs with student understanding. These studies have left unanswered the question whether a creationist belief system provides a barrier to understanding evolution. Dagher and BouJaoude did not think that the question has been examined sufficiently within the context of religious beliefs. "What is worth pursuing in future research are ways in which students' outright rejection of the theory of evolution interferes with their development of a clear understanding of its concepts" (p. 441).

Schommer (1990) reported findings that college students who held a strong belief in the certainty of knowledge were less likely to understand written passages. Applied to a belief in the certainty of creation, this particular epistemology may correlate with a lack of understanding of evolutionary theory.

Another potential barrier to student learning may be found in the belief that evolution cannot be tested or be used to make predictions as other scientific theories are. In Lord and Marino's study (1993), 42% of 392 college students thought that evolution cannot be tested or that it is based on speculation, not on scientific facts. This attitude may be reinforced by the paucity of laboratory sessions using factual evidence. In a review of high school laboratory manuals, McComas (1991) reported that the preferred mode of teaching evolution was that of using natural selection simulations, such as using beads to represent prey and different colored cloths to represent the environment. These simulations may be conceptually difficult for students who are at the concrete stage of reasoning and who may not be able to visualize the analogies. Additionally, mere simulations may not be convincing to students who doubt the validity of the theory, and
the use of these simulations may, in fact, affirm to these students the impossibility of observing evolution in the natural world. Very few laboratory experiments are devoted to having students observe the evidence of evolution. Could the current lack of hands-on experimentation with factual evidence also contribute to evolution's reputation of being only a theory? Sinclair et al. (1997) found that 75% of college students were influenced by objective scientific evidence rather than by the beliefs of teachers, parents, or peers. Hardly any laboratory activities at the introductory college level are designed to take advantage of this preference for using factual evidence to instruct students about evolution. This raises the question, can college laboratory activities be tailored to overcome students' barriers to learning evolution?

Inquiry-Based Laboratory Sessions

There are several educators who have advocated teaching concepts by using student-directed laboratory sessions that are fashioned after scientific inquiry as it is practiced by scientists (Hodson, 1996; Lewis, 1986). Recognized goals in science education include the development of both critical thinking and independence in learning. Leonard (1983) recommended that biology investigations take advantage of concept development by having students develop their own procedures. Nickels (1987) suggested introducing “students to the study of the [evolutionary] evidence for evaluation by utilizing specimens that they can readily relate to and better understand” (p. 148). This type of hands-on activity was chosen for this study. The students incorporated factual evidence to test evolutionary theory by applying specific hypotheses derived from evolutionary theory.
The purpose of this study was to examine college students’ conceptual understanding of evolutionary theory and the theory of common descent within the context of traditional instruction and a guided-inquiry student-designed laboratory session. Students were asked to design an experiment applying the theory of common descent to factual evidence. In order to explore the role of barriers to understanding the complex and controversial subject of evolution, student epistemologies were classified by the administration of a questionnaire. The research was grounded in two theoretical frameworks: (a) epistemological beliefs, and (b) inquiry-based learning based on what Hodson (1996) called a “theory-driven activity.”

Theoretical Rationale

Epistemology

Perry’s Epistemological Model

Research in the area of epistemology has indicated that there is a link between various beliefs and student understanding. Perry’s (1970) ground-breaking work with Harvard students found that many progressed through nine stages of development. Many first-year students assumed knowledge to be of a dualistic structure. As they experienced a liberal arts education, students took one of two routes: some students retreated or escaped psychologically, while other students continued on in their development to form new and strong personal commitments. As these students’ epistemology changed, and as they started to perceive the world as relativistic rather than dualistic, some students experienced various emotions, such as ambivalence, dismay, or turmoil. At this developmental stage, some students did not progress while some others chose to escape
by denying relativism’s implications. Many students realized that these changes had affected their religious views. Perry proposed that this changing epistemology had powerful reverberations in the students’ attainment of cognitive knowledge.

It appears then, that it is no longer tenable for an educator to take the position that what a person does with his intellectual skills is a moral rather than intellectual problem and therefore none of the scholar’s business. Epistemologically the knower and the known are now inseparable. The forms of knowing entwine with the forms of the known, and this involvement includes the forms of the knower’s responsibility. The alienated student . . . may imitate or parody the forms of other people’s knowledge, but he is . . . sterile intellectually. (p. 212)

In Perry’s (1970) study, several students referred to the impact their intellectual learning had to their religious beliefs and their belief in God. For example, a freshman student reflected that, “It has involved the tearing away of a lot of beliefs in what has been imposed by convention and I think that it does come down to you tearing away your faith” (p. 116). As students struggled with the unsettling feelings that correspond with epistemological change, they faced conflict in relationship to their religious beliefs.

This particular type of struggle just described may occur especially when students consider the implications of biological evolution to their world views and self views. Wirtz (1993) proposed that “. . . to pretend that evolution has no meta-physical implications is to encourage teleological and typological misconceptions of evolution.” (p. 117).

In today’s institutions of higher learning, there may be some college students like those in Perry’s (1970) study who refused to move onto a relativist epistemology. If so, these students certainly may recognize that conflict exists with their belief systems, but they may choose to not abandon their epistemology or their alternate conceptions. The
research in this study attempted to identify and measure creationist epistemology in an effort to see if there was a correlation between belief and the understanding of evolution for the participating college students.

**Schommer's Epistemology Model**

Schommer and others (Schommer, 1990; Schommer, 1994a; Schommer, 1994b; Schommer, 1998c; Schommer, Calvert, Gariglietti, & Bajaj, 1997; Schommer, Crouse, & Rhodes, 1992; Schommer & Walker, 1995) have built upon Perry's (1970) research by re-conceiving personal epistemological beliefs to be part of a system. She developed and validated a survey instrument (Schommer, 1998b) whose factor analysis identified four separate epistemological factors of the system: (a) stability of knowledge, (b) structure of knowledge, (c) speed of learning, and (d) control of learning.

Schommer (1990) found that the first epistemological factor, stability of knowledge, encompasses the viewpoint that knowledge never changes to the viewpoint that knowledge is tentative and is expanding. Perceiving that knowledge is tentative could be compatible with a sophisticated understanding of the uncertain nature of science, with one major difference. This epistemology of stability of knowledge is the personal approach used by the subject, not just a viewpoint that a student recognizes as one that others use. It is possible that a student could recognize that scientists may change their minds, while the student holds firm in his or her own beliefs and knowledge. This study investigated whether a sophisticated epistemological viewpoint in this area is related to an understanding of evolutionary theory, a theory that has been interpreted in different lights as new scientific discoveries have been made.
The second epistemological factor identified in Schommer's (1990) research is the *structure of knowledge*, which is how strong a person believes knowledge to be interconnected versus a belief in discrete and unrelated knowledge. Schommer claimed that students who strongly believe that knowledge is connected are able to apply information and transfer knowledge from one setting to another. Those students who believe that knowledge is simple and unconnected do not readily make associations of knowledge across fields or experiences (Schommer, 1998c). This study postulated that these students might have difficulties in understanding the complexities of evolution.

Schommer (1990) identified a third epistemological factor, *the speed of learning*. A student with a strong belief in quick learning will devote little time for studying and learning regardless of the difficulty of the topic or task. Conversely, the student who believes that learning is gradual will assess the task’s level of difficulty and modify the time devoted to learning. If students believe learning to be quick, they may assume they already know the subject and remain firm in their naïve conceptions. This study looked at the relevance of this epistemological belief to the complex subject of evolution, which has various components that are covered in biology courses in both high school and college. Through a factor analysis, Schommer (1990) identified a fourth epistemological factor, *control of learning*. Strong believers in fixed ability often have feelings of frustration and failure and an unwillingness to persevere in difficult learning situations. On the other hand, believers in a malleable ability to learn demonstrate increased interest in studying difficult concepts. These students are persistent over extended lengths of time.
This study explored whether this epistemological perspective correlates with how well the students comprehend the complex theory of evolution.

Beliefs and Epistemology in Evolution Education

Evolution. In a preface to the special issue of the *Journal of Research in Science Teaching* devoted to evolution, Good (1994) lamented that "only several dozen studies on students’ many difficulties in understanding evolution-of-life concepts have been published since the 1970's, but hundreds of such studies in physics (mechanics) have appeared" (p. 443). Although few in number, several of these evolutionary studies examined not only student understanding, but also additional aspects, such as student acceptance of evolution. This sort of treatment is unheard of for any of the other topics or theories in science, and thus research in the teaching of evolution has required a unique approach. Cobern (1994) elucidated this special consideration:

> It is assumed that if students understand evolution they will believe it. From a constructivist perspective it can be argued that understanding and belief, though related, are distinct concepts and that each is a potential goal for instruction. Though there are good reasons why belief should not be an instructional goal, achieving conceptual understanding requires that issues of belief be addressed. The point is that students are not likely to gain much understanding of something that they dismiss outright as unbelievable. (p. 583)

Creationism. This study identified the degree of students’ belief in creationism versus their acceptance of evolution. This was accomplished by scores obtained on items in the *belief in evolution/creationism* factor subscale of the epistemology instrument. Belief in creationism was studied rather than a belief in religion, because previous studies
have found that some students reconcile beliefs in both evolution and religion (Dagher and BouJaoude, 1997; Demastes, Good and Peebles, 1995). This made it necessary to treat evolution/creationism as a separate epistemological domain than that of religion.

The five epistemological factors discussed were examined as to their potential influence on student learning and understanding of evolutionary theory. Together they form the first theoretical base for this study.

Inquiry-Based Laboratory Experiences

The second theoretical underpinning of this study is that of learning through inquiry during investigative laboratory experiences. Learning science by doing science is the central underlying theme in the National Science Education Standards (National Research Council, 1996).

[Scientific] inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence, using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. (p. 23)

This instructional method takes large blocks of time, and thus depth of understanding of science concepts becomes the teacher’s goal for the student. The inquiry method is more than just an occasional “hands-on” task; it is the foundation for science education. Hodson (1996) cautioned that a deductivist rather than an inductivist model is more appropriate for science education. He asserted that practicing scientists use a “theory-laden” approach when conducting scientific research. Hodson wrote, “Learning science involves an introduction into the world of concepts, ideas, understanding and
theories that scientists have developed and accumulated" (p. 127). This approach is particularly relevant for student understanding of evolutionary theory. Hodson declared, "What students will notice and choose to report, and how they will report it, depend not just on their powers of discrimination, but on their possession of relevant theoretical criteria to employ" (p. 126).

Lewis (1998) pointed out that scientific theories are largely neglected by science educators and advocated that instructors should emphasize these theories in introductory college courses. It would be helpful for students to know the application of theories and how they can be used to explain facts and predict observations. Perhaps, this knowledge of scientific theories can best be learned when students test theories in a laboratory setting.

Leonard (1988) chose to study a particular form of inquiry learning. He investigated a nontraditional instructional strategy that allowed the learner to exercise discretion in what Leonard called the "extended discretion laboratory approach" (p. 80). When this approach is used for instruction, students are given laboratory assignments but not a detailed step-by-step procedure. The students are assigned a task with a list of available resources, and they are to design a procedure to follow. The intent is to foster student thinking in an active rather than a passive way as the student experiences both the methods and concepts of science. The effectiveness of this particular strategy has not been reported in the context of teaching evolution.
Research Questions and Hypotheses

The findings from the literature and the theoretical considerations have led to the following research questions and null hypotheses. The first research question is of a descriptive nature. The next two questions are of a correlational nature and lead to null hypotheses. The last research question is of a qualitative nature, and therefore null hypotheses are not appropriate.

Research Question 1

What is the level of college student understanding of the theories of evolution and common descent as measured on a knowledge test both before and after instruction?

Research Question 2 With Null Hypotheses

Which, if any, of the five epistemological factors are associated with college student understanding of the theories of evolution and common descent?

Hypothesis $H_{01}$

There will be no relationship between scores on the epistemology factor, belief in evolution/creationism, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

Hypothesis $H_{02}$

There is no relationship between scores on the epistemology factor, stability of knowledge, and understanding of evolutionary theory as measured by:

20
Hypothesis $H_{03}$

There is no relationship between scores on the epistemology factor, *structure of knowledge*, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

Hypothesis $H_{04}$

There will be no relationship between scores on the epistemology factor, *speed of learning*, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

Hypothesis $H_{05}$

There will be no relationship between scores on the epistemology factor, *control of learning*, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.
b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

*Research Question 3 With Null Hypotheses*

*Do demographic variables, such as gender, year in college, and number of biology courses previously taken, have a relationship with college student understanding of the theories of evolution and common descent?*

*Hypothesis $H_{06}$.*

There will be no relationship between gender and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

*Hypothesis $H_{07}$.*

There will be no relationship between year in college and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.
Hypothesis $H_{08}$

There will be no relationship between the number of biology courses previously taken and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

Research Question 4

What, if any, are the alternate conceptions that students have about the theory of common descent?

Significance

When a topic, such as evolution, is particularly difficult for students to understand, it is important to identify the reasons why. Evolution carries with it a further difficulty, in that within our present-day American culture, it remains a controversial topic. Therefore, it is important to identify student characteristics that may potentially interfere with student understanding of evolution. Findings pertaining to an association between individual epistemological elements and student understanding could guide further research. Plus, both the development and demonstration of guided-inquiry student-directed laboratory sessions are of potential interest to the science education community.

The science literacy of future generations is a worthwhile goal for our country’s progress and advancement. The theory of evolution is recognized as one of the most
important explanatory underpinnings in the field of biology. However, the general public’s lack of understanding of evolution continues to be a major concern for science educators. Furthermore, there are studies that have found that college students majoring in biology do not demonstrate a thorough understanding of evolutionary theory. This lack of understanding results in students not being able to apply evolutionary theory to explain or predict scientific observations and phenomena.

While there have been a few studies that examined student understanding of natural selection, there are no studies known to this researcher that have focused on student understanding of the theory of common descent. It is beneficial to develop a laboratory experience helpful to students in understanding this theory. Also, it is of value to discover any conceptual difficulties that students might have with common descent.

This study has the potential to contribute to educators’ further understanding of certain barriers to college students’ understanding and application of biological evolution. The identification and characterization of these barriers may help educators better confront college students’ alternate conceptions. Additionally, educators may be able to identify students who are at a greater risk to reject the theory of evolution and address students’ associated epistemological beliefs.

Reform efforts at the school level call for a renewed commitment to inquiry-based learning. By basing a college-level laboratory session on inquiry-based learning, this study will add to the research base of the feasibility and effectiveness of this kind of laboratory session. The findings from this study may also be found to be useful for
curricular adaptations in introductory college biology laboratories for the teaching of evolution.
CHAPTER 2

REVIEW OF THE LITERATURE

This literature review focuses on three main areas of research pertaining to science education. First, the status of evolutionary theory in science and in education will be reviewed. Parallels between the historical treatment of evolutionary theory and students' naïve conceptions will be examined. The second body of literature that will be reviewed pertains to the role of epistemology in student learning and its implications in learning the complex theory of evolution. Finally, the research on the role of laboratory investigations on student understanding will be explored. These three areas combine to form a background as to the need to explore the potential of their contributions to student learning of evolutionary theory.

Biological Evolutionary Theory

*Evolutionary Theory in the Scientific Community*

The concept of evolution is understood by an overwhelming majority of scientists and science educators to be the single most important and unifying theory in the field of biology (American Association for the Advancement of Science, 1993; National Academy of Sciences, 1998; National Research Council, 1996). Before Darwin and Wallace jointly announced their independent arrivals at the theory of natural selection, the
study of biology was basically conducted as a task of collecting and cataloguing specimens of natural history. Historically, biologists had classified specimens with little thought to the explanation of observed similarities and differences because special creation was accepted as the origin of species with their differences in essence. But evolutionary theory revolutionized biology by giving it a footing on par with other scientific disciplines. Evolution has been found to be a robust theory that explains evidence from many sources of various historical times and geographical locations and that predicts new discoveries. The theory of evolution has demonstrated itself to be a powerful explanatory tool by which scientists can begin to better understand life’s complexities, such as biological diversity, the fossil record, molecular genetics, and biochemistry. Mayer (1984) recognized the historical importance that evolution has played in biology: “Evolution is the warp and woof of biology as the atomic theory is for chemistry. Biology no more makes sense without the unifying conceptual scheme of evolution than the elements could be ordered without an understanding of atomic theory” (p. 430).

Additionally, evolution unifies biology with other scientific disciplines, such as geology and astrophysics. Thus, evolution has gained acceptance in the scientific community as evidenced by its pervasive use as a foundational underpinning for research in various disciplines as reported in prominent scientific journals, such as *Science* and *Nature*.

This acceptance of the theory of evolution within the scientific community has followed a similar course as the acceptance of other paradigm shifts in science. New
scientific theories are revolutionary in their impact upon established thinking and interpretation of natural phenomena. The acceptance of any scientific theory occurs over time as natural evidence and data are reexamined and interpreted in the light of the new theory. For example, Copernicus's theory that the earth orbited the sun was finally accepted some 100 years after the theory was first proposed (Dennett, 1995), and Wegener's theory of continental drift was accepted after 50 years (Mayr, 1991). Although Darwin's theory was accepted by many scientists immediately after it was publicly presented in 1858, it also sparked intense opposition, which continues up to the present, by people whose world view has been threatened by the theory's philosophical implications. (Dennett).

Darwin's thorough delineation of natural selection was the first published explanation of a plausible mechanism for the changes that had been observed in the fossil record. Just as the scientific theories in other fields are a product of the process of redefining evidence and discoveries through the lens of a revolutionary construct, the enlightenment that evolution has brought to biology is not without controversy within the ranks of the scientists. However, within the scientific community, this controversy is not one of acceptance versus rejection of evolution, but rather one that involves the various perspectives of applying and refining evolutionary theory. "Most—if not all—of the controversies concern issues that are 'just science'; no matter which side wins, the outcome will not undo the basic Darwinian idea. That idea . . . is about as secure as any in science" (Dennett, 1995, p. 19).
However secure evolution is within the mainstream science community, the general public in the United States has viewed evolution as a controversial topic. Evolution, particularly the theory of common descent, is perceived by many to erode traditional concepts concerning the origin, meaning, and purpose of humanity. Indeed, the concept of evolution has been expanded beyond that of a scientific theory and developed into a philosophy with sociological, political, and theological implications (Dennett, 1995). The acceptance of evolution has resulted in a major paradigm shift away from the philosophical view of a young, constant earth, with each species being designed specially and humans possessing a unique place in God’s creation (Mayr, 1991). Many citizens perceive evolution as a threat to their religious beliefs because they think it is in direct conflict with a literal interpretation of the Genesis accounts of creation, especially as to the origin of humans. Historically, there have been heated debates carried out in state legislatures and courts dealing with the teaching of evolution and the alternative creation story (Moore, 1998). In a recent poll (The Gallup Organization, July 9, 1999), 68% of Americans thought that both creationism and evolution should be taught in the public schools while only 29% of Americans oppose the teaching of creationism. Surprisingly, 40% of Americans think that creationism, and not evolution, should be taught in the public schools. One might assume that those who reject biological evolution based on their theological beliefs would possess an understanding of the scientific theory that initiated the philosophy that they perceive to threaten their beliefs. However, recent Associated Press and National Broadcasting Company polls (as cited in Lord & Marino,
1993) revealed that the general public lacks a thorough understanding of evolutionary processes.

Evolutionary Theory in Education

The public’s lack of understanding persists in spite of efforts by the educational community to produce graduates that are part of an informed, science literate society. Specifically, science educators perceive evolution to be central to biology, and have incorporated the teaching of the theory as part of the content standards of the National Science Educational Standards (National Research Council, 1996), Benchmarks (American Association for the Advancement of Science, 1993), and Science: Ohio’s Model Competency-Based Program (Ohio Department of Education, 1994).

Teachers

However, teaching this framework of evolution poses a challenge to the classroom teacher. Special interest groups that reject evolution have taken a proactive stance by using the courts, legislation, and pressure applied to members of school boards to advance the teaching of the creation story as an alternate theory to evolution, worthy of acceptance in the scientific community, and therefore on equal footing to evolution (National Academy of Sciences, 1998). Because of the controversy involved in teaching evolution and the demands of equal time for creation science, some secondary school educators have decided to not teach evolution in their science classes (Johnson, 1985). In a national survey of high school biology teachers, nearly 20% of the 467 respondents indicated that high school biology can be taught without including evolution and 5% thought the topic should be excluded altogether (Affannato, 1986). In a more recent
study, 43% of Indiana high school biology teachers reported that they either avoided teaching evolution or only briefly mentioned it in their teaching (Rutledge, 1996).

Furthermore, science instructors report experiencing their own personal doubts about evolutionary theory. In one survey of high school biology teachers in Ohio (Zimmerman, 1987), 22% of the teachers reported that they did not believe in evolution. In a survey of South Dakota high school biology teachers, approximately 27% of the respondents reported that they did not believe in evolution (Tatina, 1989). Rutledge (1996) found 23% of Indiana biology teachers had either a low or very low level of acceptance of evolution. Shankar and Skoog (1993) found 25% of Texas biology teachers rejected the application of the theory of common descent for humans.

While these figures represent that it is the minority of teachers who reject evolution and the majority of teachers polled who believe in evolution, the evidence is weak that these same teachers have a thorough and precise understanding of evolution. Tatina (1989) and Zimmerman (1987) reported that only 7% of South Dakota teachers and 12% of Ohio teachers, respectively, chose the best answer on a question asking for the definition of evolution. Only 75% of Texas teachers scored greater than 60% correct on a knowledge test covering evolution (Shankar & Skoog, 1993).

**Students**

Thus, it is not surprising that students enter college with a less than adequate understanding of evolution since a large proportion of these students have received scant instructional treatment from secondary teachers who do not ascribe to it or from teachers
who do not fully understand it. The lack of understanding by high school biology teachers does nothing to facilitate students' understanding of evolution.

In addition to the controversial nature of evolution teaching, there is evidence that students have conceptual difficulties with learning the theory of evolution, particularly natural selection. However, this particular area of alternate conceptions appears to be understudied when compared to other topics, such as the concept of physical force. There have been only several dozen studies of evolutionary alternate conceptions of all age groups while there have been hundreds of studies reported in the field of physics (Good, 1994). A few studies do delineate the persistence of various alternate conceptions of evolutionary theory held by precollege students (Demastes, Good, et al., 1995; Lawson & Thompson, 1988; Settlage, 1994). For example, Settlage found that over half of 200 high school students held alternate conceptions of natural selection, such as teleological and Lamarckian explanations, but that the occurrence of these alternate conceptions dropped to less than 20% after instruction. However, the Settlage study reported only the number of occurrences of alternate conceptions, not the number of students who held them.

Lawson and Thompson (1988) studied 131 seventh-grade students and found that reasoning ability was significantly related to the number of misconceptions held by each student after instruction. In a similar study of high school students, Lawson and Worsnop (1992) found reflective reasoning skill to be significantly related to gains in knowledge of evolution.

As students progress into college, there are additional, enhanced opportunities for them to learn evolutionary theory in a setting where it is not viewed by the instructors to
be controversial. Instruction in higher education reflects the scientific community's acceptance of evolution. One might think that in such a climate college students would come to understand and accept evolution, particularly those taking a biology course, or majoring in biology. Two relevant studies of college students have looked at both understanding and acceptance of evolution. Johnson and Peeples (1987) conducted a survey of 971 biology majors and 841 non-majors in 35 institutions. Senior biology majors demonstrated a significantly higher understanding of evolution than did freshmen and sophomores. Overall, the students were neutral in their acceptance of evolution. In a survey of 392 university students, Lord and Marino (1993) found that the students' acceptance of evolution was higher among juniors and seniors than that of freshmen. Overall, 28% did not believe in evolution. As for understanding, only 7% chose the best definition of the mechanism of natural selection.

Other studies have focused on college student understanding of evolution. Bishop and Anderson (1990) conducted research with 110 college juniors and seniors that were not majoring in biology. They identified three distinct alternate conceptions of natural selection held by college students. Students thought that organisms developed new traits through the disuse and use of organs or abilities, through a change in response to an environmental stimulus, and through the need to change.

In a study of 30 nonbiology majors enrolled in two separate sections, Scharmann (1990) found that after instruction there was a significant increase in a greater acceptance of evolution, but there was not a significant increase in understanding evolution, in either the control group or the experimental group.
In a college biology course, Jensen and Finley (1995) used an instructional strategy to teach evolution that incorporated historical arguments to address conceptual change. After this novel approach, scientifically correct conceptions increased from less than 25% to 45%. However, Jensen and Finley reported that performance was still less than optimal. It should be noted that the number of correct conceptions demonstrated was the unit of analysis, not the individual student, so it is not known what percentage of students experienced an increase in understanding of evolution.

In addition to studies that focused on nonbiology majors, there are studies that have shown that more advanced biology students also have misconceptions. Brumby (1984) interviewed 32 first-year medical students in Australia and found that only 10% “were consistently able to recognize and correctly apply the concept of natural selection and were categorized as having sound understanding” (p. 497). Dagher and BouJaoude (1997) reported misconceptions in some fourth-year college students majoring in biology in Lebanon. Misconceptions were similar to those that had been observed in other studies of less educated students. These misconceptions included the idea that humans evolved from modern apes and the idea that evolution progresses to the end product of perfection.

It can be seen that the current climate consists of the general public's lack of acceptance of evolution as a believable scientific theory and the permeation of students' misconceptions concerning the theory, even at the college level. There is a need for further studies into the barriers that block student understanding.
Educational Goals

What are the goals that we want college students to attain in the area of understanding of evolution? A worthwhile goal for science literacy in the field of evolution would be for college students to acquire an understanding of the two major theories, the theory of natural selection and the theory of common descent. Lewis (1986) outlined the main postulates of these two theories, and those of natural selection are listed as follows:

1. A population has the potential to increase at a geometric rate.

2. The number of individuals in a population remains fairly constant over a relatively short time.

3. Resources, the environment, competitors, and predators limit the rate of growth of a population.

4. The environment of most populations is constantly changing, albeit very slowly.

5. Only a fraction of a population survives long enough to reproduce.

6. Individuals vary in inherited traits.

7. Some traits are favorable or unfavorable for survival and reproduction.

8. Individuals with the favorable traits will, on average, produce a greater number of offspring than the individuals with unfavorable traits will produce.

9. New variations accumulate and unfavorable variations disappear over time through the process of natural selection. These new variations may accumulate to the
extent that the individuals with these variations are isolated from reproducing with the original population, resulting in the development of a new species.

The postulates of the theory of common descent are as follows:

1. All life on earth evolved from either one kind, or a few kinds, of simple organisms.
2. All species, whether still living or extinct, arose out of another species.
3. Evolutionary changes occur over such a long time that they appear to be gradual.
4. The same change that produces new species also produces new genera, families, orders, classes, and phyla.
5. Species originate in a single locale.
6. Organisms are related when they share a common ancestral group. Relationships of shared ancestry can be assessed by ascertaining how similar two groups are to each other, both phenotypically and genotypically.
7. Environmental change and new forms result in extinction of species and groups of organisms.
8. A truly extinct species has never reappeared.
9. Evolution is proceeding today in generally the same way it has in preceding eras.
10. Fossilized organisms are relatively rare, making the geologic record incomplete with gaps between groups of organisms.
Creationism as a Competing Ideology

Many, if not all, of these postulates are not accepted by the creationist movement. While this movement is itself not unified, but rather diverse, there are some general assumptions that can be made about the shared beliefs of the creationists. From the Creation Science website, the following points were cited from Gish (1985):

1. Life originated from the acts of a Creator.
2. Basic types of animals and plants were created with complete characteristics.
3. While there is variation, it is limited within each kind.
4. Species do not change into other species. Instead, there are sharp boundaries between taxonomic groups. There are no organisms that bridge two or more groups.
5. The fossil record reveals a sudden appearance of many complex forms.

Mayr (1988) pointed out that another crucial element of creationism is a belief that a benevolent God specially created humans. “Perhaps the most important consequence of the theory of common descent was the change in the position of man. For theologians and philosophers alike man was a creature apart from all other living nature” (p. 176). The creationism movement also includes a belief in intelligent design, as represented by Behe’s (1996) *Darwin’s Black Box. “A rigorous theory of intelligent design will be a useful tool for the advancement of science in an area [natural selection] that has been moribund for decades” (p. 230).

Creationists place the Bible as the supreme authority, rather than scientific evidence. Creation science purports that the factual evidence is best interpreted within the framework of creation, which is on equal (or superior) footing with evolutionary theory.
Both creationism and creation science hold a world view that does not tolerate biological evolution. However, as previously discussed, evolution is well accepted by the mainstream community of biological scientists.

Epistemology

This section will first provide an overview of epistemology within the context of education. Next, the application of epistemology in science education will be considered. Finally, a look at student beliefs within the framework of epistemology may shed some light on the problems that college students may have with the understanding of evolution.

*Perry’s Epistemology Model*

Perry (1970) found that some Harvard college freshmen entered college with a dualistic epistemological viewpoint that framed their educational experiences by the following examples: (a) right answers versus wrong answers, (b) good versus bad, and (c) what the professors want versus what the professors do not want. As the students in the study were exposed to multiple opinions within a liberal arts college education, and they observed rewards based on a different basis than expected, they proceeded to a more relativistic epistemological framework. Perry identified nine sequential stages of development through which these students progressed: (a) *basic duality*, which includes the belief that any problem can be solved by alignment with authority; (b) *multiplicity pre-legitimate*, which includes the perception that either others are wrong or confused, or that authorities are providing multiple routes to arrive at the one right answer; (c) *multiplicity subordinate*, which includes a perception of the implications of multiplicity, but the student still trusts authority while recognizing that authorities may not have yet
discovered all absolutes; (d) *multiplicity correlate or relativism subordinate*, which includes the position in which the student considers absolutes to be inaccessible, or the position in which the student thinks that authorities value multiplicity; (e) *relativism correlate, competing, or diffuse*, in which students divide the world into areas where knowledge is dualistic (science) versus areas where knowledge is relativistic (English), or in which absolutism competes with relativism; (f) *commitment foreseen*, in which a student accepts relativism in secular contexts, but feelings come into play, such as eagerness, dismay, or turmoil; (g) *initial commitment*, in which a student affirms commitment based on personal experience and choices; (h) *orientation in implications or commitment*, in which a student recognizes the implications of commitment, such as personal identity; and (i) *developing commitment*, in which a student reaffirms commitment through reflection and actions. The movement through these stages occurred at different rates and at different times for various students. Perry found that some students remained dualistic thinkers throughout their college years.

*Schommer's Epistemology Model*

Schommer and others have expanded the epistemology of Perry’s (1970) model in several studies and reports (Schommer, 1990; Schommer, 1994a; Schommer, 1994b; Schommer, 1998c; Schommer et al., 1997; Schommer et al., 1992; Schommer & Walker, 1995). In a more general application of Perry’s model, Schommer (1998a) examined college students’ epistemology further by exploring whether students’ belief systems about knowledge and learning are domain specific. Looking at the domains of social science and mathematics, Schommer found that, while several aspects of students’
epistemologies are similar across the two domains, students did hold different beliefs about the certainty of knowledge, which depended on the domain. Some students thought that knowledge changes in the social sciences, but not in mathematics. This finding has implications for teaching evolution, which may be perceived by students to belong to the science domain, to the religion domain, or to both domains.

Epistemology has implications for student approaches to learning and knowledge. Schommer (1998b) developed and validated an instrument with four separate epistemological factors relevant to education: (a) stability of knowledge, (b) structure of knowledge, (c) speed of learning, and (d) control of learning. This instrument is composed of 62 Likert-style items, with options ranging from 1 (strongly disagree) to 5 (strongly agree). The higher the score, the more mature or sophisticated the student’s epistemology. This corresponds to Perry’s (1970) model, which depicted movement from a dualistic to a relativistic framework. Schommer’s instrument provides a means by which students’ epistemological beliefs can be readily measured.

Beliefs

This approach places epistemology as a belief system that expands into the affective domain and that is associated with strong emotions. Although beliefs have often been studied in cognitive analyses, beliefs do have an affective component (Snow, Corno, & Jackson, 1996). Krathwohl et al. (as cited in Hopkins, Stanley, & Hopkins, 1990) delineated a diagram of educational objectives within the affective domain. This model begins with a base of awareness and proceeds up through such steps as value acceptance, value preference, commitment, value conceptualization, value system organization, and
characterization through the process of internalization. When values are involved, beliefs’ affective roots can be deeply entrenched. “Adapting instruction to individual differences, \[sic\] would be significantly enhanced by better understanding of the affective and conative character of prior knowledge and belief about the concepts to be learned” (Snow et al., p. 291).

**Role of Epistemology in Science Education**

Windschitl and Andre (1998) used Schommer’s (1998b) instrument to measure the level of epistemological sophistication in approximately 250 college students in a human anatomy and physiology course studying the cardiovascular system. They found an interaction between student epistemology scores and the instructional strategy used. One strategy used a confirmatory lesson that led students to specific conclusions, and the second strategy used an exploratory lesson in which students developed and tested their own hypothesis. Students with a less sophisticated epistemology scored higher on a comprehension test when confirmatory instruction was received and lower when an exploratory instruction was received. Students with a more sophisticated epistemology scored higher on a comprehension test when an exploratory instruction was received and lower when a confirmatory instruction was received. Windschitl and Andre concluded that the epistemological beliefs of learners may play a role in student learning.

Roth and Roychoudhury (1994) applied Perry’s epistemological framework in the context of science education. They proposed that introductory physics students may be at a different maturity stage than their teachers, and that certain instructional climates facilitate the students to shift from a dualistic position to a more relativistic one.
Role of Epistemology in Evolution Education

Scharmann (1990) pondered the role Perry's (1970) model may have in student learning of evolution:

Students often exhibit dualistic perceptions described by Perry . . . as viewing an issue from a discrete "right-wrong" rather than a more global "better-worse" perspective. How then do science educators provide an appropriate context for students to deal with their own acceptance of ambiguity, and hopefully as a consequence, to understand the nature of scientific/evolutionary theory? (p. 92)

In a later report of a teachers' institute designed to improve the teaching of evolution, Scharmann, along with Harris (1992), continued on this theme of dualism. He speculated that students with a dualistic world view might attach themselves to a creation versus evolution debate, and that the topic may cause anxiety to these students. Scharmann suggested that teachers confront their students' dualism and provide a relative stance between the two extremes.

In a qualitative study of 22 students enrolled in a biology course at a community college, Armstrong (1997) investigated the interaction between individual world views and conceptual understanding of biology, including evolution and natural selection. She found that students did not perceive themselves to be a part of nature and that the students' world views influenced their science literacy.

Sinclair et al. (1997) found that some college zoology students felt that there was a dichotomous choice between creationist religious beliefs and evolution and that these beliefs interfered with acceptance of evolutionary theory. Dagher & BouJaoude (1997) found that college students' understanding of evolution was enhanced when given the opportunity to discuss existing religious beliefs in a scientific context.
The association between rejection of evolution and understanding evolution was evaluated by Bishop and Anderson (1990). They found that college students’ belief in the truthfulness of evolutionary theory was not significantly related to posttest performance of the cognitive domain. Demastes, Settlage, et al. (1995) found that college students’ beliefs in evolution were not a contributing factor in students’ usage of scientifically correct conceptions. However, neither of these studies investigated directly a correlation between a conceptual understanding of evolution and creationist belief. These studies leave unanswered the question whether a creationist belief system is related to a lack of understanding of evolution.

Many students who believe in creationism are uncomfortable when evolutionary theory is discussed. Jackson, Doster, Meadows, and Wood (1995) analyzed the tension between evolutionary theory and religion some scientists and educators have experienced. They found that it is difficult to change thoughts and feelings about the two views, which are sometimes seen as opposite world views. They recommended that beliefs should be both considered and respected when teaching evolution. They concluded, “we must concentrate our efforts on using our insight into students’ hearts [italics added for emphasis] to engage their minds, and not on a probably futile and possibly damaging attempt to change their hearts instead” (p. 607). One of the ways to gain insight into students’ hearts is to assess their epistemological beliefs, not with the intention of necessarily changing those beliefs, but of discovering the relationship these beliefs play in students’ minds.
To summarize, college students are at different positions of epistemological beliefs concerning their own learning and their approaches to knowledge. These positions run on a continuum in several areas: (a) dualism to relativism, (b) quick learning to difficult learning, (c) innate ability to acquired ability, and (d) discrete knowledge to interconnected knowledge. The theory of evolution is associated with yet another epistemological aspect in that it is rejected by people who ascribe to a creationist world view. As students approach their own educational experiences, these beliefs, with their strong affective roots, may be involved with comprehension. It would appear that the study of epistemology may be particularly appropriate for a controversial topic such as biological evolution, with its implications and associated philosophical commitments. When the topic is human evolution, many students may feel that not only their world view is threatened, but also their self view. These students do not approach the theories of evolution and common descent in an unemotional, detached manner. All students approach evolution with a world view that that may impact their receptivity. It may be that a better recognition and understanding of students' epistemology systems will illuminate the problems students have in understanding evolution. Perhaps, college students who view the concept of evolution more within the domain of religion than within the domain of science have more difficulty in accepting and understanding evolution. Is there a greater tendency for students to misunderstand evolution should they assign evolution within the religion domain rather than the science domain? Or are there general epistemological characteristics of those students who hold misunderstandings and
reject evolution? There is a need to pursue studies that explore student epistemology within the realm of biological evolution.

Laboratory Investigations

In this section, a review of pertinent articles will be discussed. First, theoretical issues and the benefits of laboratory instruction will be reviewed. Next, the current state of laboratory sessions in learning evolution will be covered. Finally, the review will examine potential uses and benefits of laboratory instruction for learning evolution, particularly common descent.

History

In the early part of the 19th century, Thomas Thompson in Ireland and Justus Liebig in Germany introduced the laboratory method for teaching chemistry at the university level. Later that century, Thomas Henry Huxley used the direct laboratory method for teaching biology (Teller, 1942). Since then, laboratory sessions have been a widely adopted method for teaching the sciences. In 1990, over 80% of twelfth graders were in schools that had one or more science laboratories (Suter, 1992). Kirschner and Meester (1989) addressed the importance currently placed on the science laboratory in higher education.

A university study in the natural sciences, devoid of a practical component such as laboratory work is virtually unthinkable. One could even go so far as saying that it is extremely rare for anyone to question the necessity of laboratory work in either high school or university science curricula. Laboratory work is simply part of the science game. (p. 81)
Theoretical Base

The use of the laboratory method is grounded in the constructivist learning theory, as expounded by Karplus and Thier (1967) in their learning cycle model, which includes exploration, concept introduction, and concept application. Ideally, laboratory sessions provide students with opportunities to make observations and make connections between concepts learned in lectures and textbooks with observed experimental data and interpretations. Laboratory sessions can allow students to learn science in the same manner as it is practiced by scientists.

Deductive Investigations

Hodson (1996) cautioned that an inductivist model of science learning is not as appropriate as a deductivist model of scientific inquiry and learning. Rather, he recommended the use of theory-driven activities in which students observe, measure, predict, collect data, record data, make interpretations, and report findings. These theory-driven activities do not emphasize process skills, but rather, the testing and verification or repudiation of scientific theories and hypotheses, along with a critical reflection on experiments and results. By themselves, hands-on activities are insufficient, but can be made complete by the application of appropriate scientific theory in a deductivist context. According to Hodson, epistemology, as it relates to scientific theories, is a vital component of laboratory instruction that has received scant attention in science educational research and curriculum development.
Effectiveness of Laboratory Sessions

Many hands-on laboratory sessions are cookbook procedures. Students may think that laboratory experiments have "correct" results and that the instructor knows what these correct results are (Ortez, 1994). Instructors often reinforce this mindset by assessing laboratory reports in this modality. These sessions often do not have students actually practice science where a hypothesis is tested and experimental design and controls are student-initiated. There have been attempts to adjust laboratory sessions to be more inquiry-based, but these labs can be chaotic, requiring more time and a less authoritative positioning of the laboratory instructor. Leonard (1983) suggested a model of laboratory sessions that are inquiry-oriented, hands-on experiences, and in which students are allowed to make decisions regarding procedures and use of resources. He found that this type of laboratory experience provided a major benefit to college biology students in learning achievement over a traditional laboratory program.

In a quantitative synthesis of studies addressing the effectiveness of laboratory instruction for high school students, Zhou (1995) found significantly higher levels of cognitive learning of biological content for nontraditional laboratories compared to traditional laboratories. These findings supported assigning laboratory sessions to serve a more central role in instruction. Rubin (1996) reported similar results for college students, in that there were significantly higher levels of cognitive learning of content in both the biological and nonbiological sciences for nontraditional laboratories compared to traditional laboratories. She defined a nontraditional approach to include: (a) computers
and videotapes, (b) inquiry-based laboratory sessions, (c) independent laboratory sessions, and (d) organizational approaches based on student characteristics.

*Laboratory Sessions for Teaching Evolution*

Is the topic of biological evolution adequately addressed by including a laboratory component as part of the instructional strategy? Within the field of evolution, laboratory sessions have been even more problematic than in other scientific areas. A review of the published literature reveals that many evolution labs are based on simulated scenarios, or analogies, such as colored paper rabbits and pretend hawks. Few labs are truly designed for students to observe natural selection in nature. Some students who are reticent to accept evolution may never be convinced by the use of analogies, as opposed to real and natural phenomena.

McComas (1994) reported his own review of 58 separate exercises from 12 different high school textbooks.

What is most interesting is the high degree of uniformity in the activities provided in these published sources. For instance, virtually all of the laboratory manuals reviewed include some version of a natural selection simulation, and over half of all the sources consulted include human ancestry activities in which students measure and compare line drawings of various primate skulls. Unfortunately, there is nothing particularly illustrative about the primate skull approach, nor can this approach legitimately be called an inquiry activity. (p. 7)

McComas has edited a valuable book, *Investigating Evolutionary Biology in the Laboratory*, which is a compilation of 24 activities to help secondary students learn evolution. About two-thirds of the activities are simulations or demonstrations and about one-third of them are experiments.
Nickels (1987) designed a laboratory that addresses human evolution. While the exercise can be done with line drawings, he suggested that life-sized casts of hominoid skulls are preferable to drawings or pictures because they are three dimensional, they have hands-on appeal, and because students are studying their own species and can easily relate to other primates. Nickels concluded:

It is virtually impossible for any student to fail to see the continuity and gradation of form evident in these fossil specimens that is entirely consistent with the conclusion that there has in fact been descent with modification . . . After all, if there is sound, reliable, well documented evidence that humans among all species have evolved, then it is less likely that students will be reluctant to accept evolutionary explanations for the origin of other life forms. (p. 148)

It would be of interest to research learning in a context in which students examine their own evolutionary origins in an inquiry-based laboratory session. The area of human evolution is probably the one least accepted by creationists. There is a need to explore student understanding of the theories of evolution and common descent within the context of an inquiry-based instructional laboratory session. The next chapter will describe the research methods and procedures used to carry out this exploration.
CHAPTER 3

METHODS AND PROCEDURES

Research Design

The nature of this study was that of an exploratory study of college students, in which qualitative and quantitative research components were used. This combination of methodologies was patterned after the model of a dominant-less dominant research design (Creswell, 1994), which is especially appropriate for quantitative studies that include a smaller qualitative portion with interviews. This methodological model was chosen for its ability to study the relationships between the quantitative variables of interest and to explore in depth college students’ conceptions of common descent.

The quantitative method was the dominant method, with a deductivist application of the two theoretical rationales of epistemology and guided-inquiry student-directed learning experiences. This portion of the study analyzed relationships between students’ epistemologies and conceptual knowledge as measured on both preinstruction and postinstruction tests. Since this was an exploratory study that looked for possible relationships, a correlational design was appropriate for the quantitative component (Gay, 1996).
The qualitative method was the less dominant method. Data collection and data analysis included laboratory worksheets, activity sheets, and interview transcripts. The qualitative component included an analysis of the students' laboratory worksheets in order to ascertain evidence of the students' understanding of common descent. The interviews were conducted to provide a detailed investigation of the following: (a) students' understanding of the theory of common descent, (b) students' misconceptions about the theory of common descent, (c) students' reflections about the evidence presented, and (d) students' attitudes toward the teaching strategy.

Qualitative studies are appropriate when an extended analysis of narrative data is needed and when the research is conducted in a naturalistic setting (Gay, 1996). Qualitative methodologies have discovered most, if not all, of the identified alternate conceptions and misconceptions held by students in a scientific field.

This study included six elements. The first consisted of an epistemology instrument that provided scores for each student in five separate facets of epistemology: (a) belief in evolution/creationism, (b) stability of knowledge, (c) structure of knowledge, (d) speed of learning, and (e) control of learning. The second element consisted of a pretest that covered evolutionary theory in general and the theory of common descent. The third element consisted of an instructional strategy that used a guided-inquiry student-directed laboratory session in which students developed their own procedure and made observations of eight primate skull casts. The fourth element consisted of the students' laboratory reports that were assigned as part of the guided-inquiry student-directed laboratory. The fifth element consisted of a posttest that covered both
evolutionary theory in general and the theory of common descent. The final element consisted of the interviews of a few selected students, which included two activities relative to common descent.

The researcher applied for and received an exemption from The Ohio State University Human Subjects Review Committee based on the fact that the study was conducted as part of the normal activity of a college-level course. This study included students who were of legal age, and it provided no risks to the students. The students' identities were kept confidential. Written consents were also obtained. A copy of the consent form is shown in Appendix E.

Site

This study was conducted at a two-year community college. This site was chosen because of its appropriateness for this particular study and because of the scarcity of studies using community colleges as science educational research sites. The specific site was the Biology 111 course at Columbus State Community College (CSCC), a technical community college. CSCC has an enrollment of approximately 18,000 part-time and full-time students. It is located in Columbus, Ohio, an urban community with a population of 1,017,274 residing in Franklin county (Franklin County Commissioner's Office, personal communication, March, 1999). CSCC's emphasis is to provide 2-year technical degrees. CSCC has a dual enrollment policy with The Ohio State University, Columbus, Ohio, so that some students attending courses at CSCC are in four-year programs at the university.

Biology 111 is a required course for certain majors, such as medical laboratory technology and respiratory therapy. This course also meets the requirements for the core
Two separate sessions of Biology 111 were involved in the study. Each class was composed of approximately 22 students, for a total of 45 students. These two sections of Biology 111 included lecture and laboratory components, both of which met in a laboratory-style classroom. Students faced each other as they sat in groups of 3 or 4 around a laboratory bench table. In the classroom there were six black laboratory tables and various biology-related supplies, such as several aquariums, a terrarium, plants, and a large bird house with several live birds.

Subjects

The participants in this study were 45 students enrolled in two separate sections of Biology 111 in the spring quarter of 1999. Each section had a separate instructor. The topic of evolution was part of the required curriculum. The following demographic information pertaining to each subject was ascertained for descriptive purposes: (a) gender, (b) year in college, (c) number of high school biology courses taken, (d) number of college biology courses taken, (e) and college grade point average.

For the qualitative portion of this study, a purposeful sample of 11 students was selected from the 40 students who participated in the laboratory session that examined primate skulls (Out of the original 45 students, 5 students were absent for the laboratory session). The students interviewed were selected based on their scores on the epistemology instrument. Those students who were chosen had scores representing an extreme on at least one factor of the epistemology instrument. Students were interviewed to find out more about their knowledge of common descent, to discover any alternate conceptions they might have, and to learn what their attitudes were toward the teaching
strategy employed. The interviews were designed to include questions and two activity worksheets to facilitate the researcher in discovering areas of difficulty that students encounter with the theory of common descent. Descriptive statistics and characteristics of the total group and the interviewed sample were determined, including the means of the scores on each epistemology factor, the pretest scores, and the posttest scores.

**Instrumentation**

The epistemology instrument and the pretest for knowledge of evolutionary theory were administered on separate days during the first four weeks of spring quarter, 1999, to all consenting students present in class. A sample of the epistemology instrument is in Appendix A. The posttest for knowledge of evolutionary theory was given approximately five weeks after instruction. A sample of the knowledge test is in Appendix B.

**Epistemology Survey**

The epistemology instrument was used to determine a score for each of the five factors of each student’s epistemology: (a) *stability of knowledge*, (b) *structure of knowledge*, (c) *control of learning*, (d) *speed of learning*, and (e) *belief in evolution/creationism*. On the first four factors, Schommer et al. (1997) reported a test-retest reliability that had averaged .70. Inter-item correlations for items that composed each of the first four factors had ranged from .63 to .85. As part of this study, the reliability was calculated using the formula for Cronbach's alpha. The reliabilities of the five epistemology factors were found to be .74, .00, .65, .61, and .87, respectively. Due to the poor reliability of the *structure of knowledge* factor, it was subsequently dropped from this study. These reliability values are discussed further in Chapter 5.
The belief in evolution/creationism factor was included as part of a pilot study conducted for this study. Upon completion of the pilot study, the items for the belief in evolution/creationism factor were refined and additional items were added. Six of the items (64, 74, 75, 77, 78, and 79) comprising the belief in evolution/creationism factor were obtained and modified from a survey of Wisconsin teachers (Van Koevering and Stiehl, 1989). One of these items (74) was reworded to better reflect the creationist writings of Gish (1985). One item (66) was obtained from a questionnaire by Johnson and Peeples (1987). One item (76) was obtained from a questionnaire by Bergman (as cited in Lord and Marino, 1993). Five of the items (69, 70, 71, 72, and 73) were derived by the researcher from Mayr's analysis of historical objections to Darwin's work (Mayr, 1988). Six items (63, 65, 67, 68, 80a, and 80b) were written by the researcher and were based on experience and many years of personal exposure to creationist ideology. The items for the belief in evolution/creationism factor were verified for validity by professors and an instructor knowledgeable of evolution and the evolution-creationism debate.

All the items except the demographic information and items 80a and 80b contained responses based on a five-point Likert scale. Items 80a and 80b asked for a fill-in-the-blank response. The directions for the instrument were as follows:

_There are no right or wrong answers for the following questions. We want to know what you really believe. For each statement, circle the letter(s) indicating the degree to which you agree or disagree. Strongly Agree = SA; Agree = A; Neutral = N; Disagree = D; Strongly Disagree = SD_

The following demographic information was requested: (a) name, (b) gender, (c) year in college, (d) number of biology courses in high school, (d) number of biology
courses in college, and (e) college grade point average. The response for the grade point average was given as an option to mark as one of six separate categories: 3.5 - 4.0; 3.0 - 3.4; 2.5 - 2.9; 2.0 - 2.4; 1.5 - 1.9; less than 1.9. The directions for the demographic part of the survey were as follows: "You will receive credit for completing this survey, but your responses will not be graded by your instructor. Personal information will be held confidential. Thank you."

It should be noted that the directions given on the epistemology survey were aimed at obtaining the beliefs of the participants rather than testing their knowledge. This distinction was made by the following points given in the instructions: (a) the choices of the responses ranged from strongly agree to strongly disagree, (b) the responses were to be what the participants "really believe," (c) there were no right or wrong answers, and (d) the instructors were not grading the survey.

Scores were obtained by changing the polarity of certain questions in order to make responses unidirectional for each construct. Each of the five options was associated with a numerical score of 1, 2, 3, 4, or 5. The more sophisticated epistemology was scored the highest for each of the four factors. Additionally, items that loaded onto a factor were averaged for a mean factor score. For the belief in evolution/creationism factor, the polarity of each question was arranged so that the lower the score, the more the student agreed with the creationist perspective, and the higher the score, the more the student accepted evolution. Each student received a mean score for each factor.
Knowledge of Evolutionary Theory Test

The knowledge of evolutionary theory test assessed student knowledge of the theories of evolution and common descent. The knowledge pretest was entitled, "What do you know?" and the instructions directed the students to give the best answer to each question. The knowledge posttest was given as a component of a class exam for which students were receiving grades. The questions were designed to be sensitive to students who may not believe in evolution by phrasing a question, "biologists think that," or "biologists would say that," so that students could answer honestly. Furthermore, neither of these two tests was given the same day that the survey was administered.

Items 1, 2, 5, and 6 were multiple-choice questions and were written by the researcher. These questions were designed to be relevant to common descent and to address the particular student learning goals identified in Scope, Sequence, and Coordination: A Framework for High School Science Education (National Science Teachers Association, 1996).

Item 3 was a question modified from Sinclair et al. (1997), and item 7 was a multiple-choice question modified from Brumby (1984). Item 8 was modified from Bergman (as cited in Lord and Marino, 1993). Item 9 was written by a fellow student and biology teacher. Prior to any statistical analysis of the data, a decision was made to drop item 4 from this study, because the item was a modification of an item used on opinion surveys (Lord & Marino, 1993; Zimmerman, 1987). The original wording used in other studies was, "Do you think that the modern theory of evolution has a valid scientific foundation?" The question was modified in this study to read, "Does the modern theory of
evolution have a valid scientific foundation?" Although this modification changed the question from one that solicited opinion to one that attempted to solicit knowledge alone, it still had a history of being an opinion, or belief, question in its original format. It was decided to omit this item from the knowledge test in order to maintain the distinction between the belief domain and the knowledge domain, even though the students in this study were most likely to be unfamiliar with the item's history. The prior use of the item as a belief item probably did not bear on the responses the students made to the remaining items on the knowledge test. The students' knowledge of the nature of evolution's foundation within the scientific community was solicited by asking questions with another perspective in Items 2 and 5 in which students were asked how biologists would interpret evidence.

The number of correct answers was added together for a total score assigned to each student. Of the 8 questions, items 1, 2, 5, and 6 involved the theory of common descent. The number of correct answers for these 4 items was added together for a subscore on the construct of the theory of common descent. The complete test was given as a pretest. The items and options were placed in a different sequential order on the posttest.

The items on the knowledge of evolutionary theory test were verified for validity by professors and biology instructors knowledgeable of evolutionary theory.

Laboratory Worksheets

As students applied evolutionary theory during the guided-inquiry student-directed component of the instruction, they completed worksheets by recording
procedures, observations, and conclusions. These worksheets were collected and analyzed for evidence that the students arrived at scientifically correct responses. The students' answers were also analyzed for the persistence of alternate conceptions.

Student Interview Protocol

The interview protocol was developed by the researcher with help from an assistant professor knowledgeable of qualitative research methodology and evolutionary theory. Practice interviews were conducted by the researcher as a part of a pilot study to check for the appropriateness of the instrument and to determine the approximate time for each interview. A college biology instructor examined the questions for validity and also coded the interviews' transcripts to verify that the data had been categorized consistently.

Instructional Strategy

The instructional unit on evolution included both a laboratory component and a lecture component. After brief comments about common descent and a distribution of a hand-out about human evolution, there was a laboratory activity using factual genetic evidence to test the evolutionary theory of common descent and to serve as a model of the application of theory testing. This hands-on activity was a modification of Activity 4 in *Teaching About Evolution and the Nature of Science* (National Academy of Sciences, 1998). The second part of the laboratory session centered around a guided-inquiry student-directed activity. This component employed an analysis of experimental evidence and factual observations in an effort to demonstrate to the students that evolution is observable. Casts of eight different primate skulls were available for students to observe and measure. This particular activity was a modification of an activity written by Nickels
(1987). The format of the lab was that of guided inquiry in which the instructors guided, coached, and encouraged the students to develop their own procedures for making observations, analyzing data, and interpreting results while applying pertinent theories. The students assessed their findings and made conclusions relevant to the hypothesis tested as they completed worksheets that were in the same format as the worksheets in the DNA activity of the session. However, it should be noted that while this laboratory session used guided inquiry, it did not adhere strictly to the optimal instructional usage of this format. Rather, due to the exploratory nature of this study, the laboratory format was adjusted to better obtain students' conceptions of common descent. There was a concern that had the full guided-inquiry format been utilized, including a class-wide sharing of results and summation of findings, students may have changed their initial responses on the laboratory worksheets. As part of this study, these worksheets were evaluated for alternate conceptions. So in order to preserve these narrative data, the instructor did not lead a class discussion that would have summarized student and did not emphasize the current specific scientific interpretations of the skulls, other than that they were related. Thus the effectiveness of a guided-inquiry laboratory cannot fully be determined as part of this particular exploratory study. The remaining instructional strategy was a traditional one with approximately 2 to 4 hours of lecture conducted by each individual instructor who covered evolutionary theory with an emphasis on natural selection.

Procedures for Collecting Data

Early in the spring quarter, 1999, the researcher distributed the consent forms to the students. Since the students were enrolled in college course work, it was likely that all
students were at least 18 years of age. The instructors served as witnesses and signed each form as such. After the consent forms were collected, the epistemology instrument and the pretest were distributed and collected by the instructors and the researcher.

The epistemology instrument was scored and students were selected for participation in the interviews. Students were given the choice of being interviewed at a time and place convenient to them. Each student interviewed was given a token of appreciation for participating.

The interviews followed a script, but were also open-ended to enable the researcher to probe into relevant areas based on responses to the scripted questions. With the student's permission, the interviews were audio taped and transcribed. The primary purpose of these interviews was to discover alternate conceptions about the theory of common descent.

Methods of Analysis of Data

Descriptive statistics were run on each of the following: (a) demographic variables, (b) each epistemological factor, and (c) each score and subscore on the knowledge test.

An alpha level of .05 was established a priori for all statistical tests of significance. A repeated measures $t$-test was run to compare pretest and posttest scores for correct responses for both the total score and for the subscore on the common descent component. Gender differences on the knowledge tests were examined by calculating $t$-test values. Instructor effect for the two separate sections was also examined by calculating $t$-test values.
Due to the interval nature of the other demographic variables, simple correlations were computed to determine the relationships between the demographic variables and student knowledge variables. The demographic variables were: (a) year in college, and (b) number of previous biology courses. The knowledge variables were: (a) total scores on the knowledge pretest, (b) total scores on the knowledge posttest, (c) subscores on the common descent component pretest, and (d) subscores on the common descent posttest. The scores for the knowledge tests were correlated to mean scores for each of the following epistemology variables: (a) stability of knowledge, (b) structure of knowledge, (c) control of learning, (d) speed of learning, and (e) belief in evolution/creationism.

Pilot Study

A four-phase pilot study was conducted. Each phase will be described as to the procedures performed.

In the first phase, to test the epistemology instrument and the pretest, the researcher administered these two instruments to 41 students, 31 of which attended a liberal arts college and 10 of which attended a community college. As a result of the pilot, the epistemology instrument was modified to include additional questions, and items from the evolution/creationism factor were reworded for clarity. Also, some of the questions asking for demographic information were deleted due to their irrelevance to the proposed study.

The knowledge test was modified after the administration to the pilot groups. The modifications were made in order to include additional items to test knowledge about
common descent. The final knowledge test instrument was administered to a group of graduate biology students to ascertain reliability.

In the second phase, in order to practice the instructional strategy, the researcher presented the laboratory session in three different classes: (a) a class of 13 students in a human biology course at a community college, (b) a class of 11 students in a zoology course at a high school, and (c) a class of 6 students in a senior biology seminar at a liberal arts college. As a result of the pilot, the researcher modified the instructional strategy to place more emphasis on the theory of common descent.

In the third phase, the posttest was given to 10 students who participated in the instructional strategy at the community college. As a result of the focus on common descent mentioned previously, the number of items on the posttest was reduced to include only those items which tested the broader aspects of the process of evolutionary theory and the aspects of the theory of common descent.

For the fourth phase, in order to practice the interviews, the researcher interviewed 3 students that were part of the senior biology seminar at the liberal arts college. The goals for the practice interviews were to determine the amount of time to allocate for each interview and to discover if any questions should be eliminated or added.

Limitations

1. Since evolution is viewed by some students as a controversial issue, there may have been a reluctance for students to participate in the study.
2. Because some students may be influenced by a researcher, the results may have been biased toward what students may have perceived that the researcher had desired.

3. The subjectivity of interview methodology may have led to findings reflecting researcher bias.

4. Students may have acted differently when being audio taped than they would have in more natural settings.

5. Because the sample was not a random sample, no generalizations could be made concerning college students at other institutions or other kinds of institutions with respect to the variables under study.

6. Because the sample was not a random sample, no generalizations could be made concerning students of other ages with respect to the variables under study.

7. This study did not address all the potentially relevant instructional variables with which students have had contact during their precollege schooling or their postsecondary education.

8. The relatively short instructional strategy may be considered to be a limitation by some.

9. Another limitation that may be considered by some is that the students were aware that they were participating in a research study, and thus the “Hawthorne Effect” (Gay, 1996) may have come into play.

10. The inquiry-based learning laboratory sessions may have been subjected to researcher-participant interaction or to instructor-participant interactions.
Assumptions

1. Some college student conceptions are considered to be outside the scientific community's understanding of the main principles and processes of evolution and common descent.

2. College students' epistemological beliefs were measurable with the epistemology instrument.

3. College students' epistemological beliefs were related to their learning of scientific concepts.

4. Instruments used in this study were valid and reliable measurements of college students' understanding of the theory of evolution and the theory of common descent.

5. Instruments used in this study were valid and reliable measurements of college students' epistemological beliefs.

6. Subjects were open and honest in their responses to questions concerning the issues of evolution and personal beliefs.

7. The instructional laboratory session was a valid presentation of guided-inquiry student-directed learning.
CHAPTER 4

RESULTS

This chapter contains the results of the statistical analysis of the quantitative data and the results of the classification and analysis of the qualitative data. The analysis of the quantitative portion addressed the following research questions:

1. What is the level of college student understanding of the theories of evolution and common descent as measured on a knowledge test both before and after instruction?

2. Which, if any, of the five epistemological factors are associated with college student understanding of the theories of evolution and common descent?

3. Do demographic variables, such as gender, year in college, and number of biology courses previously taken, have a relationship with student understanding of the theories of evolution and common descent?

The analysis of the qualitative portion addressed the following research question:

What, if any, are the alternate conceptions that college students have about the theory of common descent?

Presentation and Analysis of Quantitative Data

This section will first report the descriptive analysis of the epistemology survey instrument, which consisted of demographic information and the five epistemological
factors, including belief in evolution/creationism. Next will be the descriptive analysis of the knowledge test followed by correlational studies of the relationships between the scores of the epistemology instrument and the scores on the pretest and on the posttest evolution knowledge test. The relationships of demographic data such as gender, year in college, and number of biology courses taken were also examined for significant differences. For all statistical tests of significance, an alpha level of .05 was established a priori. The statistical analyses were performed using the software program GB-STAT for Windows (Dynamic Microsystems, Inc., 1995).

Before the statistical analysis was completed, there had to be decisions made about how to handle the various types of data that were missing in the students' responses. There are several ways to deal with missing data (Little & Rubin, 1987). The missing data can be ignored, or the participant with missing data can be dropped from the study, or the data can be imputed or substituted based on information available. This last strategy can be accomplished by randomly assigning values, or by looking for patterns of responses to other questions asked of the participant with the incomplete data, or by examining patterns of responses given by other participants. These patterns can then be used to impute data points via regression analysis or measurements of central tendency. Depending on the nature of the missing data, different strategies were used in this study and will be described in detail in each of the sections with missing data.

The first decision that had to be made relative to missing data was to decide which participants to include in the study. There were 45 students who answered the epistemology survey, and all were included in the descriptive statistics relative to the
epistemology factors and the demographic variables. Only 39 of these same students were present for the laboratory session and the pretest administration. Because it was not possible to impute data for the knowledge test, the students who had not completed the knowledge tests were not included in the correlational aspects of the study. One additional student was present for the laboratory session and completed the pretest, but because she had not completed the epistemology survey, none of her responses was included in the quantitative portion of the study. Of the 39 students who completed the pretest, 38 of these students completed the posttest. One additional student completed the posttest and did not complete the pretest, but had completed the epistemology survey. Therefore, this student was included in the study.

**Summary of the Statistics of the Demographic Data**

The epistemology survey instrument contained five items soliciting demographic information: (a) gender, (b) year in college, (c) number of biology courses in high school, (d) number of biology courses in college, and (e) college grade point average (GPA). For a complete transcript of the questions and possible responses please refer to the epistemology survey instrument in Appendix A.

**Missing Data**

Of the 45 students surveyed, there was 1 student who omitted answering all five of the demographic items, 1 student who omitted the response to year in college, and 2 students who omitted the response to grade point average. The missing data represented 4% of the total demographic data (8 responses out of 225 total responses). The particular student who omitted all five of the items was observed by the researcher to be a man.
the response "male" was entered for gender into the data base for this student. The remaining missing data were imputed by using the group mean for each individual item. This mean was obtained by adding together all of the other students' responses for the particular question and dividing by the number of students responding. This strategy was chosen because there were no other variables on the epistemology survey that could have been used to logically predict the demographic variables. Had there been, estimates for these missing demographic data points could have been obtained through regression. However, since there were so very few missing data points, a measure of central tendency was an appropriate way to input missing data. The mean was arbitrarily chosen as an appropriate indicator of central tendency in this instance, because there were so few missing data points. Random assignment could have possibly produced outlier values that would not have truly represented the population. It was very unlikely that a measurement of central tendency would have skewed the group means or would have interfered with correlational results.

Descriptive Statistics

Of the 45 students, 27 (60%) were women and 18 (40%) were men. Two-thirds of the students (67%) had completed less than 2 years of college. Eight (18%) were in their first year of college, 22 (49%) were in their second year of college, 11 (24%) were in their third year of college, and 4 (9%) were in their fourth year of college. The distribution of these results is depicted in Figure 1.

The majority of the students (60%) had fewer than two high school biology courses. One student (2%) had not taken a high school course in biology, 26 students
Figure 1: Distribution of students by years of college
(58%) had one high school biology course, 15 students (33%) had two high school biology courses, and 3 students (7%) had three high school biology courses. The distribution of these results is depicted in Figure 2. Two students (4%) reported having no previous college courses in biology, 39 students (87%) reported that they had one college biology course, and 4 students (9%) reported that they had two college biology courses. The distribution of these results is depicted in Figure 3.

Two-thirds of the students (67%) reported that they had at least a “B” average in college coursework. Nine students (20%) reported a GPA of 3.5 – 4.0, 21 students (47%) reported a GPA of 3.0 – 3.4, 9 students (20%) reported a GPA of 2.5 – 2.9, 5 students (11%) reported a GPA of 2.0 – 2.4, 1 student (2%) reported a GPA of 1.5 – 1.9, and 0 students (0%) reported a GPA less than 1.5. The distribution of these results is depicted in Figure 4.

Summary of the Statistics of the Epistemology Factors

The epistemology survey instrument was composed in part of Schommer’s epistemology survey which had been validated in previous studies (Schommer, 1990; Schommer, 1998c; Schommer et al., 1992). Schommer et al., (1997) reported this instrument to have four consistent factors, with each of these factors consisting of subscales. The following factors were a part of this study: (a) stability of knowledge, (b) structure of knowledge, (c) speed of learning, and (d) control of learning. The factor, stability of knowledge, was composed of the following subscales: (a) depend on authority, (b) don’t criticize authority, (c) seek single answers, and (d) knowledge is certain. The factor, structure of knowledge, had only the one scale, knowledge is
Figure 2: Distribution of students by number of high school biology courses

Figure 3: Distribution of students by number of college biology courses
Figure 4: Distribution of students by grade point average
integrated. The factor, *speed of learning*, was composed of the following subscales: (a) *learn the first time*, (b) *quick learning*, (c) *success unrelated to hard work*, and (d) *concentrated effort is a waste of time*. The factor, *control of learning*, was composed of the subscales: (a) *can't learn how to learn*, and (b) *ability to learn is innate*.

**Validity of Epistemology Instrument**

The last major component of the survey instrument was the *belief in evolution/creationism* factor developed as part of this study. The items for the evolution/creationism acceptance factor were obtained from former studies (Bergman as cited in Lord and Marino, 1993; Johnson & Peeples, 1987; Van Koevering & Stiehl, 1989), from creationism literature (Gish, 1985), from historical arguments used against evolution (Mayr, 1988), and from the researcher's personal experience. The construct validity and the unidimensionality of each item were verified by a college biology instructor knowledgeable of evolution and of the evolution/creationism debate. Suggestions were incorporated into the wording of the items. To further validate the instrument, input was then obtained from a professor emeritus of evolution and from three associate professors knowledgeable of evolution and of the evolution/creationism debate.

Forty-five students participated in answering the epistemology survey instrument. The survey consisted of 79 Likert-style questions, with each item having the five options of "Strongly Agree," "Agree," "Neutral," "Disagree," and "Strongly Disagree." There were 2 additional questions, each asking for a numerical value to be expressed in a percentage.
Each Likert response was assigned a number of 1 to 5. A value of 1 was assigned for the response “Strongly Agree,” a value of 2 was assigned for the response “Agree,” a value of 3 was assigned for the response of “Neutral,” a value of 4 was assigned for the response “Disagree,” and a value of 5 was assigned for the response “Strongly Disagree” for items 1, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 16, 17, 19, 20, 21, 22, 23, 30, 31, 33, 34, 36, 37, 38, 40, 41, 42, 44, 47, 49, 50, 51, 52, 55, 56, 57, 58, 61, 62, 64, 65, 66, 67, 69, 70, 73, 74, 75, and 79. To ensure that items expressed in an opposing manner contributed to the appropriate constructs, the polarity was reversed for 29 items: 4, 7, 14, 15, 18, 24, 25, 26, 27, 28, 29, 32, 35, 39, 43, 45, 46, 48, 53, 54, 59, 60, 63, 68, 71, 72, 76, 77, and 78. The direction of the polarity was established so that the higher the score, the more sophisticated the belief for each of the factors. The level of sophistication was judged from a developmental perspective.

Initially, each factor was composed of items that appeared to contribute to the individual construct. For example, item 1, “If you are ever going to be able to understand something, it will make sense to you the first time you hear it,” was a contributor to the factor, speed of learning. Items from the epistemology instrument were assigned to the four factors reported by Schommer et al. (1997) and to the belief in evolution/creationism factor developed as part of this study. These preliminary assignments are summarized in Table 1.
Table 1: Assignment of items to epistemology factors

<table>
<thead>
<tr>
<th>Epistemology Factor</th>
<th>Item Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belief in Evolution/Creationism</td>
<td>63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79</td>
</tr>
<tr>
<td>Stability of Knowledge</td>
<td>3, 5, 6, 7^a, 11, 12, 13, 16, 19, 21, 23, 31, 33, 34, 36, 37, 38, 40, 41, 45, 46, 58</td>
</tr>
<tr>
<td>Structure of Knowledge</td>
<td>14, 18, 38, 54, 62</td>
</tr>
<tr>
<td>Speed of Learning</td>
<td>1, 10, 20, 24, 29^a, 39, 43, 49, 50, 51, 52, 53, 59</td>
</tr>
<tr>
<td>Control of Learning</td>
<td>4, 8, 15, 25, 26, 28, 32, 47, 55, 56, 57, 58</td>
</tr>
</tbody>
</table>

*^a* Not included in final analyses due to low reliability value.

**Missing Data**

The epistemology factors were calculated for the students by using the mean of the completed items that contributed to each corresponding factor. Five students left a total of 12 questions blank, or 0.3% of the total possible responses (12 out of 3645). Since the factors were calculated using the mean of contributing items, the missing values were imputed for each item by using the mean of the appropriate factor for each of the 5 students. This mean was calculated on an individual student basis by adding the values for the items that were not missing and that contributed to the construct to which the missing data point belonged and then by dividing by the number of items that were answered in this factor. This strategy was chosen because the other items of each factor

76
were indicative of the individual student's belief in that factor and thus, the central
tendency of each student's response could be imputed for these rare occurrences.

Reliability

Reliability values were calculated by using the formula for Cronbach's alpha. Upon inspection of a correlation matrix, adjustments were made in the items assigned to two of the factors. These adjustments were made to increase the reliability of the factors without jeopardizing the validity of the construct.

The epistemology factor, belief in evolution/creationism, did not require any adjustments. The value of Cronbach's alpha for this epistemological factor was .87.

The reliability of the stability of knowledge factor was reduced when item 7 was included, “I often wonder how much my teachers really know.” Since the instructors were the ones who administered this survey, the students may have had an issue of not trusting in the anonymity of their responses to this question. This item was on the first page, which was the same page on which students recorded their names. Thus, this item was judged to be invalid because some students may not have felt free to give an honest response. Before this item was removed, the value of Cronbach's alpha for the epistemological factor, stability of knowledge, was .69, and after the item was removed the reliability was .73.

The Cronbach's alpha for the factor, structure of knowledge, was .00. This factor was subsequently dropped from any further analysis due to its low reliability value. The reliability may have been low because the full dimension of this construct may not have been examined due to the limited number of items belonging to this factor. It is
unfortunate that this factor was not reliable because the relationship between student beliefs in the interconnectedness of knowledge could not be determined.

One item did not correlate well with the other items in its assigned factor and was subsequently removed from the epistemology factor, *speed of learning*. This was item 29, "When you first encounter a difficult concept in a textbook, it's best to work it out on your own." Upon closer inspection, this question appeared to consist of two separate ideas. It is suspected that some students may have responded to the "on your own" part of the question rather than to the idea of working out a difficult concept. Therefore, this item was judged to be not valid due to the implications of its dual nature being outside the construct of belief in the *speed of learning*. This item was subsequently not included in the computation of the mean for this factor. Prior to removing this item, the reliability for the epistemological factor, *speed of learning*, was .50 and after removing item 29, the resulting value of Cronbach’s alpha was .61.

The epistemology factor, *control of learning*, did not require any adjustments. The value of Cronbach’s alpha for this epistemological factor was .65.

The reliability values for the factors are depicted in Table 2.

*Descriptive Statistics*

The individual scores for the epistemological factors were determined by calculating the mean of the items that contributed to each factor. The means and standard deviations for each of the epistemology factors are summarized in Table 2. The possible scores for each factor ranged from 1 to 5. The meanings of these individual scores will now be further explained.
### Table 2: Reliabilities, means, and standard deviations for the epistemology factors

<table>
<thead>
<tr>
<th></th>
<th>$\alpha$</th>
<th>$M$</th>
<th>$SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belief in Evolution/Creationism $k=17$</td>
<td>.87</td>
<td>3.38</td>
<td>0.578</td>
</tr>
<tr>
<td>Stability of Knowledge $k=21$</td>
<td>.73</td>
<td>3.13</td>
<td>0.365</td>
</tr>
<tr>
<td>Speed of Learning $k=12$</td>
<td>.61</td>
<td>3.78</td>
<td>0.396</td>
</tr>
<tr>
<td>Control of Learning $k=12$</td>
<td>.65</td>
<td>3.46</td>
<td>0.442</td>
</tr>
</tbody>
</table>

$N=45$

Note: Score range is from 1 to 5

For the factor, *belief in evolution/creationism*, the scores ranged from 2.00 to 4.29. The distribution of scores for this factor is displayed in Figure 5. The higher the score, the more likely it was that the student accepted evolution. The lower the score, the more likely it was that the student believed creationism and rejected evolution. The mean score for *belief in evolution/creationism* was 3.38 ($SD = 0.578$). The scores on this factor displayed more variation than the scores on the other epistemological factors. The distribution of scores indicated that there were students in the study who rejected evolution in favor of creationism, and there were students who accepted evolution.

For the factor, *stability of knowledge*, the scores ranged from 2.19 to 3.81. The distribution of scores for this factor is displayed in Figure 6. The higher the score, the more likely it was that a student did not rely on authority and that a student believed in
Figure 5: Distribution of student scores on the belief in evolution/creationism epistemology factor

Figure 6: Distribution of student scores on the belief in the stability of knowledge epistemology factor
the uncertainty of knowledge. The lower the score, the more likely the student looked to authority as a source and that the student believed in the certainty of knowledge. The mean score for stability of knowledge was 3.13 ($SD = 0.365$). This score represented the lowest mean value and the lowest variation obtained for any of the epistemology factors.

For the factor, speed of learning, the higher the score, the more sophisticated the epistemology and the less likely a student believed in the simplicity and quickness of learning. The mean score for speed of learning was 3.78 ($SD = 0.396$) and the actual scores ranged from 2.83 to 5.00. This score represented the highest mean value of any of the five epistemology factors and indicated that these students as a group were less likely to believe in quick and simple learning and more likely to believe in the value of hard work and to devote more time to learning. The distribution of scores for this factor is displayed in Figure 7.

For the factor, control of learning, the scores ranged from 2.58 to 4.58. The higher the score, the less likely a student believed in innate learning ability and the more likely a student believed in the acquisition and development of learning ability. The mean score for control of learning was 3.46 ($SD = 0.442$). This score represented the second highest mean value of the epistemology factors and indicated that the views of these students as a group tended to agree with a belief in the acquisition and development of learning ability. The distribution of scores for this factor is displayed in Figure 8.

To further explore the meaning of the group scores, the variations were examined relative to each student's responses within the individual epistemology factors. First, the standard deviations for each individual student were determined for the groups of items
Figure 7: Distribution of student scores on the belief in the speed of learning epistemology factor

Figure 8: Distribution of student scores on the belief in the control of learning epistemology factor
contributing to each of the four factors. For example, if a student had a mean score of 3.06 for the belief in evolution/creationism factor, the degree of variability for each of the 17 items that contributed to that particular factor was examined. For example, a particular student's response to the 17 items averaged 3.06. Was the mean score of 3.06 obtained from the averaging of a fairly equal number of 1's and 5's? Or was the mean score of 3.06 a reflection of most of the responses being a 3? For the particular student chosen for this example, the standard deviation of the responses to the belief in evolution/creationism factor was .43. This meant that for about two-thirds of the items, or 12 items out of 17, the responses were ± .43 Likert responses away from the mean score of 3.06. In other words, this student's responses were consistently close to 3, indicating a stance of neutrality toward both evolution and creationism.

This type of analysis for the belief in evolution/creationism factor was expanded to include the entire group of 45 students. It was discovered that for 12 out of the 17 items, 11% of the students responded within ± 0.5 Likert responses away from their mean score, 64% of the students responded within ± 1.0 Likert responses away from their mean score, 80% of the students responded within ± 1.3 Likert responses away from their mean score, and 100% of the students responded within ± 1.5 responses away from their mean score. Although there were only 5 Likert responses to choose from on each item, a response of ± 0.5 was rather consistent and indicated that the student did not have a large degree of variance. A standard deviation of 1.0 indicated a larger degree of variance, yet demonstrated that the students did not divide most of their responses evenly throughout all five possible responses.
To further analyze these standard deviations, the students were grouped into three groups based on the individual mean score on the belief in evolution/creationism factor: (a) those students whose mean score approximated 2, (b) those students whose mean score approximated 3, and (c) those students whose mean scores approximated 4. There were no students whose scores approximated 1 or 5. The standard error (average standard deviation) was calculated for each of these groups. The students whose mean score approximated 2 had a standard error of 1.38, the students whose mean score approximated 3 had a standard error of 0.83, and the students whose mean score approximated 4 had a standard error of 1.12. So it can be concluded that those students whose score reflected a creationist belief by having a mean score approximating 2 ($SE = 1.38$) were quite likely to have chosen a 1, 2, or 3 response plus a few items favoring evolution. Those students whose mean score approximated 3 ($SE = 0.83$) were very unlikely to have had responses that reflected strong beliefs in creationism (a response of 1) or a strong acceptance of evolution (a response of 5). Those students whose mean scores reflected an acceptance of evolution by having a score approximating 4 ($SE = 1.12$) were likely to primarily have had responses of 3, 4, or 5, and only a few responses that favored creationism. In general, students whose mean scores were consistent with a belief in creationism demonstrated more variability in their responses than students whose mean scores were in the neutral range and those students whose mean scores were consistent with an the acceptance of evolution. Additionally, students whose mean scores were consistent with an acceptance of evolution demonstrated more variability than the students whose mean scores were in the neutral range.
The same type of analysis was performed for the other three epistemology factors. The most consistent responses among items were found for the *speed of learning* factor, which consisted of 12 items. For the entire group of 45 students, on about 8 of the 12 items, 16% of the students responded within ±0.5 Likert responses away from their mean score, 64% of the students responded within ±1.0 Likert responses away from their mean score, 98% of the students responded within ±1.3 Likert responses away from their mean score, and 100% of the students responded with ±1.5 responses away from their mean score. Students whose mean scores approximated 3 had a standard error of 0.96, those students whose scores approximated 4 had a standard error of 0.84, and those students whose scores approximated 5 had a standard error of 0.45. There were no students whose scores approximated 1 or 2. Therefore, the responses to the items contributing to the *speed of learning* factor were rather consistent across the range of scores.

The *control of learning* factor consisted of 12 items. For the entire group of 45 students, on about 8 out of the 12 items, 0% of the students responded within ±0.5 Likert responses away from their mean score, 49% of the students responded within ±1.0 Likert responses away from their mean score, 84% of the students responded within ±1.3 Likert responses away from their mean score, and 87% of the students responded with ±1.5 responses away from their mean score. Students whose mean scores approximated 3 had a standard error of 1.17, those students whose mean scores approximated 4 had a standard error of 1.00, and those students whose mean scores approximated 5 had a standard error of 0.90. There were no students whose scores approximated 1 or 2. Therefore, the students who had a score (4 or 5) corresponding to an epistemological belief that learning...
The stability of knowledge factor consisted of 21 items. For the entire group of 45 students, on about 14 of the 21 items, 4% of the students responded within ± 0.5 Likert responses away from their mean score, 53% of the students responded within ± 1.0 Likert responses away from their mean score, 89% of the students responded within ± 1.3 Likert responses away from their mean score, and 98% of the students responded with ± 1.5 responses away from their mean score. Students whose mean scores approximated 2 had a standard error of 1.07, those students whose mean scores approximated 3 had a standard error of 0.99, and those students whose mean scores approximated 4 had a standard error of 1.21. There were no students whose scores approximated 1 or 5. Therefore, the students with scores of 2 demonstrated a variance indicating that it was a very rare response that jumped into the "opposite" viewpoint. The students with scores approximating 4 demonstrated a variance indicating that only rarely did they answer an item on the other side of the spectrum. The students whose scores approximated 3 mostly answered items with a 2, 3, or 4 response.

The epistemology survey included an additional question in which the students were asked to indicate what percentage of their personal opinion about evolution was due to their religious beliefs and what percentage was due to their scientific knowledge. Figure 9 shows the distribution of the answers corresponding to this question. It is of
Figure 9: Distribution of students by percentage of opinion of evolution due to religious beliefs
interest to note that many of the students admitted that their opinion was due to their religious beliefs rather than to just their scientific knowledge. Only 10 of the 45 students attributed 75% or more of their opinion to be due to their scientific knowledge and 25% or less of their opinion to be due to their religious beliefs. Three students attributed 100% of their opinion to be due to their religious beliefs. Only 2 students attributed 100% of their opinion to be due to scientific knowledge.

Summary of the Statistics of the Evolution Knowledge Test

Knowledge Test

Pretest and posttest versions of a knowledge test were administered to answer the following research question: What is the level of college student understanding of the theories of evolution and common descent as measured on a knowledge test both before and after instruction?

Validity. There were originally nine items on the knowledge test, but item 4 was excluded prior to this analysis for reasons explained in Chapter 3. Four items were written by the researcher. One item was modified from a questionnaire used by Sinclair et al. (1997), one item was a question modified from research conducted by Brumby (1984), and one additional item was written by a fellow student and biology teacher. Seven of the items were multiple-choice questions and one was a true-false question.

To validate the instrument, input was obtained from a professor emeritus of evolution, from an associate professor of science education, from two associate professors of biology, from an assistant professor of biology, and from an instructor of biology, all experienced in teaching evolution at the college level. Suggestions were incorporated into
the wording of the items when feasible. Four of the items on the knowledge test (1, 2, 5, and 6) were about common descent, two (3 and 7) were about natural selection, and the remaining two (8 and 9) were about evolution in general.

Reliability. In order to establish the reliability of the evolution knowledge test, two methods were chosen. First of all, reliability was determined using a test-retest format and the Spearman-Brown formula. Two different versions of the test were administered via e-mail to 10 graduate students and 1 undergraduate student in the Evolution, Ecology, and Organismal Biology Department at The Ohio State University. These participants were solicited on the basis of their knowledge of evolutionary theory. The two versions were administered 12 days apart. The second version of the knowledge test differed from the first in the sequential order of the items and the sequential order of the options of each item. Plus, to give the appearance that the tests were not identical and to enhance e-mail returns, four additional items about evolution were added to the second version, but were not used in this study. The test-retest reliabilities of the two versions for the total test were .87 and .56 for the common descent component. The second method used to calculate reliability was based on the responses of the participants and the Kuder-Richardson 20 formula. The reliabilities of the pretest were found to be .45 for the total test and .18 for the common descent component. The reliabilities of the posttest were found to be .58 for the total test and .20 for the common descent component.

Pretest

Pretest administration. As for the subjects that were part of this study, 39 students answered the pretest knowledge test, which was administered the day of, and just prior to,
the laboratory session on the primate skulls. The unit of evolution started with this laboratory session followed by a traditional lecture format.

Pretest missing data. Two students did not choose a response for 1 question each, resulting in 2 missing data points out of 312 items (0.6%). These 2 questions were graded as being incorrect, in the same manner as most classroom tests are graded. The students’ responses to the pretest are shown on Table 10 in Appendix B.

Descriptive statistics of pretest. Total scores were assigned by summing the number of items that were answered correctly. Additionally, there was a category of subtotal scores, these scores representing the four items that dealt with the theory of common descent. The scores for this subcategory were obtained by summing the number of correct answers that corresponded to the items assigned to it.

The mean score for the pretest total score was 3.18 ($SD = 1.699$) with the lowest score being 0 and the highest score being 7 out of 8 items. Because this was primarily a multiple-choice test, students could have guessed and obtained a positive score without understanding anything about evolution. For the 8 items, there were 4 options each for 6 items, 5 options for 1 item, and 2 options for 1 item. So by chance alone, it was reasonable to expect that a student could have guessed and got the score of 2.2. To see if the group mean of 3.18 was significantly different from a score of 2.2, a $t$-test was performed. It was determined that the group mean of 3.18 differed significantly ($t(38) = 3.60, p = .001$) from a score of 2.2. However, 17 students scored 2 or less and 22 students scored 3 or more.
The mean subscore for the four pretest items corresponding to common descent was 2.00 (SD = 1.076) with the lowest score being 0 and the highest score being 4. It is possible that a student could have obtained a score of 1 by merely guessing. A t-test was performed to see if a score of 1 differed from the group mean of 2.00, and it was found to be significantly different (t(38) = 5.80, p < .0001). However, 12 students scored 1 or less and 27 students score higher than 1.

Posttest

Posttest administration. Approximately 5 weeks after the laboratory session with the primate skulls, the posttest was administered to 39 students as a part of the final exam. The items used were the same questions used on the pretest except that the sequential order of the items was changed, as was the sequential order of the multiple-choice options. The students’ responses to the posttest are shown on Table 10 in Appendix B.

Posttest missing data. On the posttest, 1 student left 1 item blank, resulting in there being a total of only 1 missing data point out of 321 responses (0.3%). This blank response was imputed as an incorrect answer because it most likely represented that the student did not know the correct answer.

Descriptive statistics of posttest. The method of computing the total scores and the common descent subscore was identical for both the pretest and the posttest. The mean score for the posttest total score was 3.18 (SD = 1.876) with the lowest score being 0 and the highest score being 8 out of 8 items. To see if the group mean of 3.18 was significantly different from a score of 2.2 that could have been obtained from a student
guessing, a $t$-test was performed. It was determined that the group mean of 3.18 differed significantly ($t(38) = 3.26, p = .002$) from a score of 2 that could have been obtained by guessing alone. However, 18 students scored 2 or less and 21 students obtained a score of 3 or more.

The mean subscore for the four posttest items corresponding to common descent was 2.08 ($SD = 1.061$) with the lowest score being 0 and the highest score being 4. A $t$-test was performed to see if a score of 1 differed from the group mean of 2.00, and it was found to be significantly different ($t(38) = 6.34, p < .0001$). However, 13 students scored 1 or less and 26 students score higher than 1.

*Values of $t$-test Between Instructional Sections*

A $t$-test value was calculated to determine if there were any differences between the two instructional sections on the pretest knowledge quiz. There was not a statistically significant difference between the two sections on the total score, $t(37) = 0.14, p = .889$, or on the common descent subscore, $t(37) = 0.29, p = 1$.

To assess a possible effect from the instructors, a $t$-test value was calculated to determine if there were any differences between the two sections on the posttest knowledge quiz. There was not a statistically significant difference between the two sections on the total score, $t(37) = -0.69, p = 0.493$, or between the two sections on the common descent subscore, $t(37) = -0.39, p = 0.696$.

*Values of $t$-test Between Pretest and Posttest Scores*

Table 3 displays the summary of the means and standard deviations for both the pretest and posttest scores for the evolution knowledge test. A dependent samples $t$-test
was performed between the pretest total scores and the posttest total scores. A t-test was also performed between the pretest subscore on the common descent component and the posttest subscore on the common descent component. There was not a statistically significant difference between the pretest and the posttest total scores, $t(37) = -0.10, p = .925$, or between the pretest and posttest subscores on the common descent component, $t(37) = 0.56, p = .579$.

<table>
<thead>
<tr>
<th></th>
<th>Pretest</th>
<th>Post Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
</tr>
<tr>
<td>Total Score</td>
<td>3.18</td>
<td>1.699</td>
</tr>
<tr>
<td>Common Descent Score</td>
<td>2.00</td>
<td>1.076</td>
</tr>
</tbody>
</table>

$n = 39$

Note: Total score possible range is from 0 to 8; common descent subscore possible range is from 0 to 4.

Table 3: Means and standard deviations for the knowledge test

To further examine the differences between the pretest responses and the posttest responses, additional statistical analyses were performed. First of all, the 38 students who responded to both the pretest and the posttest were grouped into three separate categories: (a) the first group consisted of 17 students whose total scores were better on the posttest than on the pretest, (b) the second group consisted of 9 students whose total scores were the same, and (c) the third group consisted of 12 students whose total scores were lower on the posttest than on the pretest. In order to determine if there were any differences
among these three groups, a one-factor analysis of variance (ANOVA) was performed with scores on the epistemology factors as the dependent variable. This method was chosen over correlational analyses between pretest-posttest differences and epistemology factor scores because obtaining the difference between pretest and posttest scores would have magnified the problem of the marginal reliabilities of each knowledge test.

The means of each of the epistemology factors for the three different groups are displayed in Table 4. The only significant difference found was on the epistemology subscale, *knowledge is certain*, $F(2, 35) = 3.65, p = .036$. The mean of the group whose posttest scores improved was 3.23 on this subscale, the mean of the group whose scores were the same was 2.84 on this subscale, and the mean of the group who scored lower on the posttest was 2.72 on this subscale. The Bonferroni test was performed and it was discovered that the 3.23 mean differed significantly ($6.579, p < .05$) from the group mean of 2.72. There were no significant differences among the three groups on the scores of the following epistemology factors: (a) *belief in evolution/creationism* factor, $F(2, 35) = .688, p = .509$, (b) the *speed of learning* factor, $F(2, 35) = 1.09, p = .349$, (c) the *control of learning* factor $F(2, 35) = .714, p = .497$, and (d) the *stability of knowledge* factor, $F(2, 35) = 1.133, p = .334$. 
Knowledge is certain

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (M)</th>
<th>Standard Deviation (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower (n=12)</td>
<td>2.72</td>
<td>0.447</td>
</tr>
<tr>
<td>Same (n=9)</td>
<td>2.84</td>
<td>0.823</td>
</tr>
<tr>
<td>Higher (n=17)</td>
<td>3.23</td>
<td>0.374</td>
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</table>

Belief in evolution/creationism

<table>
<thead>
<tr>
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<th>Mean (M)</th>
<th>Standard Deviation (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower (n=12)</td>
<td>3.38</td>
<td>0.501</td>
</tr>
<tr>
<td>Same (n=9)</td>
<td>3.33</td>
<td>0.774</td>
</tr>
<tr>
<td>Higher (n=17)</td>
<td>3.57</td>
<td>0.417</td>
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</table>

Speed of learning

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (M)</th>
<th>Standard Deviation (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower (n=12)</td>
<td>3.72</td>
<td>0.361</td>
</tr>
<tr>
<td>Same (n=9)</td>
<td>3.94</td>
<td>0.377</td>
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<tr>
<td>Higher (n=17)</td>
<td>3.72</td>
<td>0.449</td>
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</table>

Control of learning

<table>
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<tr>
<th>Group</th>
<th>Mean (M)</th>
<th>Standard Deviation (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower (n=12)</td>
<td>3.39</td>
<td>0.308</td>
</tr>
<tr>
<td>Same (n=9)</td>
<td>3.59</td>
<td>0.394</td>
</tr>
<tr>
<td>Higher (n=17)</td>
<td>3.39</td>
<td>0.529</td>
</tr>
</tbody>
</table>

Stability of knowledge

<table>
<thead>
<tr>
<th>Group</th>
<th>Mean (M)</th>
<th>Standard Deviation (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower (n=12)</td>
<td>2.97</td>
<td>0.347</td>
</tr>
<tr>
<td>Same (n=9)</td>
<td>3.09</td>
<td>0.487</td>
</tr>
<tr>
<td>Higher (n=17)</td>
<td>3.18</td>
<td>0.312</td>
</tr>
</tbody>
</table>

Table 4: Means and standard deviations for epistemology factors and knowledge is certain subscale by groups of students based on differences in posttest and pretest scores

Relationships Between Epistemological Factors and Knowledge of Evolution

Which, if any, of the five epistemological factors are associated with college student understanding of the theories of evolution and common descent?

In order to answer this research question, the value of Pearson's product moment correlation was calculated between the scores of each epistemology factor and the pretest scores and between the scores of each epistemology factor and the posttest scores on the evolution knowledge test. It was hypothesized in Chapter 1 that there would be a relationship between the students' epistemology mean scores and the scores on the pretest and the posttest knowledge tests. A positive linear correlation between scores on the epistemology factors and the scores on the knowledge quiz would indicate that students who scored higher on the epistemology survey would also be more likely to have scored
higher on the test measuring understanding of the theory of evolution and the theory of common descent. Table 5 displays the correlation values obtained between each factor and the knowledge tests.

<table>
<thead>
<tr>
<th></th>
<th>Evolution/Creationism</th>
<th>Stability of Knowledge</th>
<th>Speed of Learning</th>
<th>Control of Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest Total Score</td>
<td>.35</td>
<td>.13</td>
<td>-.04</td>
<td>.06</td>
</tr>
<tr>
<td>Pretest CD Score</td>
<td>.21</td>
<td>.09</td>
<td>-.09</td>
<td>.04</td>
</tr>
<tr>
<td>Posttest Total Score</td>
<td>.37</td>
<td>.27</td>
<td>-.07</td>
<td>.08</td>
</tr>
<tr>
<td>Posttest CD Score</td>
<td>.33</td>
<td>.17</td>
<td>-.08</td>
<td>.07</td>
</tr>
</tbody>
</table>

n = 39; CD = Common Descent

Table 5: Pearson correlations for the relationship between epistemology factor scores and knowledge test scores

Hypothesis $H_{01}$

There will be no relationship between scores on the epistemology factor, belief in evolution/creationism, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

A significant positive relationship was found between the scores on the epistemology factor, belief in evolution/creationism, and the knowledge pretest total
scores \( (r = .35, p = .031) \). This statistic led to the rejection of the corresponding null hypothesis, \( H_{01\text{a}} \). This relationship was such that the higher the acceptance of evolution as opposed to creationism, the higher the total score on the knowledge pretest. Conversely, the more creationism was accepted, the lower the total pretest score. A graph of this relationship is shown in Figure 10.

A significant positive relationship was also found between the scores on the epistemology factor, belief in evolution/creationism, and the knowledge posttest total scores \( (r = .37, p = .019) \). This relationship was such that the higher the acceptance of evolution as opposed to creationism, the higher the total score on the knowledge posttest. The more creationism was believed, the lower the total posttest score. The corresponding null hypothesis, \( H_{01\text{c}} \), was rejected. A graph of this relationship is shown in Figure 11.

A significant positive relationship was also found between the scores on the epistemology factor, belief in evolution/creationism, and the common descent component of the knowledge posttest scores \( (r = .33, p = .042) \). This relationship was such that the higher the epistemology score indicating an acceptance of evolution as opposed to creationism, the higher the total score on the knowledge posttest. The lower the epistemology score indicating a belief in creationism, the lower the total posttest score. The corresponding null hypothesis, \( H_{01\text{d}} \), was rejected. A graph of this relationship is shown in Figure 12. There was not a statistically significant relationship found between the scores on the epistemology factor, belief in evolution/creationism, and the subscores on the pretest knowledge component, common descent \( (r = .21, p = .195) \). The corresponding null hypothesis, \( H_{01\text{b}} \), was not rejected.
Figure 10: Correlation of belief in evolution/creationism scores to knowledge pretest total scores
Figure 11: Correlation of belief in evolution/creationism scores to knowledge posttest total scores
Figure 12: Correlation of belief in evolution/creationism scores to knowledge posttest common descent component scores.
Hypothesis $H_{02}$

There is no relationship between scores on the epistemology factor, *stability of knowledge*, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

A significant relationship was not found between the scores on the epistemology factor, *stability of knowledge*, and the total scores on the knowledge pretest ($r = .13, p = .424$). The corresponding null hypothesis, $H_{02a}$, was not rejected.

There was not a statistically significant relationship found between the scores on the epistemology factor, *stability of knowledge*, and the subscores on the pretest knowledge component, common descent ($r = .09, p = .570$). The corresponding null hypothesis, $H_{02b}$, was not rejected.

A significant relationship was not found between the scores on the epistemology factor, *stability of knowledge*, and the total scores on the knowledge posttest ($r = .27, p = .098$). The corresponding null hypothesis, $H_{02c}$, was not rejected.

A significant relationship was not found between the scores on the epistemology factor, *stability of knowledge*, and the common descent component of the knowledge posttest ($r = .17, p = .290$). The corresponding null hypothesis, $H_{02d}$, was not rejected.

The relationship between the epistemology factor, *stability of knowledge*, and the total scores on the knowledge posttest, was further explored. In spite of this correlation
not being statistically significant, the value was considerably greater than the other correlation values (other than that of the belief in evolution/creationism factor). It was thought that perhaps a further investigation could yield more insight into this relationship.

As mentioned previously, the epistemology factor, stability of knowledge, was composed of four subscales: (a) depend on authority, (b) don’t criticize authority, (c) knowledge consists of single answers, and (d) knowledge is certain. In order, the values of Cronbach's alpha for these subscales were .49, .34, .56, and .37. Correlations were calculated between the scores on each of these subscales and the total scores on the knowledge posttest. However, it is noted than any findings should be interpreted with caution due to the low reliability and the lack of statistical significance. The results of the correlations were .18 \((p = .280)\), .19 \((p = .257)\), .30 \((p = .068)\), and .12 \((p = .467)\), respectively. While there were no significant relationships found, it seems that much of the correlation was due to the subscale, knowledge consists of single answers.

**Hypothesis** \(H_{03}\)

There is no relationship between scores on the epistemology factor, structure of knowledge, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

This hypothesis was not tested due to the low reliability value obtained on the structure of knowledge factor.
Hypothesis $H_{04}$

There will be no relationship between scores on the epistemology factor, *speed of learning*, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

A significant relationship was not found between the scores on the epistemology factor, *speed of learning*, and the total scores on the knowledge pretest ($r = -.04, p = .801$). The corresponding null hypothesis, $H_{04a}$, was not rejected.

There was not a statistically significant relationship found between the scores on the epistemology factor, *speed of learning*, and the subscores on the pretest knowledge component, common descent ($r = -.09, p = .583$). The corresponding null hypothesis, $H_{04b}$, was not rejected.

A significant relationship was not found between the scores on the epistemology factor, *speed of learning*, and the scores on the knowledge posttest ($r = -.07, p = .693$). The corresponding null hypothesis, $H_{04c}$, was not rejected.

A significant relationship was not found between the scores on the epistemology factor, *speed of learning*, and the common descent component of the posttest knowledge quiz total scores ($r = -.08, p = .628$). The corresponding null hypothesis, $H_{04d}$, was not rejected.
Hypothesis $H_{05}$

There will be no relationship between scores on the epistemology factor, *control of learning*, and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

A significant relationship was not found between the scores on the epistemology factor, *control of learning*, and the total scores on the knowledge pretest ($r = .06, p = .714$). The corresponding null hypothesis, $H_{05a}$, was not rejected.

There was not a statistically significant relationship found between the scores on the epistemology factor, *control of learning*, and the subscores on the pretest knowledge component, common descent ($r = .04, p = .799$). The corresponding null hypothesis, $H_{05b}$, was not rejected.

A significant relationship was not found between the scores on the epistemology factor, *control of learning*, and the total scores knowledge posttest ($r = .08, p = .633$). The corresponding null hypothesis, $H_{05c}$, was not rejected.

A significant relationship was not found between the scores on the epistemology factor, *control of learning*, and the common descent component of the knowledge posttest ($r = .07, p = .666$). The corresponding null hypothesis, $H_{05d}$, was not rejected.

Because only one set of hypotheses was found to be statistically significant, it was necessary to further analyze the nature of the relationships found. It is possible that a
correlation could have been found to be significant but instead actually have been a random event or statistical "noise." For example, at the alpha level of .05, 5 out of 100 random events would appear to be significant, but actually not be. The nature of the correlation found between the test scores and the belief in evolution/creationism factor scores was further explored in to discover if this significant finding was due to chance alone. This additional analysis used simple correlations between the 79 items on the epistemology survey and the 8 items on each of the knowledge tests. (The correlations among the epistemology survey items and the correlations among the knowledge test were not part of this particular analysis.) For example, each item on the knowledge test was correlated with each of the 79 items on the epistemology survey. Thus, by chance alone, at the .05 alpha level, 5% or 4 epistemology items would likely be found to have a significant relationship with an individual knowledge test item. So if there were considerably more than 4 significant relationships found at this item-by-item level and several of these items belonged to the same epistemology factor, this finding could strengthen the likelihood that there was a significant relationship at the factor-by-test level. Also, since there were only 8 items on the pretest and 8 items on the posttest, it would be unlikely that the same epistemology item would correlate significantly with more than 1 test item on an item-by-item correlation matrix by random chance alone. So, if a single epistemology item was found to be significantly correlated with more than one test item, the possibility would increase that there was actually a significant relationship. Therefore, an item-by-item correlation was performed and the results of this analysis revealed the following patterns. Out of 632 correlations run between the epistemology
survey items and the pretest items, there were 30 significant correlations found (5%). Twelve (40%) of these 30 correlations were of items belonging to the belief in evolution/creationism factor. This factor represented only 17 out of the 79 items (22%), therefore this relationship was probably not random in nature because 40% is considerably larger than 22%. Additionally, items 77 and 79 each had two significant correlations with pretest items, and item 74 had three significant correlations. Items belonging to other epistemology factors showed no correlational patterns, other than item 36, which had 3 significant correlations and item 32, which had 2.

Out of the 632 simple correlations between the epistemology items and the posttest items, there were 37 significant correlations found (6%). Eight of these belonged to the belief in evolution/creationism factor (22%). Item 74 had 2 significant correlations and item 79 had three. Items belonging to other epistemology factors revealed no strong patterns, other than item 57, which had 4 significant correlations, item 17, which had 3, and item 33, which had 2.

Thus, it appeared that there could have been a significant relationship between the belief in evolution/creationism factor and the pretest, particularly with items 74, 77, and 79. The relationship between the belief in evolution/creationism factor and the posttest could be due to random chance or noise, however, there appeared to have been a significant relationship between the knowledge test and two of the epistemology items, item 74 and item 79.
**Relationships Between Categorical Demographic Data and Scores on Knowledge of Evolution Tests**

*Do demographic variables, such as gender, year in college, and number of biology courses previously taken, have a relationship with student understanding of the theories of evolution and common descent?*

The relationship between gender and knowledge was examined. A *t*-test was used to test the significance of the differences by gender. The means for each test score and the results of the *t*-tests are displayed by gender in Table 6.

<table>
<thead>
<tr>
<th></th>
<th>Men Mean</th>
<th>Men SD</th>
<th>Women Mean</th>
<th>Women SD</th>
<th><em>t</em></th>
<th><em>p</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest Total Score</td>
<td>3.71</td>
<td>1.961</td>
<td>2.78</td>
<td>1.378</td>
<td>1.75</td>
<td>.089</td>
</tr>
<tr>
<td>Pretest CD Score</td>
<td>2.24</td>
<td>1.200</td>
<td>1.82</td>
<td>0.958</td>
<td>1.21</td>
<td>.235</td>
</tr>
<tr>
<td>Posttest Total Score</td>
<td>3.81</td>
<td>2.198</td>
<td>2.74</td>
<td>1.514</td>
<td>1.81</td>
<td>.079</td>
</tr>
<tr>
<td>Posttest CD Score</td>
<td>2.56</td>
<td>1.094</td>
<td>1.74</td>
<td>0.915</td>
<td>2.55</td>
<td>.015</td>
</tr>
</tbody>
</table>

*n* = 39

Note: Total score possible range is from 0 to 8; CD (Common Descent) subscore possible range is from 0 to 4.

Table 6: Means, standard deviations, and *t*-test values of the knowledge tests by gender

**Hypothesis H₀₆.**

There will be no relationship between gender and understanding of evolutionary theory as measured by:
a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

The mean of the common descent posttest subscore for the men was 2.56 (SD = 1.094), and the mean for the women was 1.74 (SD = 0.915). This difference was statistically significant, t(37) = 2.55, p = .015. The corresponding null hypothesis, H_{06d}, was rejected.

The mean of the pretest total scores for the men was 3.71 out of a possible score of 8 (SD = 1.961), and the mean for the women was 2.78 (SD = 1.378), but this difference was not statistically significant, t(37) = 1.75, p = .089. The mean of the common descent pretest subscore for the men was 2.24 out of a possible score of 4 (SD = 1.200), and the mean for the women was 1.82 (SD = 0.958), but this difference was not statistically significant, t(37) = 1.21, p = .235. The mean of the posttest total scores for the men was 3.81 (SD = 2.198), and the mean for the women was 2.74 (SD = 1.514). This difference was not statistically significant, t(37) = 1.81, p = .079. The corresponding null hypotheses, H_{06a}, H_{06b}, and H_{06c}, were not rejected.

To further explore the role of gender, an analysis was performed of other gender differences in the variables of interest, such as the epistemology factor scores and the demographic variables. As a group, the men reported a higher grade point average (M = 3.0-3.4) while the mean grade point average of the women was between 2.5 – 2.9 and 3.0 –3.4. It should be noted that this was an ordinal variable, and thus, was a relatively
imprecise comparison. Also, the men reported having taken more biology coursework \((M = 2.7)\) when compared to the number of biology coursework taken by the women \((M = 2.3)\). However, neither of these differences was significant. What was found to be significantly different \((t(43) = -2.188, p = .034)\) was the difference between the men's score on the speed of learning factor \((M = 3.5)\) and the women's score \((M = 3.9)\). The men apparently had a stronger belief than the women did that learning was quick and simple.

**Relationships Between Interval Demographic Data**

and Scores on Knowledge of Evolution Tests

To determine the relationships between other demographic variables and student knowledge, values for Pearson’s product moment were computed due to the interval nature of the following variables: (a) year in college, and (b) number of previous biology courses (both high school and college). The results of the correlations are summarized in Table 7.

<table>
<thead>
<tr>
<th></th>
<th>College Year</th>
<th># of Biology Courses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(r)</td>
<td>(p)</td>
</tr>
<tr>
<td>Pre Total</td>
<td>-.11</td>
<td>.499</td>
</tr>
<tr>
<td>Pre CD</td>
<td>-.09</td>
<td>.599</td>
</tr>
<tr>
<td>Post Total</td>
<td>-.07</td>
<td>.651</td>
</tr>
<tr>
<td>Pre CD</td>
<td>-.08</td>
<td>.637</td>
</tr>
</tbody>
</table>

\(n = 39; CD = \) common descent

Table 7: Correlations between demographic variables and knowledge test scores
Hypothesis $H_{07}$

There will be no relationship between year in college and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.

There was not a statistically significant relationship found between the year in college and the pretest total score ($r = -.11, p = .499$), or the year in college and the pretest common descent subscore ($r = -.09, p = .599$). Also, the correlational analysis did not reveal a significant relationship between the year in college and the posttest total score ($r = -.07, p = .651$), or between the year in college and the posttest common descent subscore ($r = -.08, p = .637$). The corresponding null hypotheses, $H_{07a}$, $H_{07b}$, $H_{07c}$, and $H_{07d}$, were not rejected.

Hypothesis $H_{08}$

There will be no relationship between the number of biology courses previously taken and understanding of evolutionary theory as measured by:

a. the total scores on the knowledge pretest.

b. the subscores on the knowledge pretest component, common descent.

c. the total scores on the knowledge posttest.

d. the subscores on the knowledge posttest component, common descent.
There was not a statistically significant relationship found between the number of biology courses and the pretest total score \( (r = .02, p = .911) \), or the number of biology courses and the pretest common descent score \( (r = -.08, p = .645) \). Also, there was not a significant relationship found between the number of biology courses taken and the posttest total score \( (r = -.01, p = .959) \), or the number of biology courses taken and the posttest common descent subscore \( (r = .02, p = .907) \). The corresponding null hypotheses, \( H_{08a}, H_{08b}, H_{08c}, \) and \( H_{08d} \), were not rejected.

*Summary of Quantitative Data Analysis*

The following is a summary of the hypotheses examined and tested as part of the quantitative analysis of this study. The conclusions given are a result of the Pearson’s product-moment correlations, the ANOVA values, and the \( t \)-test values that were computed and presented in detail in this chapter.

The results of this study seem to suggest that a score indicating a belief in creationism correlated with a lower score on the knowledge test covering evolutionary theory, including the theory of common descent. Also, a score indicating an acceptance of evolution was correlated with a greater understanding of the theory of evolution as measured by the knowledge test. This correlation was statistically significant at the .05 alpha level.

The two disturbing findings were that learning did not significantly improve after instruction and there was an overall lack of understanding of evolution. The pretest mean was 3.18 out of 8 (40% correct) and the posttest mean was 3.18 out of 8 (40% correct).
The results showed that one demographic variable, gender, demonstrated a statistical relationship to knowledge scores at the .05 alpha level. The men in this study scored significantly higher than the women did on the common descent component of the posttest. However, this result should be interpreted with caution due to the low reliability of the common descent component.

The results did not show significant relationships between the knowledge scores and the following demographic variables: (a) number of previous biology courses, and (b) year in college. Also, the results did not show a statistically significant relationship between the knowledge scores and the scores obtained on the three different epistemology factors: (a) stability of knowledge, (b) speed of learning, and (c) control of learning. While the factor, stability of knowledge, had a relationship with the knowledge test scores that was stronger than the other two factors, this relationship was not statistically significant. Much of the correlation value was due to the subscale, knowledge consists of single answers.

Finally, the results of the quantitative component suggest that the students who believed in creationism may have had more difficulty in understanding evolutionary theory. An acceptance of evolution may be more important in understanding than other variables, including other epistemology factors that had been associated with comprehension in other content areas. One outstanding result was the low overall understanding of evolutionary theory demonstrated by the college students in this study.
Presentation and Analysis of Qualitative Data

The qualitative portion of this study focused on the research question: What are the alternate conceptions that college students have about the theory of common descent? Data for analysis included: (a) laboratory worksheets, (b) interview transcripts, and (c) activity worksheets obtained during interviews. It was hoped that the qualitative analysis would uncover alternative conceptions about the theory of common descent that have persisted even at the college level. The qualitative data were analyzed in two basic methods that differed in perspectives. In the first method, the data were analyzed as a complete set by looking for emergent categories of alternate conceptions. In the second method, the data were analyzed by looking for evidence of epistemology beliefs of individual students who had different kinds of conceptions of evolutionary theory.

Interviews

Participants

A purposeful sample of 11 students was chosen out of the 45 original students who completed the epistemology survey instrument. These choices were based on the scores on the various epistemology factors with the purpose of selecting students whose scores represented the extremes of each epistemology factor. All the selected students consented to be interviewed except for 1 student who refused, giving his poor English language skills as the reason. One other student did not come to the appointed interview place and did not communicate to the researcher the reason why. This left a sample of 9 students.
The statistics for the demographic variables of the interviewed sample and the total sample are given in Table 8. The statistics for the epistemology factors and the knowledge test scores of the interviewed sample and the total sample are shown in Table 9.
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<th>Interviewed Sample</th>
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<td>21 (46.7%)</td>
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Table 8: Distribution of demographic variables of total sample and interviewed sample
<table>
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<tr>
<th></th>
<th>Total Sample</th>
<th>Interviewed Sample</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Posttest CD Score</td>
<td>2.08</td>
<td>2.22</td>
</tr>
</tbody>
</table>

Note: Scores for epistemology factors range from 1 to 5; Total scores for knowledge tests range from 0 to 8; CD (common descent) subscores range from 0 to 4

Table 9: Mean scores for the epistemology factors and the knowledge tests of total sample and interviewed sample

**Protocol**

The interviews followed a semistructured, one-on-one protocol. This format used allowed the interviewer to probe deeper in areas or to revise questions when necessary. The interviewer selected particular attributes to portray suggested by Glesne and Peshkin (1992): (a) she was a warm and caring listener, (b) she established rapport, and (c) she
patiently probed for more information. This particular interviewer was experienced in this mode of interviewing. These selected attributes were demonstrated by the interviewer's verbal and nonverbal clues. The interviewer listened to the student, maintained eye contact, leaned slightly forward toward the student, and nodded her head to the statements made. Because the interviews were designed to elicit information about students' conceptions and alternate conceptions, and did not have an instructional goal, the interviewer verbally agreed with students' statements by saying, "Yes," "OK," or "Uh huh," even when students were making erroneous statements. The use of these verbal clues was verified on the audio tapes. The interviewer thought that this friendly, nurturing position was especially essential in making the students feel comfortable and not threatened, so that they would reveal their ideas in a nonjudgmental setting. The effectiveness of this strategy was apparent when several students told the interviewer personal aspects about their lives not related to the study.

The interview script is presented in Appendix C. The example of the time lines used to initiate the interview activities is shown in Figure 13 in Appendix C. The interviews were approximately 45 – 55 minutes in length and were conducted at a time and place convenient for the student. After verbal permission was obtained from each student, the interview was audio recorded and transcripts made from the audio tapes.

The purpose of the interviews was to discover alternate conceptions that these college students had about common descent and speciation. Once these conceptions are known, other research studies could search for the presence of similar conceptions in other students and in students in other settings. The compilation of an alternate
conception catalogue can aid in the development of future curriculum design and in instruction. This purpose led to the exploration of student ideas about evolutionary processes, rather than looking for student recall of factual information. Therefore, the first two parts of the interview consisted of two activities designed to elicit information about how the students would construct relationships between organisms. The last part of the interview consisted of scripted questions written specifically to find out what the students' conceptions were about human evolution and common descent.

For the first activity, the interviewer presented the names of eight organisms on the table in front of the student. These names were written on small pieces of paper with an adhesive backing that enabled the students to make a permanent arrangement by applying the stickers to a sheet of paper. The interviewer asked the students to arrange the names in an order that showed how the students thought the organisms were related to each other. To explain the activity to the students, the interviewer showed them two sample diagrams and explained these samples as stated in Figure 13 in Appendix C. The interviewer told the students that they could use one of the sample formats or they could use any other kind of diagram that they thought would show how these organisms were related evolutionarily. The interviewer provided the students with triplicates of the names and informed the students that they could use an organism's name more than once on the diagram if they wished to show its existence through time. The interviewer asked the students to draw a time line with one end representing "long time ago" and the other end representing "the present." The students were asked to "think out loud" as they arranged the names so that the interviewer would know what they were thinking as they grouped
the organisms. The interviewer also asked the students if they wanted to draw lines connecting the organisms, and if so, to explain what these lines represented. The interviewer instructed the students to place any organisms they thought were unrelated to the others off to the side of the activity sheet, under a header labeled, "Unrelated."

In the first activity, the students arranged the names of eight organisms on a sheet of paper. The names of organisms used were: (a) amphibian, (b) bacterium, (c) bird, (d) cockroach, (e) fish, (f) human, (g) lizard, and (h) whale. These were chosen as representatives of various hierarchical levels of biological classification schemes, and as organisms having obvious similarities, such as the amphibian and the lizard. Additionally, the bacterium was chosen because of its history of existence a long time ago. Examples of the students' work are shown in Figures 14, 15, and 16 in Appendix C.

The second activity was similar to the first, but the interviewer presented the students with triplicates of nine pictures instead of eight names. These nine pictures depicted skeletons of the right manus of various vertebrates including those of two extinct animals and seven existing animals. The choices of these drawings were made based on availability and stylistic similarity. The instructions given were the same as for the first activity. During both activities the interviewer encouraged the students to "think out loud" as they thought through the process of organizing the pictures. This encouragement was made by the interviewer saying such things as, "What were you thinking when you did that?" and "OK, so you're putting them halfway in between. Is it in one direction or do you want them halfway?" An example of a student's work is shown in Figure 17 in
Appendix C. The students were given opportunities in both activities to draw lines connecting the organisms and to explain what these lines meant.

After these two activities, the students were shown four diagrams and asked to select which one, if any, of the sample diagrams most closely fit their ideas of relationships among these organisms. These diagrams are shown in Figure 18 in Appendix C. Diagram 1 was a horizontal depiction of all organisms suddenly appearing at the same time and was the diagram that corresponded most closely with creationism. Diagram 2 was a depiction of a bean stalk with organisms coming off of one central branch. Diagram 3 was a depiction of a bush with many branching offshoots and was the diagram that corresponded most closely with modern evolutionary theory. Diagram 4 was a vertical depiction of one organism changing into another, sequentially in time. Diagram 2 and diagram 4 represented a less sophisticated view of evolutionary theory.

Classification of living organisms is a complex task, with experts debating the merits of different classification schemes. In spite of the scientific debate, experts do agree that species have evolved from other species and that a scientifically acceptable way to show evolutionary pathways is through a branching diagram (Doolittle, 1999). It was not the purpose of this activity to necessarily judge the correctness of the students’ work, or to ascertain its scientific merit. The purpose was to discover the students’ preexisting conceptions about common descent.

Analysis of Interviews

The narrative data were analyzed and coded for emergent themes. For example, in the beginning stages of the data analysis, it became apparent that students used
"organizers" to aid them in grouping the organisms. Subsequently, the worksheets and the interview transcripts were analyzed according to which organizers the student used as they worked through the process of demonstrating relationships. The worksheets and the interview transcripts were analyzed as to what “organizer” the student used as they worked through the process of demonstrating relationships. The data were also analyzed for evidence that the students applied evolutionary theory as they grouped the organisms. Excerpts from the transcripts will be presented later in this dissertation to exemplify the findings. To emphasize the researcher's point in each section, particular words are italicized. Because all students' ideas were relevant to the research question, the interview dialogue is presented verbatim, including grammatical errors and phrases that appear to not make sense. Punctuation was used to designate pauses, phrases, and questions.

Evidence of Use of Evolutionary Theory

All 9 students that were interviewed completed both branching/grouping activities. One student completed 3 diagrams by choosing to do the first activity in 2 different ways, making a total of 19 diagrams for both branching/grouping activities. Students were shown 4 sample diagrams and were asked which, if any, of the 4 was most like the diagrams they had drawn. The odds of any one diagram being randomly chosen was approximately 1 out of 4. With 9 students, any 1 of these 4 diagrams could be randomly chosen by 2 students. However, since the instructions for the activities included 2 diagrams that vaguely corresponded to the horizontal diagram and to the branching diagram, students may have been predisposed to design their diagrams like one or both of these two samples.
Only 1 student chose the horizontal diagram as being closest to each of her two drawings. This diagram was the one that most closely corresponded to the creationist perspective of the similarities found in organisms. It is of interest to note that this particular student had a low score (2.53) on the belief in evolution/creationism factor, indicating a belief in creationism, which became evident in how she depicted the relationships among organisms. Only one other student chose the horizontal diagram; the student who chose to do three separate diagrams. She indicated that one of her diagrams was “horizontal, kind of” and that the other two were in the category, “not like any of the them.” Two other students chose the “not like any of them” category. Three students chose the vertical diagram for four diagrams. Four students chose the branching tree diagram for both of their activities.

Thus, of the 9 students, 4 students chose the more sophisticated depiction that corresponded with modern evolutionary theory, and 3 other students chose a less sophisticated depiction of evolution. There was 1 student who chose only the horizontal diagram that corresponded to creationism. The remaining student did not think that her activities matched any of the diagrams.

The students were asked if they wanted to draw lines connecting organisms and, if so, to indicate what the lines represented. Of the 9 students interviewed, 7 students chose to draw connecting lines. Of these 7 students, the following connections were made: (a) 5 students connected amphibian-lizard, (b) 4 students connected fish-whale, (c) 3 students connected the bacterium with each of the other seven organisms, (d) 1 student connected bacterium with all the other organisms except cockroach, (e) 2 students connected lizard-
bird, (f) 1 student connected fish-amphibian, (g) 1 student connected bird-human, (h) 1 student connected whale-human, (i) 1 student connected whale-amphibian, (j) 1 student connected fish-lizard, (k) 1 student connected amphibian-bird, and (l) 1 student combined into one category the whale, bird, and human, which she then labeled as mammals.

When 7 of the 9 students chose to draw a connecting line, they were asked to relate the meaning of the line. One student indicated that a connection meant something other than common descent. It is of interest to note that this student used the term "related" in a way that definitely did not mean the same thing that a modern evolutionist means when using the term. This instance demonstrated a case when terms used to illuminate instruction in evolution may have been construed by a student to mean something different than what was intended by the instructor.

Kelly: I'm indicating that they're similar, that I think that they're similar. Like I know the whale is a mammal . . . right? [laughs] and the fish is a fish, but they're similar in the way that they work and the way they're designed, and I'm really not sure which came first . . . but I think they're similar.

Interviewer: Similarity meaning they came from each other, or they didn't come from each other?

Kelly: I guess not necessarily that they came from each other. Knowing that they're different, it's that they're similar, maybe they are related to each other in some way.

Interviewer: When you say related, what do you mean?

Kelly: Like in the same . . . . . . . they're either, I think they're similar species? I mean like they have a lot of the same characteristics. It would be something like that.
Other students indicated that the connections referred to evolution and common descent. However, some of these concepts about the connections between specific organisms were rather unsophisticated and not scientifically based, as seen in the statements from Allison, Jessica, and Paula.

Allison: Because of lizards and salamanders are kinda the same...

Interviewer: So the connections don’t necessarily mean that one species evolved from another species?

Allison: Yeah, in a way, I think somehow the fish, I don’t know if the fish came from the whale or the whale came from a larger fish. I think the bacterium kind of grew from different particles and materials.

Jessica: I want to draw a line from here to there, from amphibian to lizard because I feel like the amphibians had to learn how to live in a dry spot. They’re probably not related at all, I don’t know.

Interviewer: ... And the lines represent?

Paula: uhm . . . . evolution, from where each of them came, the lizard goes to the bird, the lizard amphibian go to the bird and then they go to the whale, the whale goes to the fish whale and human, I hope it’s kinda clear.

There were students who had a clearer idea of evolution as represented by this statement.

Cindy: This is long ago and I believe, you know, like I said, the bacterium was probably present then and it is now and then . . . . now, I know that probably, essentially, at one point everything kind of evolved from it.

Organizers Used to Group Related Organisms

As the students arranged the organisms, they used organizers, such as: (a) similarity of traits, (b) size, (c) complexity, (d) function, (e) environment, and (f) knowledge about common descent.
Similarity of traits as an organizer. Similarity of traits was one of the simpler organizers used. Kelly, who had a score consistent with a belief in creationism, used similarity as her only organizer as she put the term “similar” in different contexts, such as similarity of traits, function, and design.

Interviewer: So you’re arranging them, what have you got in mind as you’re switching them around?

Kelly: Similar traits . . . I’m indicating that they’re similar, that I think they’re similar . . . they’re similar in the way that they work and the way they’re designed and I’m not . . . really not sure which came first or how they were created, first, which order.

She used the term repeatedly as she tried to explain how she was grouping organisms.

Kelly: This is some kind of, this looks like . . . ok . . . . . . ok . . . well . . . similar . . . This category is ones that are similar and what I think the reason for it.[sic]

Again, the interviewer asked her for a further explanation.

Interviewer: When you say something is similar, do you mean they could have come from that, or are they just similar?

Kelly: I think they’re similar. . . .

Size as an organizer. Relative size was another of the simpler organizers used.

Two of the students thought that smaller organisms proceeded larger ones as time progressed.

Terry: This one looks like, this one might be in front of it, just because it’s smaller.

Interviewer: You want to tell me how you arranged them in your mind?

Elaine: Well, I guess I just tried to select the ones that’s [sic] been around forever. And then I went from, what seemed like, I don’t know, I guess the ones that were smaller, I guess from smallest to biggest.
Another student used size as an organizer, but rationalized that larger animals proceeded smaller animals.

Samuel: Big birds turn small. Lizards are small. But I know small insects exist, too, maybe a long time ago it was not that small, and not as small as it is right now . . .

And later in the same interview . . .

Samuel: Long time ago all the animals used to be big, huge, enormous size, but since the environment persists, that, I mean the environment only doesn’t change the size, but, the population changed size, so, and the competition . . . if you’re so big, and you cannot protect yourself, you cannot fight with your rival, you have to, I mean, develop . . . yourself, so you can hide. You could . . . maybe looking for more food too, in the, in the between the rocks and stuff, it would be hard, if you’re so big you cannot grab those food. [sic]

Interviewer: . . . So you mean, the relationship is so that it started out big and got small?

Samuel: Yep.

*Complexity as an organizer.* Complexity was another organizer used by some students. The use of complexity consisted of several variations, such as ability, highest, lowest, and stages of development. When students referred to complexity, they implied that evolutionary change progressed over time from less complex to more complex.

Paula: I just think that bacteria would be the lowest form, the cockroach the amphibian . . .

Interviewer: and when you say lowest form . . .

Paula: Lowest life. In terms in how they’ve evolved, with intelligence and the ability to do things. So that’s kinda from right to left with the exception of . . . . . . the bird. I think the bird is probably more intelligent than the fish.

Interviewer: You did it very quickly and you had a method to it, so I would like to know. . .

Paula: In the order of a developmental situation.
Interviewer: Basically these are lined up, so what did you use to organize these?

Jessica: Well, simple to complex. I'm not real sure why I put the whale in there. The bacterium, I put that way down in simple. Complex, the cockroach has the least amount of stuff inside and then I put the whale there, I don't know how to explain it. I put the fish next because it's pretty simple, moves back and forth, they're easy bones [sic], they're not all that simple, they've got like gills and I think that's pretty complex. I can't breathe underwater, so he's doing better than I am.

An organism's relationship to humans was used as an organizer as students perceived humans to be a "higher" life form.

Paula: I believe this is a human so it's the highest form. . . . . . and this is obviously something very close to human.

Kelly: Ok, and the human, I'm going to put it right up there, after these, after these, and still remaining.

Elaine: I thought maybe they're a little more smarter and closer to the humans.

And then later during the interview . . .

Elaine: I just think this is more like the human side and this is more the animal side.

Clark: This one looks like a human hand and I'm just arranging them as they appear similar to the human hand. . . I'm putting the human at the top. We're most evolved and we're present.

*Function as an organizer.* Function was used as an organizer, especially as students tried to make sense of the manus drawings. Function was also an organizer in the activity that grouped organisms' names.

Interviewer: If you can talk aloud and tell me what, once you're ready to, tell me what you're using to organize them.
Allison: Kinda of in a way counting the amount of fingers they have, as far as time wise, because, I think now, I mean in a way we use all five fingers, but the four fingers I think would have helped them in different ways, as far as grabbing a hold of poles, or swimming if it were fish, or flying, as far as a bird goes.

Jessica: The bird’s kind of in a class of their own, but they can fly and I can’t, that’s pretty cool. The lizard can’t fly, so they’re [birds] above a lizard . . . The human’s the most complex. The whale, I put them there because they’re close to fish, but they breathe air.

Environment as an organizer. Surprisingly, the environment was used as an organizer as exemplified by these excerpts from 4 students’ interviews.

Interviewer: So, you put them in order as to how old you think they are.

Terry: Yeah.

Interviewer: Did you put them in any other way?

Terry: No, I mean, most humans are in the present and so, like the fish and the whales, and I mean there was water but a long time ago, so there had to have been fish and whales a while ago.

Allison: The bacterium is kinda off by itself I think because they can grow in so many different places and so many different climates.

Jessica: The fish and the amphibian are closely related because they have to be in water sometimes, but not all the time, under specific conditions, they absorb moisture. Fish are always in the water.

Samuel: I put the whale next to the fish.

Interviewer: OK, and why did you do that?

Samuel: Well, because they’re both . . . they both can’t survive out of the water . . . which leads me to believe that they both . . . uhm . . . originated in the water. Well, I feel everything originally came from the water, it’s just that the amphibians were the first to be able to [sic] land and water.
Knowledge about common descent as an organizer. Knowledge about common
descent was an organizer for students with a more advanced understanding of evolution.

Allison: The birds, the whales, I think all of the others have come from one form
or another, they descended, multiplied and mated and then gone their separate
ways later.

Cindy: I think that these three are probably pretty closely related, but I also think
that they probably share some sort of a common ancestor between this branch and
this branch. The same thing with these over here. I don’t know, to me, they would
probably be related, but as far as something I’m not really sure . . . these
somehow, they could still be alive, but they may have evolved also.

Relationships

The relatedness of certain organisms was indicated by most of the students. One
such concept shared by 7 of the 9 students was that the amphibian and lizard were closely
related. At least 5 students thought that the bird and lizard were closely related. There
were 7 students thought that the bacterium was the oldest organism, and 4 of these
students thought that the bacterium branched off to form the other organisms.

A surprising finding was that these college students thought that fish and whales
were closely related. This misconception was held by some students even while they
admitted that the whale and fish did not share certain important characteristics.

Allison: Other than that, I don’t think a lot of them are connected . . . well, the fish
and the whale, because they’re both in water.

Interviewer: So the connections don’t necessarily mean that one species evolved
from another species?

Allison: Yeah, in a way, I think somehow the fish, I don’t know if the fish came
from the whale, or the whale came from a larger fish.
Jessica: The whale, I put them there [next to the fish] because they’re close to fish, but they breathe air.

Cindy: I’m assuming that the fish and the whale are probably pretty closely related . . . ok, fish and the whale and probably I think the amphibian and the fish are probably closely related as well, but the fish is more closely related to the whale.

Interviewer: You’re basing that on what?

Cindy: Just as far as my knowledge of animals I guess.

And then later during the interview, this same student said,

Cindy: And the fish and the whale I know that they’re related somehow.

Paula: Whales are mammals, aren’t they . . . are more closely related to the fish . . . Ok. I would put the fish and the whale as having come off of something. Kinda together . . .

This grouping of fish and whale together also appeared in less sophisticated ways of thinking.

Samuel: I put the whale next to the fish.

Interviewer: OK, and why did you do that?

Samuel: Well, because they’re both . . . they both can’t survive out of the water . . . which leads me to believe that they both . . . uhm . . . originated in the water.

Elaine: I don’t really know my reasoning in terms of why I chose the bird before the whale, but I kinda thought the lizard was more closer to the fish than the whale was, but I could have put the fish before the whale, but I thought the fish was more like the amphibian.

Terry: I mean, most humans are in the present and so like the fish and the whales, and I mean there was water but a long time ago, so there had to have been fish and whales a while ago.
Kelly: I'm indicating that they're similar, that I think they're similar. Like I know the whale is a mammal, ... right? (laughs) and the fish is a fish, but they're similar in the way that they work and the way they're designed, and I'm ..., really not sure which came first ... or how they were created, first, which order.

**Evidence of Understanding of Human Evolution**

Forty students were present for the laboratory session that investigated common descent. Their laboratory worksheets were evaluated for evidence of scientifically acceptable perceptions of the relationships among modern apes, humans, and prehistoric hominids. While the students completed their own worksheets, they did work in groups of 3 or 4, so some of the narrative data was the result of group efforts. However these data were evaluated on the individual student level. Samples of the students' work are shown in Figures 19, 20, and 21 in Appendix D.

Three narrative data sources were analyzed for conceptions about human descent: (a) student worksheets of laboratory activity 1, (b) student worksheets of laboratory activity 2, and (c) transcripts of questions and answers given during interviews of selected students. The transcripts from the third part of the interview were analyzed to see whether students thought humans had descended from other species and whether the students recognized that modern apes had descended from a common "missing link." Specific questions were designed to elicit students' conceptions about human evolution and common descent. The data were analyzed to determine whether students viewed human evolution as separate from evolution of other organisms, whether alternate conceptions existed, and whether the students' understanding of human evolution was helped or
hindered by examining casts of primate skulls. All excerpts are presented verbatim, including students' phrases, punctuation (or lack of it), and symbols used.

*Worksheets for DNA Activity*

*Humans closely related to chimpanzees.* Laboratory activity 1 involved the analysis of a portion of DNA sequences for hemoglobin from humans, chimpanzees, and gorillas. The correct results were as follows: (a) humans and chimpanzees have 15 out of 20 sequential bases in common, (b) humans and gorillas have 10 out of 20 sequential bases in common, and (c) gorillas and chimpanzees have 15 out of 20 sequential bases in common. The students were asked to compare these three sequences and determine to which species, the chimpanzee or the gorilla, humans are more closely related. Out of the 40 students, 37 students made the correct conclusion in this laboratory activity by recognizing that humans are closer to chimpanzees than they are to gorillas. The conclusions of the remaining 3 students were either undecipherable or missing and were not analyzed for this activity. No student made the incorrect conclusion that humans are closer to gorillas. However, only 19 students referred to the connection between humans and chimpanzees as one of being "related." One of these students went on to explain further that humans and chimpanzees "share a common ancestor."

*Terms used to show similarities.* Seventeen students chose to use alternative terms to "related," such as "like," "similar," "similarity," "closely," or "closest." One student wrote, "share the same amount," and another student wrote, "incredible likeness . . . share . . . similarities." The remaining 3 students did not articulate a conclusion on the worksheet.
Misconception. These results indicate that although this activity was designed to demonstrate common descent and relatedness, not all students were willing or able to see the similarities in DNA as evidence for common descent. Students may have been predisposed to assume that the similarities in DNA represented an ancestor-descendent relationship instead of one of shared ancestry. The method of instruction may not have adequately addressed this misconception.

Worksheets for Skull Activity

Hypothesis testing. The second activity in the laboratory session was based on the students testing a specific hypothesis by analyzing skull casts. Each of these skulls was labeled with a number. These numbers corresponded to the skulls as follows:

#1 = Modern Homo sapiens sapiens
#2 = Australopithecus boisei
#3 = Homo erectus
#4 = Modern Chimpanzee
#5 = Australopithecus afarensis
#6 = Modern Gorilla
#7 = Neanderthal
#8 = Homo habilis

The possible evolutionary relationships can be found diagrammed in Figure 22 in Appendix E (Day, 1984).

The hypothesis tested by the students in the laboratory session was stated on the worksheets as follows: “Comparing modern human skulls with skulls from modern
species and from 'fossilized' species will indicate to which humans are more closely related and to which humans are more distantly related." The laboratory worksheet instructed the students to make “observations of modern skulls and prehistoric skulls.”

All 40 of the students present for the laboratory session conducted observations and/or measurements of the skulls. However, their conclusions varied. Some students perceived the variations in the skulls to represent evolutionary changes and evidence that modern humans and modern apes share a common ancestor.

Student 9: Large possibilities that human share common ancestors with apes.

Student 32: It is possible that all of these species came from another central species.

Other students were able to see relationships and evidence of evolution.

Student 43: # 7, #3, & #2 whose skulls were shaped more relevantly to current humans and led to #1 which is probably a *homo sapien sapien* and there [*sic*] closely related to normal *homo sapiens* [*sic*] of today.

Student 42: Nos 1, 7, 8 are probably most related to modern man.

Student 6: The earlier skulls of the humans look very similar to the skulls of apes. As time went on and we are able to study more recent skulls of humans and apes, we see how we as humans have evolved from primitive hunters with a need for large canine teeth and an angled spinal cord to a more upright species with a larger cranial cavity.

*Human or animal.* Other students used a more elementary approach as they used their observations to group each skull into one of two categories, human and animal (or ape). These students did not demonstrate a thorough understanding of common descent as they segregated organisms into a simple dualistic system.

Student 25: The animal skulls were the ones with ridges on their head. 1, 3, 7 were human skulls & 2, 4, 5, 6, 8 were animal origins.

134
Student 36: There are many similarities between the skulls of humans and animals, but there are distinct differences that separate them. 7, 1, 3 are humans. 2, 4, 5, 6, 8 – animals.

Student 34: From our results we believe 7, 3, 1, are all human. 2 4 5 6 8 all appear to be ape or chimp skulls.

Student 40: The skulls of humans are similar to those of apes, but there are also very distinct differences. #7, 1, + 3 are human. The others are not.

Student 14: It is hard to determine whether a skull is human or ape . . . Some of the older skulls appear to be apes, but are really human. The jaws in many could distinguish animal from human.

Interviews

Uncertainty. Interview transcripts were analyzed for student understanding of human origins. This analysis showed that some students were able to deal with uncertainty better than other students. Kelly had a score on the epistemology factor, belief in evolution/creationism, which favored creationism. This student mentioned that “they” [scientists] are not sure about human origins. This is an argument that creationists make against evolution.

Another student, Jessica, had a high acceptance of evolution as indicated on her score on the evolution/creationism acceptance factor. This student also had a more sophisticated view of human origins. While Kelly used uncertainty as a reason to not accept evolution, Jessica was able to deal the uncertainty.

Interviewer: Do you think any of the five skulls, either all of them, some of them, or none of them, were human?

Jessica: uhm . . . I would think they’re different stages of human. They’re not all like human as we think of it. I mean, standing 3 ½ feet tall, so it’d be like a midget. There are differences, the shape of the face, the forehead, if you could see brains and everything, but generally you know the change. It’s like if we went backwards, I could see us ending up looking like that.
And later in the interview . . .

Interviewer: Some people have used the term “missing link.” What do you think is meant by that?

Jessica: We don’t know exactly how this human-like thing came about because there was like chimps and monkeys and all them over here and there’s something missing right in here, in between the primates and the skull over there.

Another student, Allison, was also able to deal with uncertainty without questioning the validity of evolution. In fact, her statements show a great deal of advanced thought as she made her points by asking questions. This particular student indicated on the epistemology survey that she was comfortable with uncertainty and that she did not need clear-cut answers.

Interviewer: The term missing link, what do you think is meant by that?

Allison: I guess when you look at Lucy [refers to the Australopithecus afarensis skull] and you compare her to today’s human skull and you think where’s the connection? What is here in the middle that we’re not seeing? What don’t we have? Where’s the connection between Lucy and us? Where’s the connection between Lucy and actual prehistoric humans? Or was she a combination between the ape and the gorilla? Or the chimp? Where is the connection, or where did it split? Was Lucy here, and then here went the humans, one way and the chimp and the gorilla went another way and then those two branched off somewhere else? I guess, where’s the connection between Lucy and the new, and the humans?

Another student referred to how she dealt with uncertainty. This student had a score on the certainty of knowledge subscore that indicated that she believed in the certainty of knowledge, and she had a score on the belief in evolution/creationism epistemology factor that indicated that she accepted evolution.

Interviewer: You say that this does represent our ancestors? [refers to the Australopithecus afarensis skull]
Paula: I believe that. I mean I have to have some faith in the authorities, in what they’re telling me and the research that they’ve done because I don’t have that expertise, their knowledge.

Interviewer: OK, so if I were to say to you, why do you think these were our predecessors, would you say anything besides, “because experts say so”?

Paula: Well, now that I’ve seen it, it certainly does appear that way and I would look at all the information. I mean when this all came out I did read about it . . . Obviously there’s a lot of research that’s been done on this skull and I know mistakes can be made, but I have to have some faith in the experts because we can’t all be experts in everything.

*Alternate conceptions.* Kelly, who had a score that suggested that she believed in creationism, appeared to be accepting of various forms of humans, but did not make the connection that apes and humans are related. She found common ground in creationism and evolution in that both perceptions view humans as being formed from earth’s chemical elements. She was vague in some of her comments, but was certain in her belief that humans had been designed and cited her disbelief in chance. This student implied that she had previously searched for answers, but had been unsuccessful in finding out about human evolution. Her references to similar points made in creationists’ arguments against evolution could be interpreted that this student approached instruction in evolution through the lens of creationism.

Interviewer: Do you think humans evolved from something like this, these skulls? [points to the *Australopithecus afarensis* skull]

Kelly: Like they were our ancestors?

Interviewer: Yes.

Kelly: Some of them? We came up with 1, 3, and 7 as being human and so I think it would depend when they were found. I don’t know which one is modern. I can’t remember what they look like. [laughs] But I mean depending on when they were found, I definitely think those three were related.
Interviewer: OK. So do you think that those three could have come from something more, let’s just say for the sake of it, primitive, like this? [points to the *Australopithecus afarensis* skull]

Kelly: Uh huh.

Interviewer: That this could have evolved from one of those three or that we could have evolved from one of those?

Kelly: They’re not really, really sure. But I think that they’re, in some areas they are. That they’re in competition is, they’re somewhat unique. I don’t think that because I’ve never been able to find out.

Interviewer: So you’re not convinced. So do you have any ideas where humans came from?

Kelly: I think that we came from the same stuff everything else came from. [laughs] If it’s true, we’re made of the same things, just put together differently.

Interviewer: Designed differently?

Kelly: Designed differently, yeah, definitely, definitely. I know there’s a chance but I don’t believe in chance. But I do, I mean, we’re all made up of what? Oxygen, carbon, nitrogen, things like that so we’re similar in a way.

Terry expressed the naïve concept that humans came from gorillas or chimpanzees. This concept persisted even after analyzing primate skulls in the laboratory session.

Interviewer: So where do you think humans came from?

Terry: Well, from books and everything else that you learn, either a chimp or a gorilla, either one. You still have, you know, some people who walk around who have really long arms and I think of the gorilla or something. Either one of those. The gorilla.

There was evidence that less sophisticated organizers were used as the students sorted out the evolution and descent of humans. In particular, the organizer “size”
emerged from some of the students' discussion of human descent, just as it did in the branching/grouping activities.

Interviewer: Did you find anything interesting about the skulls?

Jessica: I found it interesting that there was this big one and then the little one and then a big one. There were these two huge skulls and an itty bitty one [laughs], and I suppose everything changed, so why did they need to be smaller all of a sudden?

Paula: I believe we keep evolving, you know, most certainly, the people probably that were extremely old were a lot different than the people who were 20,000 years ago, but a lot closer to, because we’re evolving, such as size, and just a few hundred years ago as far as size. [sic]

Missing link. Cindy had a more sophisticated conceptual framework of human origins. This advanced understanding corresponded to a relatively high score on the epistemology factor, belief in evolution/creationism, indicating an acceptance of evolution.

Interviewer: So where do you think humans came from?

Cindy: Definitely, I would think . . . apes. I do. I think somehow, that I know we’re all closely related in some different ways, but I think that we’re more, maybe more, I don’t want to say we’re probably smarter, because we’re probably not. [laughs] I’m not really sure, but I do know that we’re all supposed to be related.

Interviewer: Have you ever heard the term “missing link”?

Cindy: Yes.

Interviewer: What do you think that means?

Cindy: That means, to me that means I think that there’s some sort of link between probably you know, as far as what we know where man came from and you know the apes that, the primates, that are alive now. There’s some sort of link in between us that maybe we just haven’t found yet.
Attitude toward skull activity. Some students mentioned that they found the session with the skulls to be valuable.

Interviewer: Did anything surprise you about the skulls?

Cindy: I guess as far, it was really kind of neat. It was very interesting I thought to me to actually see them and feel them and you know because I've seen these on TV before but I've never actually up close, and I think that, I know I gained a lot of knowledge just from that and I thought it was just kind of neat. To see actually as far as the structure about how, I mean, yeah, it did surprise me to see how actually close we are to them.

And later in the interview . . .

Cindy: I think I learned a lot. I think, I mean, I knew that we were related to, you know, chimpanzees and apes, so I didn’t know how really close, and I think we’re a lot closer than I once had thought.

Allison: I think as far as the evolution goes it kind of helps encourage that theory because of just the different types of skulls, and I mean, it just kinda emphasizes more the evolution.

Terry: I think that like little kids need to start learning about this earlier, 'cause I didn’t know about this stuff. At least until high school, I didn’t hear much about it. I think they start us too late to tell us what they believe about where we came from.

Interviewer: So what advantages do you think there are in starting younger?

Terry: They could learn more about who maybe they came from or what they came from. They could just learn about all this stuff. You know about the jaws and the skulls and how they stand up, whether they walk on four feet or two feet.

Representations of Individual Students

This next section will report the analysis of the data on the individual student level. Of the 9 students who were interviewed, 4 were selected to illustrate individual student conceptions, their alternate conceptions, and their epistemological stances. The
selections were based on a purposeful sampling designed to provide a wide diversity in terms of the students' epistemological viewpoints. This selection was informed primarily by the students' responses to the epistemology survey and by the statements they made during the interview sessions. By chance, the selection process chose 4 females.

The sources of data included: (a) demographic information, (b) epistemology survey, (c) pretest responses, (d) laboratory worksheets, (e) interview transcripts, (f) interview activity worksheets, and (g) posttest responses. All data provided by the students were marked by identifiers that could be traced back to the student who provided the data. However, it should be noted that the name given to each student in this section is an alias in order to keep the identity of these students confidential.

Multiple sources of data were reviewed and analyzed so that the representation of each of the individual students would have contributions from more than one mode. These data were analyzed through the lens of the epistemology theoretical model, in an effort to discover if these epistemological viewpoints were apparent in the students' approaches and responses in multiple data sources and to illuminate how these various student approaches impacted learning of the theories of evolution and common descent. It is hoped that the snapshot of each student pictured in this section will provide insight into individual epistemologies. These illustrations are not meant to exemplify all the students in this study or to show a holistic view of the individual student's epistemological belief system. Rather, they are meant to highlight evidence of a narrow aspect of a student's approach to learning evolutionary theory.
Kelly's epistemology - belief in creationism. Kelly was a friendly female student in her second year of college. In addition to attending school, she worked part time as a waitress. She reported having one biology course in high school and one biology course in college. She did not respond to the question asking for grade point average. Her scores for each of the epistemology factors were as follows: (a) speed of learning, $M = 3.58$, $SD = 0.67$; (b) control of learning, $M = 3.42$, $SD = 0.90$; (c) stability of knowledge, $M = 2.86$, $SD = 1.11$; and (d) belief in evolution/creationism, $M = 2.47$, $SD = 0.80$. These scores can be interpreted to depict Kelly as: (a) believing that learning involves hard work over time, rather than being quick and easy; (b) believing that the ability to learn is acquired, rather than innate; (c) slightly believing that authority has the answers and these answers are simple and dualistic in nature; and (d) believing in creationism.

Before the interview started, Kelly asked the interviewer where she taught and seemed pleased to find out that she taught at a church-related college. Kelly's approach can best be described as a creationist, albeit a very subtle one in her actions and statements. She did not appear to want to debate her stance, but rather she provided clues in various responses that indicated that she did not fully ascribe to the theories of evolution and common descent. It appeared that she wanted to understand the theory, even when not believing it. There were also indications that she tried to reconcile evolution with her belief in creationism.

Her belief in creationism was illustrated by her responses on the epistemology survey. She strongly disagreed with the statement, "There is sufficient scientific evidence to support evolution." There were only 3 other items on the 79-item survey that she used
the strongly agree or strongly disagree response, so it can be surmised that she reserved this strong response for only a few key points. She agreed with the following statements: (a) "There is sufficient scientific evidence to support creation," (b) "Evolution should not be taught in the public high schools," (c) "Creation makes more sense than evolution," (d) "Humans hold a unique position as master over all species," (e) "Today's living species share common ancestry with other species," (f) "Changes in species over time are controlled by a wise and benevolent Creator and are not due to chance," and (g) "A great variety of highly complex forms appeared as a sudden event of creation."

Kelly disagreed with the following statements: (a) "The different species of plant and animals that are alive today are the same as they were when life first began," (b) "Creation science should not be taught in the public high schools," and (d) "Evolution accounts for the development of present forms of life."

She was neutral for the following statements: (a) "Any scientific findings that contradict Biblical Scripture should be discarded," (b) "For me, evolution explains how life has changed over time," (c) "Humans share a common ancestor with other species," (d) "The Flood explains much of the fossil record," (e) "One can believe in both creation and evolution," and (f) "Evolution and God are not compatible." She reported that 50% of her personal opinion about evolution was due to her religious beliefs.

Kelly got four questions correct out of eight on the pretest. She responded correctly to the following: (a) the best example of the term "common descent" is different species sharing the same recent ancestor; (b) biologists interpret similarities in physical traits by thinking that humans, chimpanzees, and gorillas evolved from another primate;
(c) the analogy for HUMAN: CHIMAPANZEE is DISTANT COUSIN: DISTANT COUSIN; and (d) the mosquito resistance to DDT is best explained by some mosquitoes being resistant to DDT prior to exposure. Her incorrect responses included: (a) changes in species are best explained by organisms running out of food and dying while the survivors migrated to new territories, (b) evolution of new species resulted from environmental changes causing genetic mutations, and (c) the phrase "Survival of the Fittest" is the best explanation of the modern theory of evolution. She also indicated that evolution does not have a valid scientific foundation because it is principally based on speculation and not on facts. She explained that humans are not more evolved than apple trees are by stating, "Neither have evolved, therefore one cannot be more evolved than another."

Kelly answered four questions correctly on the posttest, however the questions she got correct were not exactly the same four that she got correct on the pretest. She moved from incorrect to correct responses by changing her answer on two questions and moved to incorrect responses on two questions. She changed her answers to the correct ones for the following: (a) the best explanation for species evolving, and (b) the best explanation of changes over time. She changed to the wrong answer for the response on the analogy question by choosing the option, GREAT-GREAT-GRANDCHILD: GREAT-GREAT GRANDPARENT. She maintained the same "No" response to whether the modern theory of evolution has a valid scientific foundation. She also answered incorrectly the question that compared evolution of humans to evolution of apple trees. Her explanation was more scientific and less opinionated than her response to the same question on the pretest, but
her written answer still showed an incomplete understanding of evolution. In fact, it is very interesting to note how she phrased terms that indicated that her stance was still outside the acceptance of evolution. Kelly wrote,

True. Since evolutionary theory focuses on change over time, and since apples [sic] trees took far longer to "evolve," according to theory. As to which is more specialized, both undergo very complex processes. Because of the heart and mind in humans, I would say they are also more specialized.

It seems that Kelly was trying to explain evolution while still not totally accepting it by calling evolution a theory and putting the word, "evolve" in quotation marks. In other students' responses to this question, none of the students referred to theory or used quotation marks for the word evolve. Kelly's explanation was rather naïve, as demonstrated by her referral to the heart and mind of humans as evidence of specialization in comparing the evolution of apple trees to the evolution of humans.

In the interview activity, Kelly's time line of related connections were rather simplistic (Figure 14 in Appendix C). She chose the horizontal diagram as most closely representing her drawing. Five organisms, the bacterium, cockroach, amphibian, whale, and bird, were depicted to have originated at the same time, while the lizard came later and was connected to the amphibian, and the fish came later and was connected to the whale. The human appeared at the midpoint of the time line and was not connected to any other organisms. Kelly subtly revealed her creationism viewpoint in the interview by explaining these connections as being due to similarities in design. When asked what the connecting lines represented, Kelly responded:

I'm indicating that they're similar that I think they're similar. Like I know the whale is a mammal, ...right? [laughs] and the fish is a fish, but they're similar in the way that they work and they way they're designed, and I'm . . . really not sure
which came first or how they were created, first, which order. It would seem to me that, the amphibian I think that they probably would be and I think they're similar. I don't know about these. [laughs]

Interviewer: The whale and the fish.

Kelly: But I think they're similar.

Interviewer: Similarity meaning they came from each other, or they didn't come from each other?

Kelly: I guess not necessarily that they came from each other. Knowing that they're different, it's that they're similar, maybe they are related to each other in some way.

Interviewer: When you say related, what do you mean?

Kelly: like in the same . . . . . they're either, I think they're similar species? I mean like they have a lot of the same characteristics. It would be something like that.

The interviewer wanted to verify Kelly's creationism viewpoint that the Creator's design is evident in organisms. Later in the interview she asked Kelly if she thought that the eight skulls represented species that were designed differently.

Kelly: Designed differently, yeah, definitely, definitely. I know there's a chance, but I don't believe in chance.

The implications of creationism and design were demonstrated as Kelly attempted to explain the presence of various features of the skulls. She thought that characteristics were related to the needs of an individual.

Interviewer: Did anything about the skulls surprise you?

Kelly: The only thing, no not, no, nothing really surprised me. One of the things, some of them had, I think in one of the human skulls it had a really prominent brow, brow bone, and I've never seen a human with that prominent of a brow before. It definitely had the larger brain cavity, so I mean, and when compared to the other ones that we determined were not human, it was more similar, I mean it was less similar to the other ones, it was more similar to the humans. It had such a
prominent brow bone, I thought that was unusual, that was really surprising. Well, I mean it seems like humans don’t live outside, and so we have that hair and stuff like that, and so, we don’t need that prominent brow bone which probably causes in front a shadow in modern gorilla faces and things like that. So they’re going to need that more than say humans, and I think that’s probably why theirs is more prominent because their hair is so short. I mean it’s not as long in the head area, it’s not real long as we have it. Our hair keeps growing, and we shave it so, I think that’s one reason why they have it. [the prominent brow] Anyway, that might be one reason, I don’t know. [laughs]

Interviewer: Did anything seem particularly interesting besides the brow?

K: I don’t think so. Particularly interesting....Like the canines of that one [the gorilla] is interesting, like we said in class, he doesn’t use that for eating meat. I thought, "So why does he have the canines? Because he eats meat?" And I was wrong about that. And you said, no. That was the only thing.

When discussing the laboratory session on the skulls, Kelly revealed her thoughts about common descent.

Interviewer: Do you think your procedure tested the theory of common descent?

Kelly: Whether it tested the theory of common descent? I don’t think it really did. It just compared several different kinds of skulls and I don’t think in that particular lab we did anything that showed descent.

Interviewer: Ok. If you were to do the lab again, would you do anything differently?

Kelly: I don’t think so.

Interviewer: Do you think there’s another theory that could explain the skulls other than evolution and common descent?

Kelly: Another theory?

Interviewer: Do you think there could be another explanation?

Kelly: [hesitating for about 20 seconds as she thought over her response] The only theory is that I would say is that they’re different species. You have life in different points of time and I would say, but I don’t necessarily think I could come up with a way that would prove the branching off.
So it seems that while Kelly understood that common descent involved a branching off of different species, she did not think that the similarities in the primate skulls were evidence of common descent. She vacillated between trying to explain what "they" think and explaining why she had the beliefs she did.

Interviewer: Do you think we could have evolved from one of these? [referring to the *Australopithecus afarensis* skull]

K: They're not really, really sure. But I think that they are, in some areas they are. That they're in competition is, they're somewhat unique. I don't think that, because I've never been able to find out.

Kelly was able to reconcile the evidence with her beliefs by grouping the five skulls into two categories, human and animal. She did this on her laboratory worksheets and in the interview.

Interviewer: Ok, I had the three modern skulls, the five other skulls. Do you think any of the five other skulls were human?

Kelly: Any of the five other skulls were human? [laughs] I remember what numbers I thought were human.

Interviewer: But there were a few that you thought were human?

Kelly: There were a few.

Interviewer: But not all of them?

Kelly: Not all of them, no, no.

Interviewer: Ok. So did you think this one was human? [touches the *Australopithecus afarensis* skull]

Kelly: No. [emphatically]

Interviewer: Do you think any of these skulls could be a missing link?

Kelly: [hesitates for about 10 seconds] Not really.
The laboratory session with the skulls was designed as one in which students could see evidence of gradual evolutionary changes and common descent. However, Kelly saw something other than this when she examined the skulls. She saw the similarities in characteristics as being evidence for design, rather than evidence of shared ancestry. By categorizing the eight skulls into either the human category or the animal category, she was able to assimilate the similarities among the skulls without abandoning her epistemology.

_Terry's epistemology — dualistic knowledge and depending on authority._ Terry was a quiet female student who was in her second year of college. She reported a grade point average in the range of 3.0 – 3.4. Her mean scores for each of the four epistemology factors were as follows: (a) _speed of learning_, $M = 3.42$, $SD = 1.08$; (b) _control of learning_, $M = 3.00$, $SD = 1.35$; (c) _stability of knowledge_, $M = 2.43$, $SD = 1.03$; and (d) _belief in evolution/creationism_, $M = 2.93$, $SD = 0.97$. These scores can be interpreted to depict Terry as: (a) slightly believing that learning involves hard work over time, rather than being quick and easy; (b) having mixed beliefs about whether the ability to learn is acquired or innate; (c) believing answers are simple and dualistic in nature; and (d) having some beliefs in creationism while accepting some aspects of evolution.

Terry's approach to the interview activity revealed that she used ideas of "right" and "wrong" as points of reference and that she depended on authority for knowledge. From the interview transcript and from her responses to the epistemology survey, it appeared that she thought knowledge was certain. For example, she agreed with the following statements on the survey: (a) "Truth is unchanging," (b) "Being a good student
generally involves memorizing facts," (c) "Sometimes you just have to accept answers from your teachers even though you don't understand them," and (d) "If professors would stick more to the facts and do less theorizing, one could get more out of college." She strongly agreed the statements, "It's a waste of time to work on problems which have no possibility of coming out with a clear-cut answer," and "How much a person gets out of school mostly depends on the quality of the teacher." Her trust in authority was also apparent when she strongly disagreed with the statement, "I often wonder how much my teachers really know."

Terry got only one question right out of eight on the pretest. She correctly selected the right option for the question asking for the best explanation for how new species evolved. She selected the following incorrect responses: (a) common descent is when different species fill the same environmental niche, (b) humans evolved from the gorilla, (c) changes in species can be explained by some organisms running out of food while the survivors migrate, (d) the best analogy for HUMAN: CHIMPANZEE is GREAT-GREAT-GRANDCHILD: GREAT-GREAT-GRANDPARENT, (e) mosquitoes survived DDT by learning to adapt to their environment, (f) the phrase "Survival of the Fittest" best explains the modern theory of evolution, and (g) humans are more evolved than apple trees. Terry explained her response to this last item by writing, "True, because apple trees are more plain than humans. Humans contain so much more."

Terry's score did not improve on the posttest. However, her responses to some of the items did change. Instead of responding that humans evolved from gorillas, she chose the correct response (her only correct response on the posttest), but on another question,
she responded that humans evolved from either the chimpanzee or gorilla in Africa. She mistakenly indicated that the best example of common descent is when different species have common adaptations, such as the evolution of wings in both birds and bats. Her only correct response on the pretest was changed on the posttest, where she opted for the environment causing genetic mutations as the best explanation for evolution of new species. On the pretest, Terry had indicated that the modern theory of evolution has a valid scientific foundation because it is possible to test predictions, but on the posttest, she chose a different answer, one that stated that we can never be sure about the past. Her posttest answer comparing the evolution of apple trees to humans was very similar to her answer on the pretest, "An apple tree was planted then it grows in height like a human but there are so many more parts involved with us." Terry's responses on these two tests indicated that her understanding of evolution was simplistic.

Other sources of data reveal her incomplete view of evolution. The drawing she made for the interview activity had no lines connecting organisms (Figure 15 in Appendix C). She chose a vertical depiction that was compatible with evolutionary theory, but was a very simple way to show change over time. Her conclusions about the laboratory session with the skulls were more advanced, as she was able to see gradual changes.

In viewing the skulls I noticed that as time progressed the shape of the skull changed. The brain cavity becomes larger, the jaw line starts protruding inward instead of outward. The larger canines started to become much smaller as they become closer to human like.

However, she still did not understand thoroughly the theory of common descent as demonstrated in the following exchange.
Interviewer: So do you think this one was human or not? [touching the *Australopithecus afarensis* skull]

Terry: It could have been. With a really small brain. I think it still has the bone structure of like, say a chimp, of like it kinda looks half and half, kinda like animals and half like the human, so this one could be either one.

Interviewer: So where do you think humans came from?

Terry: Well, from books and everything else that you learn, either a chimp or a gorilla, either one. You still have, you know, some people who walk around who have really long arms and I think of the gorilla or something. Either one of those. The gorilla.

Terry's reference to books provided insight into her epistemological beliefs in that knowledge depends on authority and that knowledge is dualistic. It is interesting to note that the interviewer asked Terry, "So where do you think humans came from?" Terry did not respond, "I think . . .," but instead she referred to what books and other sources of knowledge had to say, and she was incorrect in her answer. This dependence on an authority to provide her with the "right" answers did not prevent her from making the wrong conclusion that humans evolved from gorillas. Her dependence on outside sources of information can also be seen in statements she made later on in the interview.

Terry: I think that like little kids need to start learning about this earlier, 'cause I didn't know about this stuff. At least until high school, I didn't hear much about it. I think they start us too late to tell us what they believe about where we came from.

Interviewer: So what advantages do you think there are in starting younger?

Terry: They could learn more about who maybe they came from or what they came from. They could just learn about all this stuff. You know about the jaws and the skulls and how they stand up, whether they walk on four feet, or two feet.

Interviewer: Do you think you'll ever apply this stuff?
Terry: You could. I mean, you learn a lot from books, if someone asks the question, you know the answer.

Once again, it can be seen that Terry thought there was "the answer" and that if she learned "all this stuff," she would know the answer. Perhaps her desire to see human evolution taught sooner was because she was overwhelmed by having to memorize all the facts, a strategy she had agreed with on the epistemology survey. She had also responded on the survey that sometimes a student has to accept what a teacher says, even when the student does not understand. It seems that Terry was accepting of evolution, but did not fully understand it. There is no evidence that her learning was facilitated by her view that knowledge consists of the "right" answer and by her dependence on authority. Although she referred to books and "they" as sources of knowledge, she did not make the right conclusions about common descent during the interview and her score did not improve on the posttest.

Allison's epistemology – learning is not quick and simple. Allison was a very talkative female student who was in her second year of college. She told the interviewer that she loved the outdoors and fossils were "the greatest thing." She reported a grade point average in the range of 3.0 – 3.4. She had one biology course in high school and one in college. Her mean scores for the four epistemology factors were as follows: (a) speed of learning, $M = 5.00$, $SD = 0.00$; (b) control of learning, $M = 4.58$, $SD = 0.90$; (c) stability of knowledge, $M = 3.71$, $SD = 1.45$; and (d) belief in evolution/creationism, $M = 3.67$, $SD = 1.55$. These scores can be interpreted to depict Allison as: (a) strongly believing that learning involves hard work over time, rather than being quick and easy;
(b) strongly believing that the ability to learn is acquired, rather than innate; (c) believing answers are not simple and are relativistic in nature; and (d) accepting evolution.

Allison's approach to learning was that it was not quick and simple. She was the only student out of 45 that had an extreme mean score for any of the epistemology factors. She strongly agreed with the following statements: (a) "Getting ahead takes a lot of work," and (b) "Wisdom is not in knowing the answers, but in knowing how to find the answers." Allison strongly disagreed with the following statements: (a) "For success in school, it's best not to ask too many questions," (b) "How much a person gets out of school mostly depends on the quality of the teacher," (c) "Things are simpler than most professors would have you believe," (d) "Being a good student generally involves memorizing facts," (d) "Learning definitions word-for-word is often necessary to do well on tests," (e) "If professors would stick more to the facts and do less theorizing, one could get more out of college," and (f) "It's a waste of time to work on problems which have no possibility of coming out with a clear-cut answer."

Allison obtained a score of 1 out of 8 on the pretest, by correctly choosing humans, chimpanzees, and gorillas as having evolved from another primate. Her incorrect choices were as follows: (a) common descent is exemplified by different species having common adaptations, such as the evolution of wings in both birds and bats, (b) changes in species are best explained by some organisms running out of food and dying while the survivors migrate to new territories, (c) the best analogy to HUMAN: CHIMPANZEE is ROLLS ROYCE: HONDA, (d) new species evolve due to environmental changes causing genetic mutations, (e) resistance to DDT in mosquitoes happened because mosquitoes
learned to adapt to their environment, (f) the best explanation of the modern theory of evolution is that humans evolved from either the gorilla or chimpanzee in Africa, and (g) humans are more evolved than apple trees. Allison explained this last response by writing:

Humans have learned how to adapt to their surroundings and if they cannot live in an area, they move. Trees have no choice. Once a tree is a certain age it cannot be transplanted, it must be killed or cut down.

On the posttest, Allison's score increased to 3. The 2 answers she switched to correct answers were: (a) the best example of the evolution of new species is that individual variations help in survival and reproduction, and (b) the best example of common descent is that different species share the same recent ancestor. She changed another response to one that was still incorrect by choosing the best analogy to HUMAN:CHIMPANZEE is GREAT-GREAT-GRANDCHILD: GREAT-GREAT-GRANDPARENT. Her explanation for humans being more evolved than apple trees was changed to incorporate scientific terms and ideas, but Allison did not demonstrate an integration of these ideas to form a thorough understanding of evolution. "Humans mate with other humans to develop new offspring completely unlike any other. Trees evolve from seeds that are wind pollinated and then grow as sporophytes."

Allison changed her response to the question asking if the modern theory of evolution has a valid scientific foundation. On the pretest, Allison indicated that it does, even though predictions about events in the past cannot be tested. On the posttest, Allison thought that predictions made by evolutionary science could be tested.
On the laboratory worksheet, Allison grouped the skulls into just two categories, human and animal. Her conclusion stated, "There are many similarities between humans and animals but also distinct differences." However during the interview the next day, Allison revealed a more sophisticated view of the skulls.

Interviewer: The term missing link, what do you think is meant by that?

Allison: I guess when you look at Lucy [the *Australopithecus afarensis* skull] and you compare her to today's human skull and you think where's the connection? What is here in the middle that we're not seeing? What don't we have? Where's the connection between Lucy and us? Where's the connection between Lucy and actual prehistoric humans? Or was she a combination between the ape and the gorilla? Or the chimp? Where is the connection, or where did it split? Was Lucy here, and then here went the humans, one way and the chimp and the gorilla went another way and then those two branched off somewhere else? I guess, where's the connection between Lucy and the new, and the humans?

Interviewer: So you think we could have come from Lucy or something like her?

Allison: Uh huh. [yes]

However, not all of Allison's statements during the interview showed this advanced understanding, particularly when she discussed the causes behind differing structural characteristics.

Interviewer: So do you think she was human? [points to the *Australopithecus afarensis* skull]

Allison: I think she's kind of one of the ancestors of the human, probably more prehistoric. Just because if you really look, I guess, I don't know if it's right to think of it this way or not, but as far as the cave men pictures I've ever seen when you go at museums and look at them their teeth stick out and their face is kinda caved in a little bit, their eyes, their nose, it kinda comes out more toward the mouth and I think, I think kinda they leaned forward more. *I think that's why Lucy's spinal cord where it's attached to the head, it's so far back because mostly they were hunched over.* I think that's the way they carried things, I'm sure they didn't know that you lift with your legs, you use your arms a lot more than your back. And I'm sure it probably gave them a lot more muscle in their backs and *that's why they leaned forward a lot more.*
And later in the interview . . .

Allison: Her [the *Australopithecus afarensis* skull's] teeth really surprised me. At least the older ones. You think that their teeth are going to be more separated where today humans, like we have dentists so they kinda keep our teeth closer together and they're all there. Like I was surprised how close Lucy's teeth were. I know she's got a couple gaps, but they're relatively together. Her front teeth are so smooth and they way they stick out. It kinda makes you wonder what she was eating. Whether she used her teeth to maybe bite onto things and to help her do something like, maybe she had her hands full and so she used her teeth to do it.

Allison asked many questions during the interview that provided a glimpse of how she might approach learning new concepts. As mentioned previously, she strongly disagreed with the statement, "For success in school, it's best not to ask too many questions." By asking a lot of questions, Allison showed a lot of curiosity that the other students interviewed did not.

Interviewer: Did anything disturb you about the skulls?

Allison: Not really. It just kind of makes you wonder a little bit more. I mean you really look at them and you think what was it really like? You know, you think I wouldn't want to go back to that, you know, because of the technology and everything, could we ever go back to something like that? How could they do it?

While Allison did not demonstrate an understanding of evolution that was above average on the knowledge tests, she did improve her posttest score. She also revealed a more advanced understanding of common descent during the interview than she did on any other data source. Her belief that learning is not quick or easy may be a reflection of her own learning style in how she assimilates new information. This was evidenced by her enthusiasm about a nonscience class she was taking. She told the interviewer, "They let you set your own pace."
Cindy's epistemology — accepting evolution. Cindy was a cheerful female student who was in her first year of college. She reported that her grade point average was in the range of 3.0 – 3.4. She had one biology course in high school and was enrolled in her first biology course in college. Her mean scores for each of the four epistemology factors were as follows: (a) speed of learning, \( M = 4.33, SD = 1.23 \); (b) control of learning, \( M = 4.25, SD = 1.06 \); (c) stability of knowledge, \( M = 3.71, SD = 0.78 \); and (d) belief in evolution/creationism, \( M = 4.29, SD = 1.29 \). These scores can be interpreted to depict Cindy as: (a) believing that learning involves hard work over time, rather than being quick and easy; (b) believing that the ability to learn is acquired; (c) believing answers are not simple and knowledge is relativistic; and (d) accepting evolution.

Cindy's epistemology was examined for her acceptance of evolution. Cindy strongly disagreed with the following statements: (a) "Evolution should not be taught in the public high schools," (b) "Any scientific findings that contradict Biblical scripture should be discarded," (c) "Humans hold a unique position as master over all species," (d) "Changes in species over time are controlled by a wise and benevolent Creator and are not due to chance," (e) "A great variety of highly complex forms appeared as a sudden event of creation," (f) "The Flood explains much of the fossil record," and (g) "Evolution and God are not compatible." She disagreed with the statement, "The different species of plants and animals that are alive today are the same as they were when life first began." Cindy strongly agreed with the statement, "One can believe in both creation and evolution," and she agreed with the following statements: (a) "There is sufficient scientific evidence to support evolution," (b) "For me, evolution explains how life has
changed over time," (c) "Today's living species share common ancestry with other species," (d) "Humans share a common ancestor with other species," and (e) "Evolution accounts for the development of present forms of life." Cindy attributed 30% of her opinion about evolution to be due to her religious beliefs.

Even though Cindy's scores indicated that she accepted evolution, her understanding was incomplete, as measured on the pretest and the posttests. On the pretest, Cindy chose the correct response for four questions out of eight: (a) humans, chimpanzees, and gorillas evolved from another primate; (b) the analogy most like HUMAN: CHIMPANZEE is DISTANT COUSIN: DISTANT COUSIN; (c) the best explanation for the evolution of new species is that individual variations enable organisms to survive and reproduce more successfully than others; (d) and humans are not more evolved than apple trees. Her explanation for this last answer was, "This is probably not true due to the fact that apple trees have been around for a long time and must have evolved quite a bit due to environmental changes and cross pollination." Her incorrect responses included: (a) the best example of common descent is that different species have common adaptations, such as the evolution of wings in both birds and bats, (b) the best explanation for changes in species over time is that an individual organism can adapt in order to survive, (c) mosquito resistance to DDT can be explained by the need in mosquitoes to survive, and (d) the best explanation of the modern theory of evolution is that humans evolved from either the gorilla or chimpanzee in Africa.

Cindy's score of 4 correct did not improve on the posttest, even though she changed some of her answers: (a) she switched to the correct answer for the term
common descent by choosing that different species share the same recent ancestor, (b) she switched to an incorrect answer for the best explanation of how new species evolve by selecting the response that physical barriers separate individuals, and (c) she changed from an incorrect response to another incorrect response by choosing the best explanation of the modern theory of evolution as being a purposeful striving toward "higher" forms.

For the question comparing human evolution to that of apple trees, her written explanation on the posttest was very similar to what she had written on the pretest, "False, I am sure that apple trees have been around for a long time and evolved from some ancient ancestor. Everything living evolves over time to some degree."

On the laboratory worksheet, Cindy organized the skulls on a continuum based on the degree to which each was related to modern humans. She did not group them into two categories, animal or human, as did some of the other students. Cindy demonstrated a knowledge of common descent by connecting different organisms in her diagram (Figure 16 in Appendix C), making it look like a tree with branches. She stated that she thought various species evolved from another species.

Cindy: And I believe, you know, like I said the bacterium was probably present then and it is now, and then . . . now, I know that probably, essentially, at one point everything kind of evolved from it.

Later in the interview, Cindy also stated that the branches meant that organisms shared a common ancestor.

Cindy: I think that these three are probably pretty closely related, but I also think that they probably share some sort of a common ancestor between this branch and this branch.

Cindy demonstrated an understanding of human's relationship to modern primates.
Interviewer: Where do you think humans came from?

Cindy: Definitely, I would think ... apes. I do. I think somehow, that I know we're all closely related in some different ways but I think that we're more, maybe more, I don't want to say we're probably smarter, because we're probably not. [laughs]

Interviewer: [laughs]

Cindy: I'm not really sure, but I do know that we're all supposed to be related.

Interviewer: Have you ever heard the term “missing link”?

Cindy: Yes.

Interviewer: What do you think that means?

Cindy: That means, to me that means I think that there’s some sort of link between probably you know, as far as what we know where man came from and you know the apes that, the primates, that are alive now. There's some sort of link in between us that maybe we just haven't found yet.

However, while Cindy demonstrated an understanding of the relationship between the skulls, she did not completely understand all the connections between different species. In her diagram, she connected the fish to the whale and the bird to the human.

Cindy: And the fish and the whale I know that they're related somehow. The bird and the human I believe are, are related definitely.

Cindy may have understood the relationships among the primate skulls because she had the opportunity to test evolutionary theory. She had indicated on both the pretest and the posttest that the modern theory of evolution has a valid scientific foundation and that the many predictions made by evolutionary science can be tested. During her interview, Cindy thought that she had tested the theory of common descent in the laboratory session with the primate skulls.
Interviewer: And how did your group decide what you were going to measure?

Cindy: [laughs] We basically, just I guess from past knowledge. I was pretty much the person in the group who said, we should look at this, we should look at that just to see how they differ.

Interviewer: And how did you come up with those?

Cindy: I don’t know, I guess from just knowledge, I don’t know. I was just picking things that I thought would be easy to identify as far as like the teeth and how far apart they were spaced and the size and like the jaw line, I think that’s really important. And as far as the size of the head, I thought that was important, too.

Interviewer: So things that not only you could measure but made sense?

Cindy: Yeah, right, right.

Interviewer: And the hypothesis was that you would find something or maybe more than one thing that would be related to humans. So did you think about that when you were designing the procedure?

Cindy: I would say yes, definitely.

Interviewer: Do you think that your procedure tested the theory of common descent?

Cindy: Yes.

Interviewer: Do you?

Cindy: I do, I do.

Interviewer: And why?

Cindy: Because I think we were pretty much on right on key with a lot of the answers that we were discussing in class like I mean, just from what we looked at and about what you were talking about in class, it really made a lot of sense. I know there was one specific one, where a lot, where most of the class thought it was more closely ape-related and our group, we thought it was more closely man-related and we ended up being actually right. [both laugh]
Cindy related that she learned a lot from the laboratory session. Her acceptance of evolution and her willingness to see the evolutionary relationship between humans and chimpanzees may have allowed her to learn more about this relationship.

Interviewer: Did anything surprise you about the skulls?

Cindy: I guess as far, it was really kind of neat. It was very interesting, I thought to me to actually see them and feel them, and you know because I've seen these on TV before, but I've never actually up close and I think that, I know I gained a lot of knowledge just from that and I thought it was just kind of neat. To see actually as far as the structure about how, I mean, yeah, it did surprise me to see how actually close we are to them.

Interviewer: So not only getting to hold them, but actually getting to make some measurements.

Cindy: Yeah, right, right.

Interviewer: So what do you think you learned?

Cindy: I think I learned a lot. I think, I mean I knew that we were related to you know chimpanzees and apes, so I didn't know how really close and I think we're a lot closer than I once had thought.

Summary of the Qualitative Analysis

Following are some of the important findings from the qualitative portion of this study.

As part of their findings in the laboratory session, the majority of the students correctly concluded that humans were closer to chimpanzees than they were to gorillas. Most students expressed this conclusion in the terms that humans are related to chimpanzees.

During an activity designed to elicit student conceptions, 4 students expressed relationships among species as being branched, which corresponds to modern
evolutionary theory. However, several students used the term "related" in a nonscientific way.

Students used organizers to arrange related organisms, and these organizers varied from unsophisticated conceptions to the more advanced conceptions of evolutionary theory. These organizers included similarity of traits, size, complexity, environment, function, and prior knowledge of common descent. These organizers surfaced not only in both the branching/grouping activity, but also in the discussion of human speciation.

The majority of the students interviewed correctly identified scientifically acceptable speciation relationships, such as amphibians and lizards. However, the majority of students also grouped fish and whales together, often depicting an incorrect relationship of these two very different organisms.

Several students chose to delineate prehistoric skulls into two categories, human and animal (or ape), rather than emphasizing the gradual evolutionary changes that have been delineated by anthropologists.

One student's misconception persisted during the interview, even after examining the skulls, in that she still expressed the unacceptable viewpoint that humans probably descended from gorillas or chimpanzees. Other students also expressed this alternate concept.

Some students showed no discomfort in the uncertainty of evolution, while 1 student used this uncertainty to justify her rejection of evolution.

When data were analyzed on a student level, it was discovered that evidence of students' epistemologies were present in multiple data sources.
Several students did refer to evolutionary change and common descent for humans and demonstrated a sophisticated understanding of evolution.

In the next chapter, these results will be discussed, and the implications will be summarized.
CHAPTER 5

DISCUSSION, SUMMARY, AND RECOMMENDATIONS

Discussion of the Results

Chapter 4 reported results from both the quantitative and qualitative components of this study. In this chapter, those results will be discussed in relationship to answering the research questions that guided this study. After the discussion of the results, a summary and implications of the findings of this research study will be given.

Discussion of the Results Addressing Research Question 1

What is the level of college student understanding of the theories of evolution and common descent as measured on a knowledge test both before and after instruction?

Before this question can be answered, pertinent information relative to the reliability of the knowledge test will be discussed. The level of understanding was measured using a test developed as part of this study. This 8-item test used 4 items derived from other research and 4 items written for this study that covered the topic of common descent. This instrument was found to be reliable (total test $r = .87$; common descent component $r = .56$) when used to test the understanding of graduate biology students, but it was found to be less reliable (total test $r = .58$; common descent component $r = .20$) when used to test the understanding of the community college
students of this study. So why would this reliability be low? A possible explanation is that perhaps the test suffered from a lack of content validity, but this explanation is rather unlikely for the 4 items relating to common descent, in that they were especially designed to correspond with the content covered in the laboratory session about common descent. Also, a comparison of the other items to the content covered by the instructors support a conclusion that the content of these items was covered in lecture.

Other possible explanations for the low reliability are that the students did not know the material and were guessing at their answers, or that the level of difficulty of the test was not appropriate for the participants. The group means of the total pretest and posttest were low (3.18 out of 8), revealing a general low degree of understanding as measured by the tests. In order to discover the chances that the students were guessing, further statistical analyses were performed. The group mean of the total tests and the group mean of the common descent component differed significantly from scores that could have been obtained from merely guessing. However, a considerable number of students (17 out of 39 on total test and 12 out of 39 on the common descent component) had scores that could have been from guessing. The level of difficulty was probably not a major problem, because three of the items had been derived from other studies (Brumby, 1984; Lord & Marino, 1993; Sinclair et al., 1997) with undergraduate college students as the participants, and the four items covering common descent had been based on objectives identified for high school students (National Science Teachers Association, 1996). However, the level of difficulty may have been a contributing factor because the
college students in this study were not biology majors, and therefore, high school level questions may have been more appropriate.

Yet another possible explanation for the low reliability is that there was a limited number of items on the test. Usually, reliability can be increased by increasing the number of items (Hopkins, Stanley, et al., 1990). However, the research conducted on student learning of evolution by Lawson and Worsnop (1992) used a knowledge test with a greater number of items on the knowledge test, and they still obtained a low reliability. So it is unlikely that the major cause for low reliability was due only to the low number of items used on the knowledge test in the research reported in this dissertation.

The major problem with the reliability was probably due to the low degree of variance ($SD = 1.876$). This low variance could have been due both to the low scores and to the uniformity of the level of understanding of the students in this study, who were not biology majors. Most of the students had very little understanding of evolution and only a few students demonstrated a greater understanding of evolution as measured by this test. The somewhat low degree of understanding was substantiated by data analyzed as part of the qualitative component of this study. For example, during the interviews, this researcher deliberately probed student understanding, yielding student responses that revealed ideas that would have led them to incorrect answers on the knowledge test. So the explanation that the reliability was low due to the lack of student understanding is supported by the qualitative data. Therefore, while there could be several reasons for low reliability, the best explanation for the depressed reliability is that it was due to the relative uniformity of scores of these particular nonmajor biology students, which in turn
was secondary to the low student level of understanding and to the considerable number of students who may have been guessing. Because the low reliability of the knowledge test primarily involved the lack of variance among the students, it becomes less likely that significant correlations will be found between the knowledge test scores and other variables, and any significance found should be scrutinized to verify the relationship.

The relatively low reliability can be compared to the reliability of knowledge tests covering evolutionary theory used in other studies. This is not an easy task because of the lack of reporting of internal consistency. For example, while Bishop and Anderson (1990), Jensen and Finley (1995), and Demastes, Settlage, et al. (1995) used tests with short answers and modified multiple-choice items, these researchers did not report instrument reliability, but reported only the reliability of the judges. Although Lawson and Worsnop (1992) reported only a test-retest reliability ($r = .46$) using the subjects' preinstructional and postinstructional scores, a value for internal consistency could be estimated by using their data that were reported in their study. By using the Kuder-Richardson 21 formula, it was calculated that their 20-item posttest had a reliability of .54. Rutledge (1996) reported a reliability of .78 on 25 items that tested understanding, but this study was of high school biology teachers who averaged 71% correct. Other studies (Tatina, 1989; Zimmerman, 1986) based assessments of participant understanding on just one item, so reliability values were not relevant.

While the reliability of the study reported in this dissertation was less than ideal, it was comparable to the reliability obtained from the Lawson and Worsnop (1992) study. The low values obtained do not totally negate the validity of the instrument, but are a
reflection of the nature of the topic under study, the uniformity of the student scores, and
the knowledge level of nonmajor biology college students. These reasons become
especially apparent when considering the higher reliability values obtained by testing the
biology graduate students and using the test-retest method to calculate reliability. While
these explanations have shed light on the reasons for the low reliability values, their
impact remained and should be considered as a limitation when interpreting the results
from this study.

In answering Research Question 1, this study did uncover two disturbing findings. The
first is that learning as measured on the posttest did not improve after instruction. The
mean score for the knowledge test was 3.18 out of 8 (40% correct) before instruction,
and after instruction the mean score for the knowledge test was the same, 3.18. The
second disturbing finding is that the mean score of 40% correct represented such a small
degree of understanding. However, these pretest and posttest means of 40% correct can
be compared to pretest and posttest scores reported by other researchers, such as Jensen
and Finley (1995). They reported college students mean scores of 25% correct on a
preinstructional test and 45% correct on a postinstructional test. In a study of high school
students, Lawson and Worsnop (1992) reported values corresponding to 41% correct on
the preinstructional test and 59% on the postinstructional test. In a study of college
students, Sinclair et al. (1997) reported that 21% of the students comprehended Darwin’s
theory prior to instruction compared to 34% after college-level instruction. There have
been other studies that have found college student learning to be less than desirable even
after instruction (Demastes, Settlage, et al., 1995; Drummer, Ingersol, & Haury, 1999).
Thus, all of the cited studies demonstrate that student understanding of evolutionary theory is often less than ideal, even after instruction. The study reported in this dissertation supports that finding.

The lack of improvement in the group scores of the pretest and posttest means in this study was most likely due to the small amount of time given to covering the topic of evolution and to the delay of 4-5 weeks in giving the posttest. Although the students may have studied for the examination, they also had to study for several other topics that were on the same course examination and that had been covered in class since the instruction on evolution and common descent. When compared to other studies, this research had either a longer delay in the posttest administration or less instructional time dedicated to evolution. In the Jensen and Finley study (1995), the instruction consisted of two 2-hour lecture-discussion sessions and the posttest was given 1 week after instruction. In the Lawson and Worsnop study (1992), the instruction was conducted over 3 weeks, and the posttest was given immediately after instruction.

It should be noted that while there was no difference between the group means of the total pretest scores and the total posttest scores, there was movement between the two tests in that 17 students did score higher on the posttest. A statistical relationship was uncovered, by performing an ANOVA to analyze the differences among the 12 students whose scores decreased on the posttest, the 9 students whose scores stayed the same, and the 17 students whose scores increased. The group of students who scored higher on the posttest than they did on the pretest also scored significantly higher on the knowledge is certain subscale ($M = 3.23$) than the group of students ($M = 2.72$) who scored lower on
the posttest than the pretest. (It should be noted that a low score on the *knowledge is certain* subscale represented a stronger belief in the certainty of knowledge because this is in the direction of a less sophisticated belief, and hence the lower score. The more sophisticated belief is a belief in the uncertainty of knowledge, which is represented by a higher score.) This finding was consistent with one reported by Schommer (1990), in that students with a strong belief in the certainty of knowledge were less likely to demonstrate understanding of written passages.

As for the common descent component of this study, the posttest mean score was 2.08 (52%). The questions on common descent were designed to test understanding of the processes of evolution and speciation and also to test the interpretation of evidence. For example, one question addressed the interpretation of DNA evidence as to how chimpanzees and humans are related evolutionarily. Another question pertained to the conditions required for the process of speciation, while yet another question was based on a specific application of the process of natural selection in speciation. The students did better on the common descent component than on the other items, but it should not be assumed that this is due to the laboratory instruction, which was the only instruction given relative to common descent. The low reliability of the common descent component ($r = .20$) does not allow this conclusion to be made. However, this analysis that includes the common descent component does make a contribution in that there are very few test questions relative to common descent available in the research literature. Because common descent has been recently addressed in the objectives found in *Scope, sequence, and coordination: A framework for high school science education* (National Science
Teachers Association, 1996), and there have been so very few studies of student understanding of common descent, the questions developed as part of this study can add pertinent data to the research literature.

Discussion of the Results Addressing Research Question 2

Which, if any, of the five epistemological factors are associated with college student understanding of the theories of evolution and common descent?

These are the epistemological factors studied: (a) belief in evolution/creationism, (b) belief in the stability of knowledge, (c) belief in the speed of learning, (d) belief in the control of learning, and (e) belief in the structure of knowledge. Before the relationships between epistemology factors and understanding are discussed, the nature of the epistemology factors measured in this study will be examined.

The epistemology instrument consisted of items soliciting responses relative to beliefs about knowledge and learning experiences (Schommer, 1990) and items developed as part of this study relative to beliefs about evolution/creationism. Schommer reported that four factors have been consistently demonstrated by factor analysis. The study being reported in this dissertation had too few students (45) to perform a meaningful factor analysis considering the number of items (62) in the Schommer survey. Therefore, items were grouped into factors based on prior studies (Schommer, Crouse, et al., 1992) and meaningful constructs. Due to the nature of constructs that belong to the affective domain, not all findings are transferable to different sets of subjects, as evidenced by the somewhat smaller reliabilities obtained in this study. Schommer et al. (1997) reported reliabilities for the four epistemology factors ranging from .63 to .85. The
study reported in this dissertation found the same four factors to have reliabilities of .00, .61, .63, and .74. If the factor with the reliability of .00 is excluded, the remaining three reliability values compare closely to those reported by Schommer et al. While reliabilities above .70 can be acceptable in measuring personality factors (Gay, 1996), those in the .60 range are marginal and any correlations run with factors in this range should be interpreted with caution.

So why were reliabilities less than .70 obtained? First of all, even with a larger number of subjects, Schommer (1990) obtained reliabilities in the .60 range, so it seems that the instrument itself has an inherent reliability issue for one or more of the factors. As for the particular study being reported in this dissertation, the reliabilities less than .70 could have been caused by the relatively small number of subjects participating (45), the small number of items assigned to each factor (Hopkins, Stanley, et al., 1990), and to the relatively low standard deviations (ranging from 0.365 to 0.578). In fact, the small number of items appears to be a major contributor to the low reliability in that the three factors with reliabilities less than .70 had 12 or fewer items, while the one factor with a reliability greater than .70 had 21 items. So a small number of items, the small number of participants, and the relatively low variance all combined to contribute to marginal reliability values and to the .00 reliability value obtained for one factor.

However, an explanation based on statistics alone is not complete. There is at least one other factor that may have contributed to low reliability. Schommer and Walker (1995) reported that beliefs about learning and knowledge can be domain specific. This aspect was not controlled in this study. When the epistemology survey was administered,
the students were not given specific instructions as to what course subject(s) to think about when responding to the items. Therefore, it is unknown whether students were thinking about the biology class or other courses when they responded to items such as, "If you are ever going to be able to understand something, it will make sense to you the first time you hear it," and "You can believe almost everything you read." So, if students were inconsistent in which courses they had in mind when answering these questions, the reliability of the instrument may have suffered.

A further analysis was conducted to determine the source for the reliability of .00 for the factor, belief in structure of knowledge. There were only five items assigned to this factor, so the small number of items was one of the major reasons for the factor being unreliable. Additionally, the standard deviation was not particularly large (0.368), so the low variance was partially responsible for the lack of reliability. A simple correlation matrix of these five items was examined, and it was revealed that there was very little correlation among the responses to these five items made by the subjects of this study. However, even when an item that had the least correlation with the others was removed, item 18, the reliability increased to only .31. It is interesting to note that this particular factor, structure of knowledge, dealt with the interconnectedness of knowledge across domains and learning situations. When the meanings of the items were closely examined, it appeared that they did not adequately measure a separate domain, and the factor subsequently suffered from a lack of construct validity. Because this factor was dropped from the study, the belief in the structure of knowledge could not be examined, and its absence became a limitation of this study. This factor may be found to be reliable when
testing another group of subjects, but it would be beneficial to increase the number of items addressing this construct and to verify that they all belong to the same narrow construct.

The factor, belief in evolution/creationism, was developed as part of this study and was found to be reliable (α = .87) for the students who were part of this study. The acceptable level of reliability is probably due to the large number of items (17) contributing to the construct, the relatively high standard deviation (0.578), and the construct specificity of the items that were not vague as to course domain.

The standard deviations for each of the factors were relatively low, with a range of 0.365 for the stability of knowledge factor to 0.578 for the belief in evolution/creationism factor. These relatively low standard deviations could have been a result of the students being indifferent to the survey instrument or not highly valuing the beliefs under study. It could have been that the length of the survey (86 total questions) caused a fatigue factor to come into play, but this was unlikely due to the relatively larger variation in the belief in evolution/creationism factor that was tested in the last group of items on the survey.

When the standard deviations of individual student's responses to items within a construct were evaluated, a greater degree of variance was discovered. As a group, approximately half of the 45 students responded to 68% of the items within a factor with a response ± 1 Likert response within their individual mean score. The largest student variance (SD = 1.38) on all the epistemology factors was observed with the students whose scores corresponded to a belief in creationism. This finding is consistent with the diversity that is found when one examines the various positions of religious organizations.
and individuals writing within the creationism world view (Behe, 1996; Dagher & BouJauode, 1997; Gish, 1985). For example, Behe stated that he has no reason to believe that common descent did not occur but is adamantly opposed to natural selection, while Gish positioned himself to be strongly against common descent. Thus, creationism is not a unidimensional belief, so it was not surprising that the greatest variance was found within those students whose scores reflected a creationism viewpoint.

The smallest student variance on all the epistemology factors was observed with the items on the speed of learning factor. This may be a reflection of the students' developmental status because the students' scores averaged the highest value of any of the epistemology factors and the range of scores was higher than that of other factors. These statistics indicate that the students in this study demonstrated a developmentally sophisticated belief that learning is a time-consuming task involving hard work. This more advanced epistemological development may have resulted in the students responding consistently to the items composing this factor.

In answering Research Question 2, the epistemological factor, belief in evolution/creationism, was found to have a correlation with student understanding of evolution, both before instruction and 4 to 5 weeks after instruction. The nature of this correlation was such that an acceptance in evolution, as measured by the epistemology instrument, was associated with a higher score on the knowledge of evolution test. Conversely, a belief in creationism, as measured by the epistemology instrument, was associated with a lower score on the knowledge of evolution test. This relationship was verified by an item-by-item analysis. It should be noted that this research did not study
whether this relationship was one of cause and effect. Additionally, it is unknown from
the findings of this study whether an acceptance of evolution preceded understanding or
whether understanding preceded acceptance.

The findings of this study can be compared to the findings of other studies relative
to the relationship between scores on the belief in evolution/creationism factor and scores
on the knowledge test. Two studies (Bishop & Anderson, 1990; Demastes, Settlage, et al.,
1995) evaluated the association between college students' rejection of evolution and
understanding evolution and did not find any significant relationships. However, these
two studies differ from the study reported in this dissertation in that neither of these
studies investigated directly a belief in creationist ideology, but rather an acceptance of
evolution. Also, the determination of this acceptance of evolution was based on only 1
item, as contrasted to the study reported here, which measured belief in
evolution/creationism with 17 items. In their study of high school students, Lawson and
Worsnop (1992) did find a significant relationship between understanding of evolution
and responses on an instrument measuring belief in special creation or evolution and
related beliefs. Their questionnaire that measured belief consisted of 11 items about
creation and 6 items about other religious nonscientific beliefs.

The variance experienced in the scores within the creationist range and reported in
this dissertation may explain why a significant relationship between belief scores and
knowledge test scores was found with the students in this study. It should be noted that
the belief in evolution/creationism had the largest standard deviation (0.578) of the four
epistemology factors and that the student scores that fell into the creationism range
exhibited the largest standard error (1.38) of any group of student epistemology scores. Because of this variance, the 1-item test used by others may not have been sufficient with this population had it been used to measure whether a student believed in creationism or accepted evolution. A mean score of 17 items may have been a better way to capture the many facets of this belief's diversity. Thus, the findings of this study were more similar to those of Lawson and Worsnop (1992), who found a significant relationship between belief and knowledge by using 17 items to measure what they called a belief in special creation or evolution. Although they used different items than those used in this study, 4 items were similar.

Other epistemological factors evaluated for relationships with student understanding were: (a) belief in the stability of knowledge, (b) belief in the speed of learning, and (c) belief in the control of learning. None of these correlations resulted in a statistically significant relationship. The strength of the correlations between each of these three factors varied, with the strongest relationship between understanding and belief in the stability of knowledge. This correlation was not statistically significant, but upon closer examination, a dimension of this factor, knowledge consists of single answers represented the major contribution to the correlation value. The nature of this relationship was such that students who had a belief that knowledge consists of single answers were more likely to have had a lower score on the knowledge test. These results should be interpreted with caution because the relationship was not significant and the subscale did not have a high reliability. The modern theory of evolution is a complex theory that has many aspects, such as the theory of common descent and the theory of natural selection.
Those students in this study who had a dualistic perspective and who perceived knowledge to consist of single answers may have had more difficulty in learning the complexities of the theory, but further research needs to be conducted before this connection can be made.

The lack of significant relationships may be due to the relatively low reliabilities of two epistemology factors and the knowledge test as found with the subjects of this study. Belief in the *stability of knowledge* was the only epistemology factor other than *belief in evolution/creationism* that had an acceptable reliability; the reliabilities of the two other factors were marginal. Thus, it cannot be concluded that other subjects would not have demonstrated a relationship, should there have been a greater reliability of the instruments in another context.

*Discussion of the Results Addressing Research Question 3*

*Which, if any, of the demographic variables are associated with college student understanding of the theories of evolution and common descent?*

The demographic variables studied were gender, number of prior biology courses taken, and the year in college. Only one demographic variable, gender, showed a statistically significant correlation to the scores on the knowledge test. The men scored significantly higher than women did on the common descent portion of the test administered after instruction. It should be noted that the only instruction specifically covering the theory of common descent was the laboratory session with the two inquiry-based activities: (a) the activity that examined DNA sequences, and (b) the activity that examined skulls. A possible explanation is that the men may have found the skulls more
appealing than the women did. Another explanation may be found in examining other
gender differences in the variables of interest, such as the epistemology factor scores, or
the demographic variables. As a group, the men reported a higher grade point average
than the women did. It should be noted that this was an ordinal variable, and thus, was a
relatively imprecise comparison. Also, the men reported having taken more biology
coursework than the women did. However, neither of these differences was significant.
What was found to be significantly different was the difference between the men's score
on the speed of learning factor and the women's score. The men apparently had a stronger
belief than the women did that learning was quick and simple. This finding may be a
reflection of gender differences in confidence that affect achievement in the science
coursework reported by others, such as Dweck (1986) and Kelly (cited in Kahle & Meece,
1994). The gender gap that favors males in science achievement was found by Mulis and
Jenkins (cited in Kahle & Meece, 1994) to have been present in the ability to analyze and
interpret data. These were precisely the tasks required of the students during the
instructional activity covering the theory of common descent as part of this study.
Therefore, the higher scores achieved by the men on the common descent component of
the posttest may possibly be attributed to a belief in simple and quick learning and to the
nature of the laboratory instruction pertaining to common descent. However, these results
should be interpreted with a great deal of caution due to the low reliability of the common
descent component.

Two demographic variables did not show a significant correlation to knowledge
scores: (a) the number of years in college, and (b) the number of previous biology
courses, which ranged from one to four. It is of interest to note that, both prior to instruction and after instruction, students who had more biology coursework did not demonstrate higher scores on the knowledge tests. A possible explanation is that these students were not biology majors and probably had only introductory level courses that traditionally cover evolution in a short time frame. This finding is similar to the finding made by Bishop and Anderson (1990) in their study of college students. They found no relationships between the number of previous biology courses taken and scores on tests covering natural selection, either before instruction or after instruction.

Discussion of the Results Addressing Research Question 4

What are the alternate conceptions that college students have about the theory of common descent?

Four alternate conceptions were identified and will be discussed: (a) humans evolved from chimpanzees, instead of being related through shared descent of another primate; (b) the term "related" had a common, everyday usage, instead of the scientific meaning; (c) eight primates were categorized into two categories, animal and human, instead of being placed on a continuum; and (d) naïve organizers were used to organize various "related" species. These conceptions will be discussed, along with evidence of their existence in the students of this study and possible explanations for their presence. These conceptions also will be compared to what has been reported by other researchers.

Even after instruction, 16 out of 39 students incorrectly identified the chimpanzee as an ancestor to humans. This result does not appear to be due to random chance when the pattern of the other responses on the posttest is taken into consideration. For example,
the knowledge test had a total of three questions in either the stem or in an option that addressed the misconception that humans descended from the chimpanzee. On all three questions, the movement from the pretest to the posttest was toward the misconception, instead of away from it. By comparing the pretest responses to the posttest responses, it was discovered that 5 students discarded this misconception in favor of the scientifically correct response while 4 students discarded the correct response for the chimpanzee response. The misconception persisted in 11 students even after an inquiry-based laboratory session in which the students investigated relatedness of humans and chimpanzees using DNA sequences and skull casts. These results are similar to those of Brattstrom (1999) and Sinclair et al. (1997). Brattstrom reported that after instruction nearly 25% of college biology students held onto the misconception that chimpanzees evolved into humans. Sinclair et al. also found that students held misconceptions about relationships between humans and other primates, even after instruction designed to address these concepts.

This tenacious misconception may not have been adequately addressed by the instructional activities. In the DNA activity, the students were assigned the task of comparing the relatedness of humans to chimpanzees and gorillas. Because the chimpanzee's DNA was more similar to the humans than the gorilla's DNA was, the students may have misinterpreted these results to mean that humans were descended from the chimpanzee instead of the relationship being one of shared descent. In the second laboratory activity, students compared eight skulls, including that of the modern human, the modern chimpanzee, and the modern gorilla. Many students concluded that humans
were most distantly related to the chimpanzee and the gorilla. Since the nature of this
distant relationship was not further delineated, some students may have interpreted the
relationship to represent one of ancestor-descendant.

A contributor to this misconception could be the conceptual framework that these
students had about evolution. In several narrative data sources, students were found to
have used complexity as an organizer when comparing various organisms. Many students
saw the evolutionary process as progressive, going from lower forms to higher forms. As
students compared the eight skulls, they may have mentally opted for the lowest skull to
represent the ancestor, and the chimpanzee's skull could have been judged to be the
lowest skull. Also, several students used size as an organizer for the evolutionary process,
with evolutionary change moving from smaller to larger organisms. Because the
chimpanzee skull was quite smaller than the other skulls, student mental comparisons of
this skull to others may have reinforced the misconception. One student did mention that
she did not understand why over time the skulls went from big to small to big,
demonstrating that she preferred to mentally construct them on a continuum of relative
size.

The second alternate conception identified in this study was the usage of the term
"related." On the laboratory worksheets, out of 40 students, 20 students used terms
referring to similarity and likeness while 17 students used derivations of the term
"related." During the interviews, students used the term related the term "related" in a
context that did not have the same meaning as the scientific term that means the sharing
of common ancestry. Therefore, even when students used the term "related," they may
have been using the more everyday common definition of being related which also encompasses ancestor-descendant connections and cases of mere similarity. Bishop and Anderson (1990) found similar problems with college students misapplying the everyday usage of the term "adapt" in scientific contexts of natural selection theory.

The third alternate conception identified was the way students separated primates into just two categories, human and animal, rather than emphasizing the gradual evolutionary changes. This alternate conception was present in both the laboratory worksheets and the interview transcripts. It is speculated that students may identify their own species as being separate from the natural world (Armstrong, 1997). This finding is in contrast to the statement made by Nickels (1987) in which he reported that it is virtually impossible for students to not see the gradual changes among primate skulls. Several of the students in this study classified the skulls of *A. afarensis*, *A. boisei*, and *Homo habilis* as belonging to animals and the modern human, the Neanderthal, and *Homo erectus* as belonging to humans. This finding is remarkably similar to claims made on the Early Man Summary of the *Creation Science* website (1998).

Man and ape remain different species: When all is said and done the fossil evidence can be justifiably divided into two buckets, man and beast. The Australopithecines (*A. africanus*, *A. afarensis*, *A. robustus*, *A. boisei*, Lucy, etc.) are all apes. *Homo erectus* and Neanderthal used tools and have brain sizes that overlap with humans. One has to ask, what's the difference? (http://emporium.turnpike.net/C/cs/emsum.htm)

The fourth alternate conception that this study found was that students used organizing concepts to contrast and group organisms in both discussions and activities during interviews. These organizers ranged in sophistication, with the simpler ones being
similarity of traits, size, complexity, environment, and function and the more advanced
organizers being prior knowledge of common descent. The less sophisticated organizer,
environment, appears to have led many students to erroneously group whales and fish
together as being part of the same evolutionary branch. While the environment does play
a role in the process of natural selection, students did not seem to truly understand the
mechanism involved. Some of these students admitted that they knew whales were
mammals or breathed air, but these same students still grouped whales and fish together.
So it seems that this less sophisticated organizer transcended the students' ideas of more
scientifically acceptable classification schemes. This misconception appeared to stem
from the students seeing these two organisms as living in the same environment and
having the same type of locomotion. Because this conception of grouping fish and whales
together was present at different levels of conceptual sophistication, it is speculated that
this naïve conception may have persisted from childhood and was incorporated into a new
conceptual framework as the students became more knowledgeable of classification.
Otherwise, students would have grouped the whale with the human, recognizing that
because they are both mammals, they are more closely related. However, it may be that
the students were unaware that whales are mammals and thought that they are a type of
fish. Or the students may have not understood fully the oral instruction of grouping the
organisms in terms of evolutionary relationships. Both of these explanations are possible,
but are unlikely explanations for all of the students because two students referred to
whales being mammals or mammal-like, and the whales were mentioned as "coming
from" fish. As mentioned previously, the most likely explanation for this finding in this
context involves the use of the environment as a naïve organizer that overrode scientific classification schemes. This researcher did not find reports in the literature of other students using these organizers within the context of the theory of common descent.

In addressing this fourth research question, this study did find that some students demonstrated a scientifically acceptable, more advanced understanding of common descent. For example, 4 of the 9 students interviewed expressed relationships among species as being branched, which corresponds to modern evolutionary theory. Out of the 9 students interviewed, 7 correctly described the scientifically acceptable speciation relationship of amphibians and lizards. About half of the students interviewed held a sophisticated view of common descent. As far as the larger sample of students, 23 out of 39 students correctly responded to a multiple-choice question about modern human and modern primate ancestry. In fact, the majority of students answered two of the four questions on common descent correctly. The posttest mean for the four questions on common descent was 2.08, and for the other four questions the mean was 1.1. So it would appear that the students in this study may have understood common descent better than they did the other aspects of evolution that were tested. However, the mean of 2.08 out of 4 is still less than desirable.

**Discussion of the Data Analysis at the Student Level**

The final section of data analysis in Chapter 4 was the presentation of the results of 4 individual students. These portraits were a synthesis of both the quantitative and qualitative methodological components of this study. By examining the data at the student level, each student's unique epistemological stance became apparent in multiple data
sources. It can be surmised that epistemology and different kinds of understanding exist together. While this study was not one of cause-and-effect, their coexistence probably do impact each other in ways described by Demastes, Good, et al. (1995), who stated that epistemological commitments shape the concepts and, in turn, the type of knowledge considered by the student changes the epistemological position.

Kelly's belief in creationism, Terry's dualism and dependence on authority, Allison's belief in learning being time-consuming and difficult, and Cindy's acceptance of evolution all surfaced in multiple data sources, such as the knowledge test, the worksheets, and the interview transcripts. Using these multiple data provided a more complete picture of the interplay between epistemology and learning. Unfortunately, the instructional laboratory session did not accomplish the learning objectives established for the students by the researcher. Neither did the traditional lecture format given by the instructors. None of these 4 students responded consistently to the relatively simple question phrased in various guises, "Where did humans come from?" When the students' knowledge of evolution and common descent was probed, the clarity of understanding became cloudy, without the students even acknowledging the muddiness of their understanding. And just when the researcher thought the students understood, their knowledge became murky with talk of gorillas evolving to humans, of an organism's needs causing structural changes, of muscle use causing skeletal characteristics, of a purpose in evolution, and of whales evolving to fish.

So what are the challenges to instruction posed by these students? First of all, the challenges discussed here are not found uniformly in all the students in this study, so
these challenges certainly cannot be expected to be found in all college students. Be that as it may, it still is beneficial to examine the challenges presented by the students who were studied in detail as part of this study.

There were students who did not see evolutionary connections among organisms, as exemplified by gradual changes of many characteristics over long periods of time. Instead these students lumped organisms into distinct groups, such as humans and animals. This was evident on laboratory worksheets and the diagrams from the interview activities. This finding is similar to that of Armstrong (1997) who found that college students did not see themselves as part of nature. The instructional goals would be to have students interpret evidence of relatedness according to evolutionary theory and to have students place their own species as part of the evolutionary processes in nature.

There were students who did demonstrate evolutionary relationships by making connections and seeing gradual changes, but these students often used naïve organizers, instead of using scientifically acceptable classification schemes. These naïve organizers included size, environment, and function, and their presence was evidenced in the interview activity diagrams and the interviews about the primate skulls. The instructional goal would be to have students understand the scientific classification systems and see why naïve organizers are not acceptable. These scientific classification systems need not be elaborate, but could be based on a familiar grouping of organisms, such as mammals.

Secondary to the previous challenge is the fact that by using naïve organizers, many students made incorrect evolutionary connections between organisms, such as depicting the whale and fish as close relatives and depicting human evolution as merely
an increase in skull size. This simplistic view of evolution appeared to be one of the aspects that led students to continue to think that humans evolved from chimpanzees because of the relative size of the skulls. The instructional goal would be to have students make evolutionary connections that are scientifically acceptable, or at least defensible. Students should be able to assimilate the differences between an ancestor-descendent relationship and a relationship of shared descent.

Another challenge presented by these students is a positive one in that several of them reported the laboratory session with the primate skulls to be valuable and interesting. At least 2 students had epistemologies that could enable the students to benefit from laboratory sessions. One of the students reported that she had learned a lot from the skull activity and her posttest score demonstrated an increased understanding. She also thought that she had tested the theory of common descent in the laboratory session. Another student, whose epistemology incorporated questioning in her own learning process, had many questions about the skulls that had not been answered. These questions could have been addressed had there been more time. The instructional goal would be to provide opportunities that students find valuable and interesting and that provide enough time and resources for students to answer their own questions. These sessions could address the particular epistemology frameworks of these students.

Another challenge comes from the student with the creationist belief. She took the stance of standing outside evolution, trying to understand it while not believing every aspect. Demastes, Good, et al. (1995) reported that, while a creationist student in their study also tried to understand evolution, this is unusual for someone who believes in
creationism. Like the student in their study, Kelly did not fully understand evolution and poses a particular challenge for the instructor who is sensitive to respecting the beliefs of others. In this study, Kelly saw similarities between organisms as evidence of the Creator's design, rather than as evidence of evolutionary relatedness. The instructional goal for Kelly is to help her understand evolution and the interpretations of evidence made within evolutionary theory, without forcing her to debate or causing her to feel that her beliefs are threatened.

Certain challenges that emerged from this study confirm those that have been found by other researchers investigating student conceptions of natural selection (Bishop & Anderson, 1990; Brumby, 1984; Dagher & BouJaoude, 1997; Jensen & Finley, 1995). Students saw evolutionary processes as being caused by the needs of the organism, changes in characteristics as being caused by the continual use of certain structures, and adaptation as being caused by organisms learning how to adapt.

Instructional implications and possible teaching strategies that may address the challenges posed by these students will be discussed at the end of the next section.

Summary and Recommendations

This section will review the major contributions made by this research. One of the contributions is the development of a 17-item instrument that reliably measured college students' beliefs in creationism and acceptance of evolution. This instrument successfully measured subtle differences between a belief in creationism and an acceptance of evolution, as evidenced in the variation of student responses. The scores obtained on this instrument were significantly related to scores obtained on a knowledge test. The nature
of this relationship was such that student scores consistent with a belief in creationism correlated with lower scores on the knowledge tests, while student scores consistent with an acceptance of evolution correlated with higher scores on the knowledge tests. The knowledge test consisted of 8 items, 4 of which were on the topic of common descent.

The results of this study suggest that the teaching methods were ineffective in increasing the mean test scores of the group of students in this sample. The teaching methods used in this study included a traditional lecture format and a laboratory session that examined primate skulls. The group of students that scored lower on the posttest than on the pretest was found to be significantly different on only one characteristic from the group of students that scored higher on the posttest. This characteristic was the belief in the certainty of knowledge. Additionally, analyses of both the quantitative data and the qualitative data revealed that several students held onto misconceptions about human origins, even after participating in instruction designed to address these misconceptions. However, there were students who demonstrated increased learning.

Several of the students in this study used the term "related" to indicate a relationship other than that of evolutionary descent or shared ancestry. This finding would suggest that the common everyday usage of this term prevailed over the scientific usage. Additionally, students grouped eight primate skulls into just two categories, human and animal.

Another contribution is the discovery that students in this study used naïve organizers to group biological organisms to show evolutionary connections. This research has produced a structured description of these organizers and a relatively easy-to-use
mechanism that identified them. Furthermore, some students were seemingly misled by these organizers to make connections between organisms that are at odds with the scientifically established relationships and classifications of familiar animals.

Recommendations for Instruction

In retrospect, the laboratory instruction that formed a part of this study reflected two significant features that seem to directly relate to the ineffectiveness of the instructional events in assisting students to understand scientific theories of common descent: (a) modification of the laboratory-inquiry model in order to elicit students' conceptions of common descent with very little instructor input to "contaminate" the data, and (b) time constraints. In order to maintain or increase instructional impact, in future laboratory sessions, it may be beneficial to incorporate the branching/grouping diagram activity by having students hypothesize possible evolutionary connections between various skulls and then conclude the session with a class discussion of the relatedness of the skulls. This conclusion could include a review of the current evolutionary lineage of primates and why these diagrams are tentative. These diagrams could be used to distinguish the differences between ancestor-descendent relationships and shared descent relationships. At this point the misconception of the ancestral relationship between chimpanzees and humans could be strongly confronted. The experience of this researcher is that this laboratory session is interesting to students and has the potential to be effective. As for time constraints, they are an unfortunate reality in the current climate of introductory college biology. There is a great deal of content to cover and instructional time is limited, especially the amount of time dedicated to laboratory sessions. One way
that this time could be increased without adversely affecting the coverage of other topics would be to treat evolution as a unifying theory. The instructor could integrate evolution into other instructional units and specify how evolution explains biological processes. Common descent could be addressed when teaching evolution as a unit and when teaching classification schemes.

The epistemologies and understanding of certain students were studied in detail. Challenges to their learning of evolution were identified and described. These challenges can be addressed, and instructional goals could be initiated by certain teaching strategies. For example, one of the students studied in detail (Cindy) accepted evolution. She not only thought that evolutionary theory could be tested, but she also thought that she had tested it in the laboratory session on skulls. Additionally, she reported that she learned from the hands-on activity. She may have profited from an expansion of the laboratory session by the addition of a branching/grouping activity that uses names of various organisms as a prelude to examining the skulls. After organizing these various representative organisms and completing diagrams, the students could be shown the advantages and disadvantages of various organizers. Or students could present their diagrams to other students in a group setting and obtain feedback from their peers.

Another student's (Allison) epistemology included a belief that learning is not quick and simple. Should this student have been given instructional opportunities and resources to find the answers to her own questions, which were quite sophisticated, her knowledge about common descent could have improved, and perhaps she would have
demonstrated a more consistent understanding on the posttest. These opportunities could include writing assignments, such as journal entries or web-based research papers.

Certain epistemologies found in the students may have been particularly resistant to instruction. One student's (Terry) dualism and dependence on authority allowed her to think she knew the answers when she did not. She may have benefited from receiving individual feedback from the instructor during the instructional phase, with formative assessment instead of just summative assessment. A teacher could use the branching/grouping diagram to elicit student conceptions and to provide corrective instruction. Had this student learned from an authority figure that she had misinterpreted the information, her learning may have improved.

The remaining student studied in detail was the student (Kelly) who believed in creationism. This epistemology presents a unique challenge to the instructor. Several strategies have been suggested by others for teaching students who do not believe in evolution. Jackson et al. (1995) proposed that students with religious beliefs in conflict with evolution should be treated from the perspective of multicultural acceptance, instead of being disrespected, belittled, or denied acknowledgement of the extent of pervasiveness of these beliefs in personal values and morals. This perspective could be incorporated by following the strategy proposed by Kurvink (1995) who encouraged students to articulate their opinions about evolution by directing discussion around specially designed questions that brought creationist ideas to the forefront. Another strategy that may be helpful would be to inform students that various organized religions reconcile both a belief in a Creator and an acceptance of evolution and that creationism is
not a uniform system of beliefs. The results from the epistemology survey used in this study confirm that there is variance in creationism beliefs. The questions in this instrument could be used to expose students to the beliefs of others. It is the responsibility of the classroom teacher to provide a climate in which all students, regardless of their beliefs, are encouraged to learn.

While the data from certain students suggest that these strategies would address many of the challenges to learning evolution posed by the students' epistemologies, instructional effectiveness should be evaluated with different students of various epistemological frameworks. Other suggested research needs are identified in the next section.

Suggestions for Future Research

This study has investigated the relationship between college student beliefs and the understanding of the theories of evolution and common descent. Students' alternate conceptions about common descent were also explored. Possible areas of further research could include the following:

1. A confirmatory study with other subjects in different contexts could be performed. The epistemology instrument that measured belief in creationism developed as part of this study could be used in different settings to see if a relationship between belief and understanding exists in additional subjects.

2. The role of epistemology could be further explored by conducting a longitudinal study of biology students in different types of higher education institutions. The students could complete an epistemology survey and a knowledge test each year of
their college career. Changes in knowledge and beliefs could be documented to see if additional biology coursework correlates to an increased acceptance of evolution and a diminishing belief in creationism.

3. The effectiveness of various teaching strategies could be studied. These strategies include encouraging student articulation of opinions about evolution and creationism or having students explore the positions of various organized religious organizations. Not only student understanding could be measured, but also beliefs in creationism, to ascertain if there are any postinstructional changes in scores on the epistemology instrument.

4. The knowledge test could be further refined to measure student understanding of common descent and human evolution.

5. An experimental study could be performed to further study the effectiveness of a refined inquiry-based laboratory activity that uses primate skulls to teach human evolution. This study could examine student understanding of common descent and the misconceptions many students have about human origins.

6. An extensive look at alternate conceptions could be conducted to verify if these concepts are present in the minds of other subjects. Interviews and the branching/grouping activities could be used to ascertain if these alternate organizers exist in the minds of other subjects. A study could be designed to verify if other students use naïve organizers in determining the relationships among organisms.
7. Use of branching diagrams that represent relatedness of organisms as a teaching strategy could be observed and studied to further explore student understanding of common descent.

Conclusion

This study explored the relationship between epistemology and the understanding of the theories of evolution and common descent, while also attempting to discover any alternate conceptions students might have about the theory of common descent in a naturalistic setting. There appeared to be a relationship between student belief in creationism and a lower score on the knowledge tests measuring understanding of evolutionary theory, even after instruction. Learning, as measured by group mean scores, did not seem to improve significantly after instruction. Many students in this study held alternate conceptions about the facts and processes of common descent. Various students' epistemologies and students' levels of understanding were identified as posing challenges to instruction. These findings appear to provide further insight into possible reasons for the difficulties these students had in understanding evolution. A greater understanding of contributing factors to student learning of evolutionary theory is needed and effective teaching strategies employed if we are to achieve science literacy for all students.
GLOSSARY

Acceptance of evolutionary theory - the belief that evolutionary theory is a valid and sufficient explanation of biological change over time.

Alternate conceptions – include the following: (a) misunderstandings of evolutionary theory; (b) naïve conceptions, especially when applied to mechanisms and processes of evolution; and (c) alternate conceptions of natural selection and the origin of species, such as those ideas that are part of creationist ideology.

Applying evolutionary theory - the willingness and ability to use evolutionary theory to explain and predict scientific observations, data, and evidence.

Belief in evolution/creationism score – score obtained on subscale of the 5-point Likert type epistemology instrument that assesses the level to which a student believes creation, a supernatural creator, and a creator as the designer of different species versus an acceptance of evolution. An acceptance of evolution includes an acceptance of the modern scientific explanation of biological change over time, including the theory of different species having common descent from a shared ancestor and the theory of natural selection working on genetic variation as the mechanism by which populations change over time.
Common descent - the evolutionary theory that explains that modern species have descended from other species that may or may not be extinct. Related species share phenotypic and genotypic similarities, resulting from either sharing a more recent ancestor (in terms of geological time), or being a direct descendant (or ancestor) of each other.

Control of learning score - score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers learning to be an innate ability versus an acquired ability.

Creationism - a perspective based on a biblical account, rather than a scientific one, which explains the origin of species as coming from the creator who designed and created each species as a separate, definite entity, each with its own essence.

Epistemology - The approach one has toward knowledge and learning; the filter by which new information is perceived and the belief system one has towards one's own learning and educational experience.

Guided-inquiry student-designed experiment – a laboratory experiment in which students are given a theory to test and a list of materials available with which to test the given theory. The students design their own laboratory procedures, either individually, or in groups. The students then perform their procedures, testing the theory in a deductivist manner. This type of laboratory session differs from many other inquiry laboratories in that it is not an inductive experience, but a deductive experiment. It also differs from many other laboratory sessions, in that the procedures are not stated in a step-by-step manner. The guided-inquiry
component refers to the fact that the instructor acts as a coach and facilitator, guiding activity in a general direction, rather than dictating activity in a specific direction.

Natural selection - the process by which factors in the environment and inherent in an individual effect the varying success rates that individuals with phenotypic variations have in reproduction, eventually resulting in populational changes in species.

Spe&iation - the process by which one or more new species develop from another existing species, resulting in separate populations that can no longer interbreed.

Speed of learning score - score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers learning to be: (a) easy versus difficult, and (b) quick or not at all versus the belief that learning comes after the second or more efforts.

Stability of knowledge score - score obtained on a subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers knowledge to: (a) depend on authority, such as instructors, texts, and experts; (b) consist of single answers; and (c) be certain.

Structure of knowledge score - score obtained on subscale of the 5-point Likert-type epistemology instrument that assesses the level to which a student considers knowledge in one field of study to be connected to another field of study and to the practical aspects of life.
Theory of biological evolution - the explanation of observed changes in populations of living organisms over time. Evolution encompasses several facets, including related species having descended from a shared ancestor and natural selection of genetic variation as the mechanism by which populations change over time.

Understanding of evolutionary theory - the demonstration of a conceptualization of the scientifically acceptable definition, explanation, and/or application of evolutionary theory.
You will receive credit for completing this survey, but your responses will not be graded by your instructor. Personal information will be held confidential. Thank You.

Name: ______________________  Gender: __ Male  __ Female  Year in College:______________

Number of Biology Courses in High School: ____________ Number of Biology Courses in College: ____________

College Grade Point Average (GPA):

- 3.5 - 4.0
- 3.0 - 3.4
- 2.5 - 2.9
- 2.0 - 2.4
- 1.5 - 1.9
- less than 1.5

Directions: There are no right or wrong answers for the following questions. We want to know what you really believe. For each statement, circle the letter(s) indicating the degree to which you agree or disagree. Strongly Agree = SA; Agree = A; Neutral = N; Disagree = D; Strongly Disagree = SD

1. If you are ever going to be able to understand something, it will make sense to you the first time you hear it.  
   SA  A  N  D  SD

2. The only thing that is certain is uncertainty itself.  
   SA  A  N  D  SD

3. For success in school, it's best not to ask too many questions.  
   SA  A  N  D  SD

4. A course in study skills would probably be valuable.  
   SA  A  N  D  SD

5. How much a person gets out of school mostly depends on the quality of the teacher.  
   SA  A  N  D  SD

6. You can believe almost everything you read.  
   SA  A  N  D  SD

7. I often wonder how much my teachers really know.  
   SA  A  N  D  SD

8. The ability to learn is innate.  
   SA  A  N  D  SD

9. It is annoying to listen to lecturers who cannot seem to make up their minds as to what they really believe.  
   SA  A  N  D  SD

10. Successful students understand things quickly.  
    SA  A  N  D  SD

11. Good teachers keep their students from wandering from the right track.  
    SA  A  N  D  SD

12. If scientists try hard enough, they can find the truth to almost anything.  
    SA  A  N  D  SD

13. People who challenge authority are over-confident.  
    SA  A  N  D  SD

14. I try my best to combine information across chapters or even across classes.  
    SA  A  N  D  SD

15. The most successful people have discovered how to improve their ability to learn.  
    SA  A  N  D  SD
16. Things are simpler than most professors would have you believe.

17. The most important aspect of scientific work is precise measurement and careful work.

18. To me studying means getting the big ideas from the text, rather than the details.

19. Educators should know by now which is the best method, lectures or small group discussions.

20. Going over and over a difficult textbook chapter usually won't help you understand it.

21. Scientists can ultimately get to the truth.

22. You never know what a book means unless you know the intent of the author.

23. The most important part of scientific work is original thinking.

24. If I find the time to re-read a textbook chapter, I get a lot more out of it the second time.

25. Students have a lot of control over how much they can get out of a textbook.

26. Genius is 10% ability and 90% hard work.

27. I find it refreshing to think about issues that authorities can't agree on.

28. Everyone needs to learn how to learn.

29. When you first encounter a difficult concept in a textbook, it's best to work it out on your own.

30. A sentence has little meaning unless you know the situation in which it is spoken.

31. Being a good student generally involves memorizing facts.

32. Wisdom is not in knowing the answers, but in knowing how to find the answers.

33. Most words have one clear meaning.

34. Truth is unchanging.
35. If a person forgot details, and yet was able to come up with new ideas from a text, I would think they were bright.

36. Whenever I encounter a difficult problem in life, I consult with my parents or someone else I respect.

37. Learning definitions word-for-word is often necessary to do well on tests.

38. When I study, I look for the specific facts.

39. If a person can't understand something within a short amount of time, they should keep on trying.

40. Sometimes you just have to accept answers from your teachers even though you don’t understand them.

41. If professors would stick more to the facts and do less theorizing, one could get more out of college.

42. I don't like movies that don't have an ending.

43. Getting ahead takes a lot of work.

44. It's a waste of time to work on problems which have no possibility of coming out with a clear-cut answer.

45. You should evaluate the accuracy of information in a textbook, if you are familiar with the topic.

46. Often, even advice from experts should be questioned.

47. Some people are born good learners, other are just stuck with limited ability.

48. Nothing is certain, but death and taxes.

49. The really smart students don't have to work hard to do well in school.

50. Working hard on a difficult problem for an extended period of time pays off only for really smart students.

51. If people try too hard to understand a problem, they will most likely end up being confused.

52. You will get almost all the information you can learn from a textbook during the first reading.

53. Usually you can figure out difficult concepts if you eliminate all outside distractions and really concentrate.
54. A really good way to understand a textbook is to re-organize the information according to your own personal scheme. SA A N D SD

55. Students who are “average” in school will remain “average” for the rest of their lives. SA A N D SD

56. An expert is someone who has a special gift in some area. SA A N D SD

57. I really appreciate instructors who organize their lectures meticulously and then stick to their plan. SA A N D SD

58. The best thing about science courses is that most problems have only one right answer. SA A N D SD

59. Learning is a slow process of building up knowledge. SA A N D SD

60. Today’s facts may be tomorrow’s fiction. SA A N D SD

61. Self-help books are not much help. SA A N D SD

62. You will just get confused if you try to integrate new ideas in a textbook with knowledge you already have about a topic. SA A N D SD

63. There is sufficient scientific evidence to support evolution. SA A N D SD

64. There is sufficient scientific evidence to support creation. SA A N D SD

65. Evolution should not be taught in the public high schools. SA A N D SD

66. Any scientific findings that contradict Biblical Scripture should be discarded. SA A N D SD

67. Creation makes more sense than evolution. SA A N D SD

68. For me, evolution explains how life has changed over time. SA A N D SD

69. The different species of plants and animals that are alive today are the same as they were when life first began. SA A N D SD

70. Humans hold a unique position as master over all species. SA A N D SD

71. Today’s living species share common ancestry with other species. SA A N D SD

72. Humans share a common ancestor with other species. SA A N D SD
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<td>73. Changes in species over time are controlled by a wise and benevolent Creator and are not due to chance.</td>
<td>SA</td>
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<td>74. A great variety of highly complex forms appeared as a sudden event of creation.</td>
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<td>75. The Flood explains much of the fossil record.</td>
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<td>76. Creation science should not be taught in the public high schools.</td>
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<td>77. Evolution accounts for the development of present forms of life.</td>
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<td>78. One can believe in both creation and evolution.</td>
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<td>79. Evolution and God are not compatible.</td>
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<td>80. What percentage of your personal opinion about evolution is due to:</td>
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Please circle the letter that corresponds to the best answer for each multiple-choice question. The last question is a true-false question that also asks you to write an explanation for your answer.

1. The best example of the term “common descent” is:
   a) different species having common adaptations, such as the evolution of wings in both birds and bats.
   b) different species having the same number of genetic mutations.
   c) different species filling the same environmental niche.
   d) different species sharing the same recent ancestor.

2. Biologists study similarities in physical traits. These similarities are then used to hypothesize evolutionary pathways of current species. From these findings, biologists think that:
   a) humans evolved from the gorilla.
   b) humans evolved from the chimpanzee.
   c) humans, chimpanzees, and gorillas evolved from another primate.
   d) humans have not evolved from an animal.

3. Which of the following best explains changes in species over time?
   a) Organs and structures which are not needed are lost.
   b) Certain organisms have hereditary variations allowing them to compete more successfully.
   c) An individual organism can adapt in order to survive.
   d) Some organisms run out of food and die, while others survive because they migrate to new territories.

4. Does the modern theory of evolution have a valid scientific foundation?
   a) Yes, because it is possible to test the many predictions made by evolutionary science.
   b) Yes, even though we can never test predictions about events in the past.
   c) Yes (for other reasons).
   d) No, because we can never be sure about the past.
   e) No, because evolutionary science is principally based on speculation, and not on “hard” scientific facts.
   f) No, (for other reasons).

5. Similarities in DNA evidence point to possible evolutionary connections. Of the following, select the pair that biologists would say is most similar to HUMAN: CHIMPANZEE
   a) GREAT-GREAT-GRANDCHILD: GREAT-GREAT-GRANDPARENT
   b) DISTANT COUSIN: DISTANT COUSIN
   c) NEIGHBOR: NEIGHBOR
   d) ROLLS ROYCE: HONDA

6. The best explanation for how a new species can evolve from an existing species is that:
   a) individual variations enable some organisms to survive and reproduce more successfully than others.
   b) physical barriers separate some individuals from other members of the species.
   c) some adult organisms respond to a challenge and adapt.
   d) environmental change causes genetic mutations.
7. A number of mosquito populations are today resistant to the pesticide, DDT, even though DDT was effective when it was first introduced. Biologists think that DDT resistance evolved in mosquitoes because:
   a) individual mosquitoes built up an immunity to DDT after being exposed to it.
   b) Mosquitoes needed to be resistant to DDT in order to survive.
   c) A few mosquitoes were resistant to DDT before it was ever used.
   d) Mosquitoes learned to adapt to their environment.

8. Which of the following best explains the modern theory of evolution?
   a) the phrase, “Survival of the Fittest”
   b) Evolution occurred because different individuals left different numbers of offspring.
   c) Humans evolved from either the gorilla or chimpanzee in Africa.
   d) Evolution involved a purposeful striving towards “higher” forms (that is, a steady progress from microbes to man).
   e) Evolution occurred because the strong eliminated the weak.

9. Humans are more evolved than apple trees
   True ________  False ________
   Please explain your answer:

   Answers: 1.d; 2.c; 3.b; 4.a,b, or c, question not used in data analysis; 5.b; 6a; 7c; 8.b; 9. False.
Table 10: Student responses to knowledge tests

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Knowledge Test: Raw Data

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APPENDIX C
Interview Script

I. I want to concentrate on your answers, so instead of taking notes, is it alright if I tape-record this interview?

II. This interview is in three parts. First, I'd like you to do two activities, then I'll ask you some questions. For the activities, I'm really interested in HOW you do the activity, so I'd like for you to talk out loud as you think through the activity. Remember, I'm interested in WHAT and HOW YOU'RE thinking, so YOU have the RIGHT answers, not me.

III. {Activities}

IV. Now, I am going to ask you some questions about the lab session and the skulls you tested. There are no right or wrong answers. The reason I'm asking you these questions is so that I can learn from you. I want to learn more about how students learn in lab sessions and how students learn about evolution. If there are any questions you don't want to answer, just let me know and we'll go on to the next question.

1. Have you ever done any other labs where you developed your own procedure?

2. How did you decide which particular observations and measurements of the skulls you would record?

3. While you were designing a procedure to follow, how did you make sure it would test the hypothesis?

4. Were you satisfied that your procedure tested the theory of common descent? Why or why not?

5. If you were to do the lab again, what would you do differently?

6. What could explain these skulls besides evolutionary theory and common descent?

7. What other theories could you test using the same evidence (skulls)? How would you test this theory? What procedures?

8. Had you ever examined fossils or casts of fossils before?

9. Do you think these skulls came from humans? Why or why not?

10. Some people have used the term, "missing link." What do you think is meant by that term? Do you think any of these skulls could be a "missing link"?

11. Where do you now think humans came from?

12. What surprised you about the skulls? What disturbs you about these skulls? What excites you?

Thank you!

217
The diagram below demonstrates the relationships of 3 different species at a specific point in time:

![Diagram of three species: A, B, C]

Note that “A” and “B” are closer to each other than they are to “C.” This means that “A” and “B” share more similarities with each other than they share with “C.” “B” is closer to “C” than “A” is, so “B” shares more similarities to “C” than “A” does. All three species are on the same line which represents that these three species are living at the same time.

The next diagram depicts the relationships among 3 species, “D,” “E,” and “F.” “F” is the common ancestor of both “D” and “E.” “F” is more like “D” than “E” is and “F” is more like “E” and “D” is. “F” first appeared a long time ago and is still living.

![Diagram of four species: D, F, E, F]

Figure 13: Sample time lines
Figure 14: Kelly's time line
Figure 15: Terry's time line
Figure 16: Cindy's time line
Figure 17: Sample time line of pictures
Figure 18: Four diagrams of representative time lines
### Experiment 1 - Genotypes

<table>
<thead>
<tr>
<th>Scientific Method</th>
<th>Application of Scientific Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory</td>
<td>Humans share a common ancestor with other animals. We are more closely related to those species with whom we share a larger percentage of DNA.</td>
</tr>
<tr>
<td>Specific Hypothesis</td>
<td>Comparing modern human DNA sequences that code for hemoglobin to those same sequences of other species will indicate to which species humans are more closely related and to which species humans are more distantly related.</td>
</tr>
</tbody>
</table>

### Observations needed

<table>
<thead>
<tr>
<th>Sequence of a portion of DNA that codes for hemoglobin for human, chimps, &amp; gorillas.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Human DNA</strong></td>
</tr>
<tr>
<td>Position 1</td>
</tr>
</tbody>
</table>

### Procedure

1. Count and compare number of nucleic acids that are sequenced similarly between gorillas and chimpanzees.
2. Count and compare number of nucleic acids that are sequenced similarly between humans and chimpanzees.
3. Count and compare number of nucleic acids that are sequenced similarly between humans and gorillas.

### Results

<table>
<thead>
<tr>
<th>Human</th>
<th>Chimpanzee</th>
<th>Gorilla</th>
</tr>
</thead>
<tbody>
<tr>
<td>Showed 10</td>
<td>Showed 15</td>
<td>Showed 15</td>
</tr>
</tbody>
</table>

### Conclusions

In comparing and genetic that the same amount of nucleic acids at the human and chimpanzees.

---

Figure continued on next page

Figure 19: Student 23’s laboratory worksheets
### Experiment 2 - Phenotypes

<table>
<thead>
<tr>
<th>Scientific Method</th>
<th>Application of Scientific Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory</td>
<td>Humans share a common ancestor with other animals.</td>
</tr>
<tr>
<td>Specific Hypothesis</td>
<td>Comparing modern human skulls with skulls from modern species and from &quot;fossilized&quot; species will indicate to which humans are more closely related and to which humans are more distantly related.</td>
</tr>
<tr>
<td>Observations needed</td>
<td>Observations of modern skulls and prehistoric skulls.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run - how u walks</td>
</tr>
</tbody>
</table>

Figure continued next page
<table>
<thead>
<tr>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. small teeth, medium jaw, thin skin</td>
</tr>
<tr>
<td>2. very few, very small teeth, very small Jaw</td>
</tr>
<tr>
<td>3. large teeth, small jaw, thin skin</td>
</tr>
<tr>
<td>4. large jaw, very small teeth, very small jaw</td>
</tr>
<tr>
<td>5. very large, very large teeth, skull is very small, very small jaw</td>
</tr>
<tr>
<td>6. large, very large teeth, very large jaw, skull is very small jaw</td>
</tr>
<tr>
<td>7. very large, very large teeth, medium belly, very small jaw</td>
</tr>
<tr>
<td>8. small; small, very small teeth, small jaw, very small</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Likely to be a human</td>
</tr>
<tr>
<td>2. Distant human, quadrates (human-like characteristics)</td>
</tr>
<tr>
<td>3. Similar to the unresolved (early human)</td>
</tr>
<tr>
<td>4. Animals of quadrates walk on all fours, large</td>
</tr>
<tr>
<td>5. Very distant human characteristics can imagine</td>
</tr>
<tr>
<td>6. Very long, resembles goblins</td>
</tr>
<tr>
<td>7. Very close to current human</td>
</tr>
<tr>
<td>8. Very small, very small</td>
</tr>
</tbody>
</table>

Characteristics of Apes and Humans

227
## Experiment 1 - Genotypes

<table>
<thead>
<tr>
<th>Scientific Method</th>
<th>Application of Scientific Method</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Specific Hypothesis</td>
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</tr>
<tr>
<td>Observations needed</td>
<td>Sequence of a portion of DNA that codes for hemoglobin for human, chimps, &amp; gorillas.</td>
</tr>
<tr>
<td><strong>Human DNA</strong></td>
<td>![Human DNA sequence]</td>
</tr>
<tr>
<td><strong>Chimpanzee DNA</strong></td>
<td>![Chimpanzee DNA sequence]</td>
</tr>
<tr>
<td><strong>Gorilla DNA</strong></td>
<td>![Gorilla DNA sequence]</td>
</tr>
</tbody>
</table>

### Procedure

1. Count and compare number of nucleic acids that are sequenced similarly between gorillas and chimpanzees.
2. Count and compare number of nucleic acids that are sequenced similarly between humans and chimpanzees.
3. Count and compare number of nucleic acids that are sequenced similarly between humans and gorillas.

### Results

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Chimpanzee - Gorilla</td>
<td>15 similar N/A.</td>
</tr>
<tr>
<td>2. Human - Chimpanzee</td>
<td>15 similar N/A.</td>
</tr>
<tr>
<td>3. Human - Gorilla</td>
<td>10 similar N/A.</td>
</tr>
</tbody>
</table>

### Conclusions

"Humans show a link to being related to chimps, with a high number of nucleic acids the same, but also the chimps & gorillas are closely related. Although we are not closely related to gorillas, they may be closer than we think."
Figure 20 (continued)

<table>
<thead>
<tr>
<th>Scientific Method</th>
<th>Application of Scientific Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theory</td>
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</tr>
<tr>
<td>Specific Hypothesis</td>
<td>Comparing modern human skulls with skulls from modern species and from &quot;fossilized&quot; species will indicate to which humans are more closely related and to which humans are more distantly related.</td>
</tr>
<tr>
<td>Observations needed</td>
<td>Observations of modern skulls and prehistoric skulls.</td>
</tr>
</tbody>
</table>
| Procedure         | 2. skull capacity  
teeth #  
cheekbone size  
skull shape |

Figure continued next page
### Results

| 1. | Large cheek bones, ridge on top of skull, 32 teeth, large jaw |
| 2. | Smaller cheek bones, no ridge on top of skull, 32 teeth, smaller jaw, longer brain capacity |
| 3. | Small cheek bones, rounded skull (no ridge), 28 teeth |
| 4. | Small brain, 32 teeth, protruding jaws outward, small cheek bones |
| 5. | 16 top teeth (8 molars), small flat nasal skull, wide cheekbones, protruding jaws outward |
| 6. | 32 teeth, 4 large incisors, flattened skull, protruding jaws, ridge on top of skull |
| 7. | 32 teeth, large brain capacity, small cheekbones, small jaw |
| 8. | 32 teeth, 4 large incisors, large protruding jaw, large ridge on skull, big cheekbones |

### Conclusions

All had about the same amount of teeth 28-32, the animal skulls were the ones with ridges on their head. 1, 3, 7 were human skulls & 2, 4, 5, 6, 8 were animal origins.
**Scientific Method Application**

**Theory**
Humans share a common ancestor with other animals. We are more closely related to those species with whom we share a larger percentage of DNA.

**Specific Hypothesis**
Comparing modern human DNA sequences that code for hemoglobin to those same sequences of other species will indicate to which species humans are more closely related and to which species humans are more distantly related.

**Observations needed**
Sequence of a portion of DNA that codes for hemoglobin for human, chimps, & gorillas.

- **Human DNA**
  - Position 20: C-G-A

- **Chimpanzee DNA**
  - Position 20: C-G-A

- **Gorilla DNA**
  - Position 20: C-G-A

**Procedure**
1. Count and compare number of nucleic acids that are sequenced similarly between gorillas and chimpanzees.
2. Count and compare number of nucleic acids that are sequenced similarly between humans and chimpanzees.
3. Count and compare number of nucleic acids that are sequenced similarly between humans and gorillas.

**Results**
- 1) 15
- 2) 15
- 3) 10

**Conclusions**
Humans are more closely related to chimps as chimps are to gorillas, but gorillas aren't as close to humans. Which means humans are more closely related to chimps.
Figure 21 (continued)

<table>
<thead>
<tr>
<th>Scientific Method</th>
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</thead>
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<tr>
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</tr>
<tr>
<td>Observations needed</td>
<td>Observations of modern skulls and prehistoric skulls.</td>
</tr>
<tr>
<td>Procedure</td>
<td>Observations of modern skulls and prehistoric skulls.</td>
</tr>
<tr>
<td>3) Screws on skull 32 in. Waters on right. Distinct jaw. Thick cranial bones.</td>
<td></td>
</tr>
<tr>
<td>4) Screws on skull 32 in. Waters on left. Distinct jaw. Thick cranial bones.</td>
<td></td>
</tr>
<tr>
<td>5) Screws on skull 32 in. Waters on right. Distinct jaw. Thick cranial bones.</td>
<td></td>
</tr>
</tbody>
</table>

Figure continued next page
### Figure 21 (continued)

| Results | 7, 1, 3 are humans 
<table>
<thead>
<tr>
<th></th>
<th>2, 4, 5, 6, 8 - animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 -</td>
</tr>
<tr>
<td></td>
<td>2 - pre-historic human</td>
</tr>
<tr>
<td></td>
<td>3 -</td>
</tr>
<tr>
<td></td>
<td>4 -</td>
</tr>
<tr>
<td></td>
<td>5 - pre-historic</td>
</tr>
<tr>
<td></td>
<td>6 -</td>
</tr>
<tr>
<td></td>
<td>7 - human</td>
</tr>
<tr>
<td></td>
<td>8 -</td>
</tr>
</tbody>
</table>

### Conclusions

There are many similarities between the skulls of humans and animals, but there are distinct differences that separate them.
Figure 22: Possible evolutionary relationships of hominids (Day, 1984)
CONSENT FORM FOR PARTICIPATION IN EDUCATIONAL RESEARCH

I consent to participating in a study looking at community college students learning about evolution.

David L. Haury or Joyce C. Miller has explained that this study does not involve any activities beyond my normal classroom/laboratory activities. I have had opportunity to obtain additional information about this study and my questions have been answered.

In understand that information from this study will be held confidential as to my identity. I also understand that my consent is voluntary and can be withdrawn at any time.

Date: ____________________
Signed: ____________________

Signed: ____________________ (Participant)
Signed: ____________________ (Witness)
LIST OF REFERENCES


Brattstrom, B. H. (1999). Are students learning from their teachers or the media? The American Biology Teacher, 61(6), 420-422.


Creation Science (10/30/98). *Early man summary.*
http://emporium.tumpike.net/C/cs/emsum.htm


