The Effects of the Laboratory on College Students' Understanding of Evolution: Implications for Conceptual Change.

Lorna Benita Holtman

Louisiana State University and Agricultural & Mechanical College

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UMI
THE EFFECTS OF THE LABORATORY ON COLLEGE STUDENTS’ UNDERSTANDING OF EVOLUTION: IMPLICATIONS FOR CONCEPTUAL CHANGE

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

Lorna Benita Holtman
December 2000

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This dissertation is dedicated to the memory of my beloved grandmother, Cecelia Phyllis Meyer, who nurtured my love for reading and my interest in nature.

(1909-to be continued...)

ii
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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>ix</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>x</td>
</tr>
<tr>
<td>CHAPTER 1: INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Research Questions</td>
<td>4</td>
</tr>
<tr>
<td>Primary research questions</td>
<td>4</td>
</tr>
<tr>
<td>Secondary research question</td>
<td>5</td>
</tr>
<tr>
<td>Definitions Used in This Study</td>
<td>5</td>
</tr>
<tr>
<td>CHAPTER 2: REVIEW OF THE LITERATURE</td>
<td>8</td>
</tr>
<tr>
<td>The Role of the Laboratory</td>
<td>8</td>
</tr>
<tr>
<td>Research on the Science Laboratory</td>
<td>10</td>
</tr>
<tr>
<td>National Reform of the Science Curriculum</td>
<td>11</td>
</tr>
<tr>
<td>Reform Initiatives, Scientific Literacy, and Evolution</td>
<td>12</td>
</tr>
<tr>
<td>Conceptual Change Theory</td>
<td>15</td>
</tr>
<tr>
<td>Conceptual Change Research in Evolution Education</td>
<td>16</td>
</tr>
<tr>
<td>Students' Understandings of Evolution</td>
<td>22</td>
</tr>
<tr>
<td>Adaptation</td>
<td>24</td>
</tr>
<tr>
<td>Teleology</td>
<td>25</td>
</tr>
<tr>
<td>Multiple levels of causality</td>
<td>26</td>
</tr>
<tr>
<td>Selection</td>
<td>27</td>
</tr>
<tr>
<td>Factors Affecting Understanding of Evolution</td>
<td>27</td>
</tr>
<tr>
<td>Nature of Science</td>
<td>29</td>
</tr>
<tr>
<td>Worldview Research and Student Belief Systems</td>
<td>31</td>
</tr>
<tr>
<td>Summary of the Literature Review</td>
<td>36</td>
</tr>
<tr>
<td>CHAPTER 3: MATERIALS AND RESEARCH METHODS</td>
<td>38</td>
</tr>
<tr>
<td>Chapter Overview</td>
<td>38</td>
</tr>
<tr>
<td>Section One</td>
<td>38</td>
</tr>
<tr>
<td>Sampling procedure</td>
<td>38</td>
</tr>
<tr>
<td>Description of the pilot study</td>
<td>39</td>
</tr>
<tr>
<td>Development of the survey</td>
<td>40</td>
</tr>
<tr>
<td>Permission for study</td>
<td>43</td>
</tr>
<tr>
<td>Validity and reliability</td>
<td>44</td>
</tr>
<tr>
<td>Section Two</td>
<td>47</td>
</tr>
<tr>
<td>The description of the main study</td>
<td>47</td>
</tr>
</tbody>
</table>

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
The study design and the research procedures ........................................54
Observations ......................................................................................................60
Observation notes ..................................................................................................60
Field journal ........................................................................................................61
Section Three ........................................................................................................62
Data analysis ..........................................................................................................62
Time frame ..............................................................................................................64

CHAPTER 4: QUANTITATIVE RESULTS AND DISCUSSION ..................66
Chapter Overview ..............................................................................................66
Whole class conceptual change .........................................................................66
Summary of conceptual change pathways ..........................................................75
The final examination and isolated exam items .................................................78
The rest of the conceptual framework .................................................................81
The nature of science .............................................................................................82
Summary of whole class conceptual change ......................................................84

CHAPTER 5: INTERVIEW RESULTS AND DISCUSSIONS ...............86
Chapter Overview ..............................................................................................86
Lecture-only Participants’ Conceptual Change .................................................87
Ian - atheistic, scientific realist ........................................................................87
Conceptual change at the end of the semester .................................................93
Adrian - theistic evolutionist and scientific realist .............................................96
Conceptual change at the end of semester ......................................................107
Patricia - creationist and scientific relativist and skeptic ................................110
Conceptual change at the end of the semester ................................................120
Lecture-Laboratory Participants’ Conceptual Change ...................................122
Martin - scientific realist and atheistic evolutionist .........................................122
Conceptual change at the end of the semester .................................................130
Mary - creationist and scientific relativist .........................................................132
Conceptual change at the semester’s end .........................................................143
Juan - gradual creationist and scientific realist ................................................146
Conceptual change at the semester’s end .........................................................155
Rhonda - atheistic evolutionist and scientific realist .......................................156
Conceptual change at semester end .................................................................164
Brianna - quick creationist and scientific relativist ..........................................167
Conceptual change at the end of the semester ................................................182
Summary of Conceptual Change for the Two Comparison Groups ........185
Summary of lecture-only group’s conceptual change at semester end ...........186
Summary of lecture-lab group’s conceptual change at semester end .............189
Summary of participants’ conceptual inventory profiles ...............................196
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHAPTER 6: SUMMARY AND CONCLUSIONS</td>
<td>199</td>
</tr>
<tr>
<td>Background</td>
<td>199</td>
</tr>
<tr>
<td>Summary of Findings</td>
<td>200</td>
</tr>
<tr>
<td>Conclusions</td>
<td>201</td>
</tr>
<tr>
<td>Alternative conceptions associated with the evolutionary framework</td>
<td>201</td>
</tr>
<tr>
<td>Conceptual change and patterns of conceptual change</td>
<td>202</td>
</tr>
<tr>
<td>Factors influencing conceptual change</td>
<td>207</td>
</tr>
<tr>
<td>Significance of the Study</td>
<td>214</td>
</tr>
<tr>
<td>Limitations of the study</td>
<td>216</td>
</tr>
<tr>
<td>Suggestions for further study</td>
<td>216</td>
</tr>
<tr>
<td>Final thoughts</td>
<td>218</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>221</td>
</tr>
<tr>
<td>APPENDIX A: EXAMPLE OF STUDENT RELEASE FORM</td>
<td>230</td>
</tr>
<tr>
<td>APPENDIX B: IRB FOR CONDUCTING RESEARCH WITH HUMANS</td>
<td>231</td>
</tr>
<tr>
<td>APPENDIX C: PILOT STUDY DATA</td>
<td>232</td>
</tr>
<tr>
<td>APPENDIX D: FINAL VERSION OF PRETEST/POSTTEST SURVEY</td>
<td>234</td>
</tr>
<tr>
<td>APPENDIX E: VEE DIAGRAM OF RESEARCH</td>
<td>240</td>
</tr>
<tr>
<td>APPENDIX F: DEMOGRAPHIC INFORMATION REQUEST FORM</td>
<td>247</td>
</tr>
<tr>
<td>APPENDIX G: SYLLABI FOR BIOL 3040 AND BIOL 3041</td>
<td>242</td>
</tr>
<tr>
<td>APPENDIX H: EXAMPLES OF INTERVIEW PROBES</td>
<td>245</td>
</tr>
<tr>
<td>APPENDIX I: EXAMPLES OF THE INSTRUCTOR DEVELOPED ITEMS</td>
<td>249</td>
</tr>
<tr>
<td>APPENDIX J: WHOLE-CLASS CONCEPTUAL INVENTORY</td>
<td>250</td>
</tr>
<tr>
<td>APPENDIX K: EXAMPLES OF STUDENT RESPONSES</td>
<td>254</td>
</tr>
<tr>
<td>APPENDIX L: STUDENT TIMELINES</td>
<td>256</td>
</tr>
<tr>
<td>APPENDIX M: TIME FRAME OF PROPOSED RESEARCH</td>
<td>260</td>
</tr>
<tr>
<td>VITA</td>
<td>265</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Tables</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Profile of interview participants</td>
</tr>
<tr>
<td>2</td>
<td>Summary of research activities</td>
</tr>
<tr>
<td>3</td>
<td>Conceptual change pathways of the comparison groups for the major conceptions of evolution</td>
</tr>
<tr>
<td>4</td>
<td>Summary statistics for data sources (quantitative)</td>
</tr>
<tr>
<td>5</td>
<td>Summary statistics for isolated exam items for comparison groups</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figures</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Comparison of pre- and posttest scores on the species concept for lecture-only and lecture-lab groups</td>
<td>69</td>
</tr>
<tr>
<td>2</td>
<td>Lecture-only participants’ (N=21) conceptions for the unit of evolutionary change</td>
<td>71</td>
</tr>
<tr>
<td>3</td>
<td>Lecture-lab participants’ (N=7) conceptions for the unit of evolutionary change</td>
<td>71</td>
</tr>
<tr>
<td>4</td>
<td>Lecture-only participants’ (N=21) conceptions for origin of variation</td>
<td>73</td>
</tr>
<tr>
<td>5</td>
<td>Lecture-lab participants’ (N=7) conceptions for origin of variation</td>
<td>73</td>
</tr>
<tr>
<td>6</td>
<td>Comparison of lecture-only and lecture-lab participants’ mean scores for the isolated examination items</td>
<td>80</td>
</tr>
<tr>
<td>7</td>
<td>Ian’s conceptual inventory profile and conceptual change instances</td>
<td>94</td>
</tr>
<tr>
<td>8</td>
<td>Adrian’s conceptual profile inventory and conceptual change instances</td>
<td>108</td>
</tr>
<tr>
<td>9</td>
<td>Patricia’s conceptual inventory profile and conceptual change instances</td>
<td>116</td>
</tr>
<tr>
<td>10</td>
<td>Martin’s conceptual inventory profile and conceptual change instances</td>
<td>131</td>
</tr>
<tr>
<td>11</td>
<td>Mary’s conceptual inventory profile and conceptual change instances</td>
<td>144</td>
</tr>
<tr>
<td>12</td>
<td>Juan’s conceptual inventory profile and conceptual change instances</td>
<td>152</td>
</tr>
<tr>
<td>13</td>
<td>Rhonda’s conceptual inventory profile and conceptual change instances</td>
<td>166</td>
</tr>
<tr>
<td>14</td>
<td>Brianna’s conceptual inventory profile and conceptual change instances</td>
<td>184</td>
</tr>
<tr>
<td>15</td>
<td>Summary of participants’ conceptual inventory profiles</td>
<td>198</td>
</tr>
</tbody>
</table>

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This study investigated eighty junior and senior college students' understanding of evolutionary biology concepts in lecture-only and lecture-laboratory settings. The evolution lab stressed the processes of evolution, and involved simulations, experiments, discussions, report writing, and reading.

Test scores do not reveal everything about the actual process of learning in the laboratory. This study examined conceptual change patterns over a period of one semester using in-depth interviews with eight participants.

This study revealed that the lecture-laboratory group performed better than the lecture-only group on certain shared items on the objective examination. The interview participants showed various patterns of conceptual change; that is, holistic (wholesale and cascade), fragmented, and dual constructions. Dual constructions and wholesale conceptual changes were the most common types of conceptual change patterns observed.

Laboratory work in evolution allowed students to grapple with their alternative conceptions for abstract evolutionary concepts. They made use of the opportunities for cognitive conflict provided by the lab sessions.

Some students adhered to their initial alternative conceptions which constrained the provision of scientific explanations for the biological problems. Examples of alternative conceptions are a young earth, rejection of macroevolution, and Lamarckian conceptions. The belief system of one student strongly influenced her retention of alternative conceptions, although she had done the laboratory course. However, two other students (one a lecture-lab participant) who held similar religious beliefs were
able to develop a better understanding of evolution. Strong religious beliefs do not always preclude a good understanding of evolution.

This study revealed a direct, positive relationship between students’ understanding of evolutionary concepts and their understanding of the nature of science. The observation was true for both lecture-only and lecture-lab groups.
CHAPTER 1: INTRODUCTION

The importance of practical work (laboratory work) in natural science courses is illustrated by the fact that either more than half, or equal time (albeit for fewer credit hours) is assigned to it compared with the theory courses in undergraduate studies (Edwards & Scolin, 1993). Lazarowitz and Tamir (1994) identify the goals of the laboratory in natural science courses as providing concrete experiences and opportunities to identify misconceptions; providing students opportunities for data manipulation through use of microcomputers; opportunity to developing skills in logical thinking; and providing opportunities for building and communicating values concerning the nature of science. The current reform literature reiterate the importance of these goals (BSCS, 1993; NSTA, 1991; NRC, 1996; AAAS, 1993).

Evolution has been identified as the unifying principle for understanding the relationships among living things, the history of life on earth, and the dependence of life on the physical world (AAAS, 1990; BSCS, 1993; NRC, 1996). It has been identified as the unifying framework within which many diverse biological facts are integrated and explained. Scientific literacy, which has been identified as a central goal of contemporary science education reform within the realm of biology, cannot be achieved without an understanding of the nature of science and biological evolution (AAAS, 1993; NRC, 1996; BSCS, 1993).

Many authors have reported that evolution is both difficult to learn and to teach (Bishop and Anderson, 1990; Brumby, 1984). Fisher (1992) identifies five aspects that make it difficult to teach and learn about evolution: 1) Students know too little biology; 2) evolution is given little teaching time; 3) student understanding is not robust enough
to support the reasoning and extended inferences needed to comprehend evolution that is a complex, abstract construct; 4) they need knowledge from other speciality areas, like molecular biology, biogeography; and 5) university instructors are generally not familiar with school curricula and do not draw on earlier experiences. According to Hafner and Hafner (1992), although many believe that the abstract evolution concepts are not amenable to laboratory instruction, the evolution laboratory reinforces and clarifies abstract concepts. Research literature shows even senior undergraduates fail to comprehend these abstract concepts (Trowbridge and Wandersee, 1994).

Research in the field of evolution education has focused on students’ conceptions of evolution, students’ conceptual ecologies and conceptual change (Demastes/Southerland, Good & Peebles, 1995; Demastes/Southerland, Good & Peebles, 1996), teaching approaches (Jensen & Finley, 1997), the presentation of evolution in textbooks and emphasis it is given in schools, teacher attitudes and understanding of evolution (Shankar & Skoog, 1993; Jimenez-Alexandre, 1994), and the interaction between world views, beliefs, and understanding the concept of evolution (Dagher and BouJaoude, 1997; Ogunnyi, Jegede, Ogawa, Yandila and Oladele, 1995).

Research in the area of cognitive restructuring in evolution within the Conceptual Change Model (Posner, Strike, Hewson & Gertzog, 1982) and other theoretical frameworks have received attention in evolution education research. Saramapungavan & Wiers, (1997) use the ECHO framework hypothesis of Paul Thagard (1992) to explain children’s conceptual frameworks and explanations of species development. Demastes/Southerland et al. (1996) raise the question of whether
the Conceptual Change Model has been over applied to explain all forms of learning; as a result, they may have overlooked other forms of meaningful learning. This author (1995) showed in her study that holistic change (wholesale and cascade patterns) is not the only type of pattern to be expected in learners' conceptual restructuring of major organizing conceptions.

There is very little convincing data on how students learn in laboratories and on the effectiveness of learning in the laboratory (Lazarowitz and Tamir, 1994). Many students enter the science laboratory with firmly held cognitive models with which they make sense of the world, and which are believed to be resistant to change. When they acquire new knowledge through observation in the laboratory, these concepts are incorporated into the existing conceptual model whether they are scientifically acceptable or not (Woolnough and Allsop, 1985). However, Tobin (1990) asserts that meaningful learning is possible in the laboratory. In his opinion, research is needed on how students engage, how they construct understandings, and how they negotiate meaning in cooperative groups.

There are a few studies at the college level which examine the process of learning in the laboratory (Trowbridge and Wandersee, 1994). There is a shortage of studies which deal with learning evolution in a laboratory setting. Furthermore, many studies which deal with laboratory studies typically are exclusively quantitative using these techniques in data collection, analysis of surveys and objective examination scores (Lazarowitz & Tamir, 1994).

This study was a mixed methods study, utilizing both quantitative and qualitative data collection techniques and analysis to answer the research questions.
The study was conducted in two courses where evolution was the unifying theme. The evolution lecture course was a prerequisite for the laboratory course. The laboratory course involved discussions, readings, simulations and experiments. As the first part of the title suggests, this study investigated the effects of the laboratory on college students’ understanding of evolution. This study also aimed to investigate conceptual change and how this was impacted by the laboratory course. The latter aim is implied in the second part of the title (that is, “implications for conceptual change”). The study also investigated students’ conceptions about the nature of science, the nature of evolution, and alternative conceptions about evolution.

Students’ conceptions about conceptual groups of evolution identified in the research literature by Demastes/Southerland (1994) and Bishop and Anderson (1990), were investigated. These conceptions are the species concept, the unit of evolutionary change, and the origin of variation. Other concepts examined include fitness, adaptation and students’ understanding of evolutionary processes which bring about evolutionary change (e.g., natural selection). Data were collected for the whole class by means of an objective examination and surveys, and for eight interview there were the pre- and posttest interviews as well.

Research Questions

The research questions asked by this study are:

Primary research questions

1. What do the whole class data reveal about the overall difference in conceptual change between the lecture-only and lecture-laboratory course participants, and the effect of laboratory learning on their understanding of evolution?
2. What patterns of conceptual change can be observed in college students and what differences are observed for participants in the lecture-only and lecture-laboratory groups?

Secondary research question

3. How does an understanding of the nature of science relate to students’ understanding of evolutionary concepts (e.g., natural selection, adaptation, variation)?

Definitions Used in This Study

Alternative conceptions refer to experience based explanations by which a learner makes a range of natural phenomena and objects intelligible.

Conceptual ecology includes the learner’s fundamental organizing knowledge (includes conceptions, metaphysical beliefs, epistemological commitments, other knowledge, anomalies, analogies) that controls and modifies further conceptual change, and is that aspect of knowledge most influenced by the learner’s culture.

Conceptual change refers to meaningful learning occurring when a learner accepts new conceptions on the grounds that they are intelligible, plausible and fruitful.

Evolution is the unifying principle which acts as a theoretical framework for the processes which can lead to genetic change in a population over time. It is also described as descent with modification.

Laboratory refers to practical work carried out in the laboratory and includes discussions, simulations, demonstrations, and exercises.

Natural selection is a mechanism for evolutionary change proposed by Charles Darwin. Natural selection acts on variation, to select advantageous traits and delete disadvantageous traits, resulting in a better fit of the organism to its environment. It is
the process whereby certain individuals live and reproduce, and others do not (Hafner, 1998).

Lamarckism is a non-Darwinian conception/view of evolution which encompasses a number of interpretations: Each generation of a species improves itself via the inheritance of acquired traits; or the acquired traits occurred through the use and disuse of organs. It also includes using the word “adaptation” in the everyday context of the word; individuals changing in response to the environment (e.g., the coat got whiter because it adapted to the snow white environment).

Teleology a non-Darwinian conception/view of evolution. It is related to evolution on demand or it is the explanation of phenomena by the purpose they serve. Teleology is associated with terms such as: in order to; it had to evolve; it needs to. Teleological explanations therefore imply purpose, a goal, or a function to a phenomenon.

Natural theology is associated with the work of William Paley and essentially says that God produced a delicate balance in nature.

Species (Biological Species Concept associated with Mayr) are groups of (actually or potentially) interbreeding natural populations that are reproductively isolated from other such groups.

Creationism refers to the belief system which accepts a six-day creation story as contained in the book of Genesis of the Bible. It is equated with fundamentalism.

Scientific creationism is a doctrine largely associated with the Institute for Creation Research in San Diego. The scientific creationist movement’s research agenda involves using flood geology (Noachian worldwide floods) to explain earth’s geologic features.
Belief is used in this study to include knowledge which is taken on faith in a supernatural agent (e.g., God).

Belief system refers to a set of organized and interconnected individual beliefs.
CHAPTER 2: REVIEW OF THE LITERATURE

The Role of the Laboratory

According to Meester (1995), the laboratory is no longer considered as the place for confirmation of lecture material; it offers the learner the opportunity to be engaged in scientific processes. Laboratory activities have as a goal the fostering of an understanding of the nature of science within students (Shulman and Tamir, 1973). Hofstein and Lunetta (1982) laboratory activities are defined as “contrived experiences in which students interact with materials to observe phenomena.” They summarized the findings of several studies and concluded that laboratory experiences promote the formation of positive attitudes toward learning science in students who have had worked with concrete objects in the laboratory; manipulation of objects and use of tools of science enhances development in the psychomotor area. Laboratory experiences increased students’ abilities at higher levels of cognitive ability. This is in accord with Olson’s (1973) finding that the laboratory can provide conditions for both intellectual and motor skill development.

Woolnough and Allsop (1985) identify specific aims of practical work, and link these with a specific instructional strategy. Developing practical skills are best achieved through practical exercises of the structured and convergent kind. Practical investigations or projects which are open-ended or divergent can enable students to learn to work as a problem-solving scientist. Lastly, practical experiences enable the student to get a feel for the phenomenon being studied. They assert that once the students have a feel for the phenomena, they will be able to derive the underlying principles and concepts through discussion.
McComas (1991) asserts that evolution is abstract and a generally non-observable phenomenon. Many students have only marginally formed mental structures necessary to conceptualize such complex topics. Hands-on laboratory exercises are recommended to engage learners.

Hafner and Hafner (1992) observe that many evolution courses are taught without a laboratory component; one reason for this is that there is a common notion that abstract concepts (e.g., natural selection, vicariance) are not amenable to laboratory instruction. In their opinion, understanding of evolutionary processes include learning many abstract concepts. Laboratory work facilitates the shift from being passive observers to active participants who think and talk about these concepts, ideas and issues.

Based on the fact that evolution is an abstract and generally non-observable phenomenon, the NABT advises that students be engaged in learning about evolution in the most effective level available; that is, through concrete, hands-on laboratory experiences (McComas, 1994). The NABT publication, Investigating Evolutionary Biology in the Laboratory (McComas, 1994), provides activities which are aimed at a hands-on approach to evolution education and proposes a more student-centered approach.

In order to make the most of the laboratory sessions, the follow-up time after these sessions is crucial (Driver, 1983). Taking time to interpret results and to consolidate new ideas are as important as the activity itself.

Research on the effectiveness of the science laboratory is important if we are to invest the time and money into setting up laboratories.
Research on the Science Laboratory

In the Stor-Hunt study (1996) the variance analysis of the relationship between the amount of time spent experiencing hands-on science and science achievement showed that students who spent more time on activities every day, or once a week scored significantly higher on a standardized test of science achievement than students who engaged in hands-on activities once a month, less than once a month, or never. Teachers using hands-on science have other traditional methods on the periphery of preferred methods, incorporating them as needed. Hands-on methods place primary importance on experiences of students, whereas traditional methods rely heavily on teacher experience. Further research on activity-based programs is certainly warranted.

Freedman (1997), in his study on the relationship between laboratory instruction, attitude toward science, and achievement in science knowledge, found that students who had regular laboratory instruction scored significantly higher than the control in these areas. Science labs were found to be effective with diverse groups.

Shymansky, Hedges and Woodworth (1990) conducted a meta-analysis in 1990. The study was a reassessment of the effects of inquiry-based science curricula of the 1960s on student performance. They consider the laboratory as an integral part of instruction, an opportunity for skills development, understanding the nature of science, and the development of higher order cognitive skills. The latter study (1990) was a re-synthesis of previous meta-analysis data using the refined statistical procedures of Hedges and Olkin (1985). The results support earlier claims; science curricula of the 1960s and 1970s were more effective in enhancing student performance than traditional text-based programs of the time. Some notable differences were noted; the mean
effects were significantly positive for four performance clusters, namely, achievement, process skills, problem solving and attitude. In the previous study, there were seven clusters.

Support for laboratory work in science has emerged in the science education reform literature.

**National Reform of the Science Curriculum**

The reform literature clearly recommends a move toward *science for all* and a shift from traditional lecture-type lessons to more hands-on, minds-on, inquiry-based instruction. NSTA (NSTA, 1991) states that the laboratory is crucial in the process of enhancing students’ cognitive and affective understanding of science. The NSTA Position Statement on the Science Laboratory (NSTA, 1991) makes recommendations for pre-K/elementary, middle, high school (all should have 40% instruction time in laboratory) and the college level laboratory (introductory courses should have compulsory laboratory courses for all, 50% or more time should be spent on laboratory activities, equal credit for lab and lecture time). The laboratory is integral to the nature of science; problem-solving abilities are refined in the context of laboratory inquiry; it can motivate students, and enhance student performance in:

- **Process skills**: observing, manipulating, measuring
- **Analytical skills**: reasoning, critical thinking
- **Communication skills**: organizing information, writing
- **conceptualization of phenomena**

The NRC’s *Fulfilling the Promise* (1990) says that science laboratories challenge students’ beliefs about the natural world and enable them to construct more
accurate scientific conceptualizations. Students can generate knowledge directly from natural phenomena. Hands-on science provides lasting memories, and opportunity to learn about precision, accuracy, record-keeping, measuring, inferring, and problem-solving.

BSCS (1993) asserts that the science laboratory promotes inquiry, authentic experiments motivate students, helps them to construct knowledge, informs them of how scientists work and involves them in the investigation of real world issues.

In the Standards (1996), the NRC recommends that students have easy, equitable and frequent opportunities to use a wide range of equipment, materials, supplies, and other resources for experimentation and direct investigation of phenomena.

Reform Initiatives, Scientific Literacy, and Evolution

The American Association for the Advancement of Science (AAAS) has made important inroads into advancing scientific literacy through its Science for All Americans (AAAS, 1989) and Benchmarks for Scientific Literacy (AAAS, 1993). Benchmarks (AAAS, 1993), Developing Biological Literacy (BSCS, 1993), Fulfilling the Promise: Biology Education in the Nation's Schools (NRC, 1990) and the National Science Education Standards (NRC, 1996) identify evolution of life as a unifying concept. With regard to the controversy surrounding evolution, Benchmarks (AAAS, 1993) suggests that schools acknowledge it, but present only the scientific view. Benchmarks (AAAS, 1993) concentrates on the common core of learning that all students should know and be able to do in science, mathematics, and technology by the end of grades 2, 5, 8 and 12. For the evolution section of the curriculum, by the end of the 12th grade, students should know that:
• The basic idea of biological evolution is that the earth's present-day species developed from earlier distinctly different species.
• Life on earth is thought to have begun as simple, one-celled organisms about four billion years ago.
• Natural selection leads to organisms that are well suited for survival in particular environments.
• The theory of natural selection provides a scientific explanation for the history of life on earth.
• Evolution builds on what already exists, so that the more variety there is, the more there can be in the future. (p. 125).

The NRC (1996) also emphasizes that all students in grades 9-12 should develop an understanding of evolution. One of the fundamental principles that underlies the Life Sciences Content Standard C is biological evolution, in which the following are emphasized:

• Species evolve over time.
• The diversity of organisms is the result of more than 3.5 billion years of evolution.
• Natural selection and its evolutionary consequences provide scientific explanation for the fossil record of ancient life forms.
• The different species of organisms that live on earth today are related by descent from common ancestors.
• Biological classifications are based on how organisms are related. (p. 185).
These views on evolution are reiterated by the National Association of Biology Teachers (NABT) in their position statement published in 1996. They say in this regard that creation science has no place in the science classroom because science and religion differ in significant ways. Evolution should be a recurrent theme throughout biology textbooks and courses. Teachers should respect students' beliefs and can themselves hold religious beliefs and at the same time accept evolution as a valid scientific theory. They warn that teachers and administrators should be aware of the various court cases and remember that the law prohibits the teaching of creation science in the classroom.

The National Science Teachers Association (NSTA, 1997) has published their position statement declaring support for the position that evolution is a major unifying concept which should be included as part of K-College science frameworks and curricula. Their comments are that:

- Evolution be emphasized in class and in curricula in a way that is commensurate with its importance as a unifying concept in science and its overall explanatory power.
- They are opposed to creation science concepts being taught ("intelligent design," "arguments against evolution").
- Teachers should not advocate any religious view about creation, they should remain neutral about students' personal beliefs.
- Teachers should receive support to design and implement relevant curricula.
- Science education should not be bound by censorship, pseudoscience, faulty scholarship, or unconstitutional mandates.
- Textbooks should emphasize evolution as a unifying concept and publishers
should not be required to include disclaimers concerning the nature and study of evolution.

**Conceptual Change Theory**

The prior knowledge that students bring to science instruction is very important in conceptual change instruction. According to the Conceptual Change Model (Posner, et al., 1982), when confronted with a new conception concerning, for example, a naturally-occurring phenomenon like evolution, the new conception might be rejected, or incorporated into the cognitive structure. The latter process could occur as rote memorization (weak links with existing knowledge); conceptual capture (the new conception is assimilated into existing conceptions); and conceptual exchange (the old conception is replaced with the new one). In the case of conceptual exchange, the new conception is reconciled with the remaining conceptions. Reconciliation involves making sense of the new conception and giving it meaning by contextualizing it within existing knowledge and understanding.

The Conceptual Change Model has become an important heuristic for science educators interested in understanding the process of learning. The basic conditions needed before conceptual exchange can occur have been outlined by Posner et al. (1982):

1. The learner must experience dissatisfaction with existing conceptions; his/her current understanding must be unable to rationally explain some event.

2. The learner must have a meaningful understanding of the intelligibility of the newly presented concepts.
3. The learner is able to identify the new conception as plausible; this should occur when a new concept appears to have the capacity to solve the problems generated by its predecessors. The decision is again dependent on the student’s opinion and judgement.

4. The learner must be able use the new conception in fruitful ways.

Therefore, the Conceptual Change Model describes the process by which the learner acquires new concepts, restructures existing concepts, or exchanges concepts from one set to another.

The Revisionist Conceptual Change Model (Strike and Posner, 1992), revisits the composition of the conceptual ecology. The original model described the conceptual ecology as consisting of cognitive artifacts such as anomalies, metaphors, analogies, metaphysical beliefs, epistemological beliefs, alternative conceptions and knowledge from other areas of inquiry. These artifacts are assets or liabilities in instruction depending on whether they promote or frustrate progressive conceptual change. The revision calls for a view of the conceptual ecology which contains scientific and alternative conceptions in interaction with other components; it requires a developmental and interactionist view of conceptual ecologies. Motives, goals and other factors, and the institutional and social sources of these, need to be taken into account when describing the conceptual ecology of a learner. The conceptual ecology is therefore dynamic, developmental and evolving.

**Conceptual Change Research in Evolution Education**

Pretest-posttest studies enabled Settlage (1994) to observe how students’ explanations for evolution underwent change during instruction. His sample was 50
students drawn from a pool of more than 200 who sat for the pre- and posttest. Students’ responses were categorized according to the emerging themes’ approach. He concluded that teleological and Lamarckian explanations accounted for over half of the students’ explanations on a pretest. This dropped to less than 20% on the posttest. Even though most students were capable of providing explanations that described the role of population’s variation to the evolutionary process after the posttest, it is notable that certain alternative conceptions may be more difficult to change than others. The study did not involve interviewing or personal contact with the students; it utilized only pencil and paper tests. The researcher made inferences based on these tests alone. Attempts to change students’ conceptions require that their prior knowledge is known and understood.

Brumby (1984) observed that students in his sample of 150 first-year Australian medical students believed that evolutionary change occurred as a result of need. Regardless of their strong background in biology, many students had Lamarckian views of evolution.

The study by Bishop and Anderson (1990) is one of the most important and comprehensive studies into conceptual change in the areas of evolution and natural selection. In this study they demonstrate the usefulness of the conceptual change theory as it is applied to the process of learning evolution. They studied nonmajor biology students who they found were not achieving an adequate understanding of the mechanisms of evolution when presented with a fairly simple explanation of the neo-Darwinian synthesis. The study also investigated the complex relationship between belief in evolution and understanding of evolutionary theory and the extent of students’
prior course work in biology. They found that students' conceptions differed from that of scientists in three ways:

1. Issue one regarded the origin and survival of new traits in populations.
   Students held the belief that the environment exerts its influence on variation through implicitly Lamarckian ideas of need, use and disuse, and adaptation.

2. Issue two regarded the role of variation within a population.
   They mistakenly viewed evolution as a process that shaped the species as a whole rather than focusing on a population composed of individual members.

3. The third area involved evolution as the changing proportion of individuals with discrete traits.
   Students viewed evolution as a gradual change in the trait(s) themselves instead of considering the proportion of individuals in the population with a trait(s).

The investigators designed instructional materials which satisfied the criteria as described by Posner et al. (1982) to bring about conceptual change and they found that after instruction, over fifty percent of the students could use the scientific conceptions to explain evolutionary change.

According to Good, Trowbridge, Demastes/Southerland, Wandersee, Hafner and Cummins (1992) very little research has been conducted despite the centrality of evolution to an understanding of biology. The 1992 Evolution Education Research Conference (EERC) held at Louisiana State University provided a forum to discuss needed research and it culminated in the production of a research agenda for evolution education research. Representative research questions identified by the delegates at this conference are:
• To what extent are the anthropomorphic and teleological terms which students use when expressing evolutionary concepts, a conceptual or semantic problem?

• What benchmarks (precursors) are effective in developing a conceptual framework early in children’s learning in order to understand the complex, abstract ideas of evolution?

• What key concepts are important to understand evolution?

• How well do students understand proximate and ultimate causality?

The research that followed was mainly aimed at informing refinements to future benchmarks. A special issue of the Journal of Research in Science Teaching (Cummins, Demastes/Southerland and Hafner, 1994) deals exclusively with the topic The Teaching and Learning of Biological Evolution. It contained nine articles and the results of some of these articles were important in this study.

Jimenez-Aleixandre (1994) conducted a study in which she assessed textbooks to investigate the way key ideas in the Darwinian model were handled, the attention paid to students’ ideas, and the type of activities used in instruction. She also interviewed teachers about their approaches, their ideas about students’ experience using the Darwinian model, and about whether they shared students’ difficulties in using the model. On the whole, the teachers’ approach is characterized by superficial handling of key ideas, a lack of attention to students’ alternative ideas, and little variety in activities. The conclusions drawn from the study indicate that teachers experience difficulty in the exploration and diagnosis of pupils’ ideas and in some cases they shared pupils’ difficulties when trying to interpret instances of biological change. However, the researcher collected the data outside of classroom situations and she suggested more
detailed study and direct classroom observations for new ideas about how to handle evolution and promote functional learning in the classroom.

In an earlier study Demastes/Southerland (1994) found that the actions and structure of a learner's conceptual ecology vary with each individual. For some, their epistemological approach to science may have an influence on their ability to learn science. In her study, however, worldviews also played a pivotal role in controlling conceptual change, and the learner's selection of a conception was directed also by extra-logical, affective considerations. She concluded that learners should learn to deal with reconciling conflicting belief structures. Her study was unable to provide clarification on students' use of anthropomorphism and teleology; the means through which these issues influence the constructions of conceptions remains unclear and further research is required to illuminate their influence. She concluded that a student's conceptual framework can undergo the construction of dual conceptions and that research into these conceptions and their classroom implications needs to be conducted.

Demastes/Southerland, Settlage and Good (1995) conducted a replication and comparison study of the Bishop and Anderson study (1990). They confirmed that prior instruction and students' beliefs in evolution were not found to contribute to students' use of scientific conceptions in study A of the research study. They reported only a 25 percent increase in participants' use of scientific conceptions as compared to the 50 percent of the Bishop and Anderson study. They did not discern any difference between the outcome of conceptual change instruction and traditional instruction. In the second study, B, they used the same evaluation instrument as Bishop and Anderson (1990) with high school students and the instruction was based on the inquiry approach

20

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to science which does not depend on student prior knowledge. Participants showed significant increases in their use of scientific conceptions for evolution. They concluded that student restructuring of the central organizing concepts of evolution and natural selection may depend on how material is presented.

Within the conceptual change paradigm, Demastes/Southerland, Good and Peebles (1995) attempted to describe the structure of a learner's conceptual ecology within the content area of biological evolution. They gathered data using participant observations in a high school Biology II classroom. Their data collection methods were interviews, pre- and posttests, concept mapping, and sorting tasks. They found that a conceptual ecology for evolution was found to possess the following facets: prior conceptions (alternative and scientific) related to evolution, the learner's scientific epistemology, the learner's view of the biological world, the learner's scientific and religious orientation, and the learner's acceptance of evolutionary theory. Therefore, contrary to the conceptual change theory (Posner et al., 1982) conceptual change was found to be less logical with the learner's selection of a conception directed by extra-logical criteria.

In another study, Demastes/Southerland, Good and Peebles (1996) utilized an ideographic approach to investigate patterns of students' conceptual restructuring. Data sources included classroom observations, interviews, written pre-and posttest exams. Their findings have important theoretical implications for the theory of conceptual change. They found two patterns of conceptual change (incremental and dual construction) failed to conform to the changes described by the theory; the theory only allows for wholesale and cascade changes. Therefore, they concluded that conceptual
change theory describes one kind of learning and further research is needed to investigate the patterns of conceptual restructuring within other theoretical frameworks.

Jensen and Finley (1997), in a study in which they surveyed university students, found that students displayed various non-Darwinian explanations or even Darwinian ideas embedded within other non-Darwinian ideas for evolutionary change. Traditional instruction did not change things drastically. After instruction, which entailed paired problem solving that aimed to challenge these pre-Darwinian concepts, they found that students increased their use of Darwinian explanations. However, it was noted that non-Darwinian ideas were not totally eradicated.

**Students' Understandings of Evolution**

Until the end of the eighteenth century, the commonly held view was that the Earth had been created by a supernatural entity. Every species of animal and plant on Earth was individually created. In addition it was believed that every species had remained unaltered since that special creation event. To suggest an alternative explanation was to be immediately at variance with the established views of the Church.

Following this, Lamarck formulated the first comprehensive account of change or evolution with his "inheritance of acquired characteristics." In Lamarck's thinking, species played no role; new species originated by spontaneous generation from inanimate matter, producing the simplest infusorians, with each newly established line gradually moving up to ever greater perfection as organisms adapted to their environment and passed along to their offspring these newly acquired traits (Jimenez-Aleixandre, 1994). Today students still display this kind of thinking in explaining the
mechanism of evolutionary change; in Lamarck's view, it was the action of the
environment on the organisms that produced the change. The resultant change in the
phenotype is passed on to the next generation.

The Darwinian and Lamarckian theories both offer explanations of how living
things change over time. The Darwinian theory, according to Mayr (1991), had
numerous meanings for people and when later authors referred to his theory they had a
combination of some of the following five theories in mind:

1. Evolution as such; a world that is not constant, nor recently created, it is steadily
   changing, and organisms are transformed in time.
2. Common descent; every group of organisms descended from a common
   ancestor, all going back to a single origin of life on earth.
3. Multiplication of species; it explains the origin of the enormous organic
evolution.
4. Gradualism; evolutionary change is gradual change and not by saltational
   (sudden) production of new individuals that represent a new type.
5. Natural Selection; evolutionary change occurs through the abundant production
   of genetic variation in every generation. The relative few who survive as a
   result of a particularly well-adapted combination of inheritable characters, give
   rise to the next generation. Darwin himself treated these five theories as a unity.

According to Thagard (1992) Darwin's theory, which was part of a different
conceptual framework from the creationist "theory", involved the introduction of new
concepts, the deletion of old ones, conceptual reorganization, and also the
reinterpretation of the kind-hierarchy. By the addition and deletion of concepts,
Thagard is referring to the deletion of the concept of special creation and the addition of the concepts of descent with modification, common descent of living organisms, and natural selection. It also involved the deletion of central rules concerning evolution (that is, evolution operates toward increased perfection), and the replacement of these rules with rules describing random variations and natural selection. New kind-hierarchies entailed what Thagard (1992) refers to as “branch jumping”; humans were no longer a special kind of creature, they were also classified in accord with principles of evolutionary descent. Therefore the concept human became subordinated into an existing category, that is, animal. Before Darwin, organisms were classified on the basis of similarity and were ahistorical (Cuvier used anatomy of internal parts; Linnaeus used similarity of characteristics in his taxonomy). Darwin’s classification of organisms became “genealogies.” This is referred to by Thagard (1992) as an alteration of the nature of the kind hierarchy referred to as “tree switching”; species became historical entities not just groups that share a set of common traits. Part-relations in modern evolutionary theory also involve space and time since species are spatio-temporal entities.

Adaptation

Adaptation is a concept considered to be central to the student’s overall conception of evolution. It can refer to several meanings in biology which are often not well articulated to students. It can refer to the immediate physiological changes in an individual, to characteristics of an organism which suit it to the environment, and also to the process by which a population is modified to greater fitness with respect to its environment. Students rarely have this metaknowledge and therefore find it difficult to
differentiate between the various uses of the word (Brumby, 1984). Students’ viewed adaptations as being caused by some purpose of design, as a response to need (teleology), and in response to changes in the environment (Lamarckism).

Teleology

One of the world views undermined by Darwin, and one that hinders a construction of a scientific understanding of evolution, is that of teleology. From the time of the Greeks (e.g., Aristotle) there was a widespread belief in everything in nature and its processes having a purpose, a predetermined goal. The most common usage of teleology in relation to biological understandings is that of evolution being directed to an end or shaped by an ultimate purpose. It is frequently used in biology when making statements about the functions of organs, about physiological processes, and about the behavior and actions of species and individuals. Terms associated with this functional role of teleology are function, purpose, goal, in order to as used in this example:

They had to use their muscles more in order to catch their food. (Jensen and Finley, 1997).

Jungwirth (1975) points out the close relationship between teleological explanations and anthropomorphic explanations, and between functional and teleological interpretations. Teleological explanations are common in biology teaching because of their value as heuristic devices. The Tamir and Zohar study (1991), with high school students, used interviews and determined that 62% of the students understood animals in anthropomorphic terms, with 30% understanding plants in these terms. They concluded that nonteleological statements were typically combined with rejection of anthropomorphism, and teleological explanations were used to express a

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functional understanding of the organism. Teleology is unique as it may have a great impact on the construction of a scientific conception of evolution. DeWalt (1992) concedes that teleology “is probably the most difficult misconception to display and to avoid reinforcing.” He cautions us about using words like primitive, advanced, and the use of innovation when referring to the vertebrate lineage. Carefully chosen examples, critical use of terminology and accurate portrayal of evolutionary mechanisms will help to avoid reinforcing misconceptions and fostering new ones.

Multiple levels of causality

Students studying proximate cause do so by dealing with the phenotype of an organism (what and how questions guide them); when studying ultimate causes, they deal with the genotype of the organism because that is where the information from the evolutionary history is stored (why questions). Mayr (1997) states that the living world has two sets of causations. The extent to which students integrate these concepts with evolutionary causation has not been well studied.

Research into alternative explanations investigate how students deal with multiple levels of causality (Cummins and Remsen, 1992; Southerland, Abrams and Cummins, 1996). Southerland et al. (1996) found that students were able to provide biological explanations for biological situations, with older students more likely to do so (second, fifth, eighth and twelfth grades in “typical classrooms”). Students were less likely to generate anthropomorphic explanations for plants than animals (Jensen, Settlage and Odom’s “Bambi effect” and “Disney effect”, 1995). Students’ explanations were indicative of the problem they had with multiple levels of causality; they frequently offered proximal causes (usually reserved for “why” questions) and
were unable to recognize the need to identify ultimate causes for a “how” question. Hence Southerland et al. (1996) argue that the protoconcept of mechanistic causality, accompanied by a rejection of anthropomorphic and teleological reasoning, is important for the understanding of evolutionary change.

Selection

Students are often confused about the concept selection. The confusion concerned whether selection was a concept, an act or a process. Natural selection, Mayr (1991) asserts, combines aspects of both random and nonrandom processes. An understanding of natural selection should impress that selection acts on pre-existing traits, developed through random processes, with the frequencies of such traits molded by nonrandom processes. Students do not understand and recognize individual variation with respect to species.

Factors Affecting Understanding of Evolution

The problems students experience with understanding evolutionary theory are mirrored by pre-service and practicing teachers (Ogunyi et al., 1995). Teachers show misunderstanding of the nature of science, exhibit anthropocentrism, anthropomorphism, teleology and belief in special creation and a young earth.

A study by Shankar (1989) of 307 biology teachers showed many biology teachers misunderstood evolution and devoted little instructional time to the topic. Twenty three percent of the teachers disagreed with the statement that humans are a product of evolution and 17% agreed that the Earth is about 10,000 to 20,000 years old. Failure to recognize evolution’s importance as a unifying concept of biology and to emphasize evolution is shown by the 42% of the teachers who spent only 2 to 5 days on
Twelve percent spent more than 10 periods; 14% did not spend any time on human evolution.

Jimenez-Aleixandre (1994) indicates that textbooks in biology have a rather deterministic orientation, a lack of concern for students’ alternative ideas, and a lack of activities to challenge them, while also providing little discussion on the key ideas of evolution. This suggests that textbooks do not address students’ difficulties nor do they constitute a good resource for traditional teaching. Swarts, Anderson and Swetz (1994) have conducted content analyses of Chinese, American and Soviet secondary school biology textbooks. The American textbooks contained the most content on evolution (26.5%-55.8%) with the evolutionary content dispersed throughout the textbook. Also there are more themes represented, for example, human evolution and religion.

Blank and Anderson (1998) surveyed 218 pre-service elementary science teachers (EST) and secondary science teachers (SST). They found that 79% of the SSTs believed evolution, while only 40% of the ESTs believed it. Only 34% of ESTs and 58% of SSTs believed that evolution had a valid scientific foundation. Sixty percent of the ESTs believed that American society would be broken down by teaching evolution in schools and 12% of SSTs felt the same way. They also found that ESTs had difficulty understanding evolution concepts. These all have serious implications for the teaching of precursor concepts in the elementary level grades. This is especially serious given the misunderstandings and attitudes toward evolution held by these teachers.

A recent study by Rutledge and Warden (2000), indicates that Indiana high school teachers’ acceptance of evolutionary theory was relatively low. The results
showed a significant relationship between their acceptance of evolution and both their understanding of evolution and understanding of the nature of science. They had a marginal understanding of evolution and also of certain nature of science issues, for example, the means by which scientific knowledge is generated.

Nature of Science

Acceptance of evolution was found to be significantly related to the nature of science (Johnson and Peeples, 1987; Scharmann and Harris, 1992). The structure of a subject consists of its substantive structure (concepts, propositions, and their organizational framework) and its syntactic structure (means by which knowledge is generated). Evolution has a substantive structure composed of its concepts and knowledge of the theory, and a syntactic structure which entails knowledge of the nature of science (Schwabb, 1978). The ability to differentiate between scientific ways of knowing and those of other realms may allow the student to relate knowledge of evolution to their belief framework, but this may not serve to lessen the difficulties students have constructing the scientific understanding in this area.

McComas (1997) asserts that even though the goal that students understand the nature of science is regarded as equal in importance to acquiring science content, surveys show that students and adults do not appreciate the most basic aspects of the operation of science. This is attributed to the lack of information about the process of science in textbooks, and science classes. The "myths" of science are perpetuated in textbooks, classroom discourse, and in the minds of adults. There is a lack of philosophy content in teacher education programs, and these programs have failed to provide real science research experiences. He laments the shallow treatment given the
nature of science in pre-college textbooks which teachers might use as resources. He provides an inventory of at least 15 myths which are widely held, incorrect ideas about the nature of science, for example, hypotheses become theories which in turn become laws; evolution is just a theory; scientific laws are absolute; and a general and universal scientific method exists. McComas (1997) recommends that students and those who teach science focus on the nature of science itself rather than just its facts and principles; students must have the opportunity to experience science and its processes free of the myths about the nature of the scientific enterprise.

Spiece and Colosi (2000) assert that students need to learn what scientists actually do. They need to know that science is more complex than the step by step list implied by the “scientific method” which many textbooks portray. The National Academy of Sciences (1998) has published a book, Teaching about Evolution and the Nature of Science which is a resource for teachers and administrators to inform those they teach, the students, and their parents, about evolution and its role in human affairs. It also provides information about observational evidence for evolution, explains the nature of science, and provides suggestions for teaching these topics. Other sources for teaching and learning about the nature of science include, Science for all Americans (AAAS, 1990), Benchmarks (AAAS, 1993) and Standards (NRC, 1996). Evolution provides a historical context for biological questions and explains life’s diversity and relatedness among organisms. Teaching about evolution further allows educators an opportunity to illuminate the nature of science and science as a way of knowing.

In order to analyze the claims raised by advocates of creation science and to make clear some of the key aspects of supporting evidence for evolution, the National
Academy of Sciences (1999) has published *Science and Creationism*. This publication is intended for a broader audience and is intended to inform the audience of the case against teaching religious concepts in science classes. Topics covered include the nature of science, human evolution and evidence supporting biological evolution.

There are problems facing teachers who are supposed to implement the Benchmarks and Standards to guide their work toward authentic science (Chiappetta and Felske, 2000). Researchers are still trying to clarify what exactly the nature of science (epistemology of science) is (Anderson, 2000; Chiappetta and Felske, 2000). Anderson (2000) talks about the “epistemological texture” of science; that is, science consists of many disciplines each with its own broad organizing categories. But what domain knowledge will be used to frame nature-of-science test questions and curricula, and which science skills/ways of knowing will be selected? Various authors have proposed different conceptual frameworks for the nature of science statements extracted from reform documents (Cummins, 2000; DeBoer, 2000; McComas, 2000; Lederman, 2000).

**Worldview Research and Student Belief Systems**

Within the neo-Piagetian cohort of contextual constructivism, “worldview theory” has been receiving quite a lot of attention among science educators (Demastes/Southerland, 1994; Cobern, 1993; Jegede, 1991; Ogunnyi, 1988; Ogunnyi et al., 1995). Worldview has been defined in various ways by science education researchers. Cobern (1993) regards worldview as that which provides a non-rational foundation for thought, emotion and behavior. It provides an individual with presuppositions of what the world is really like, what is considered as valid, and
important knowledge of the world which cannot be reduced to a set of scientific conceptions or alternative conceptions about physical phenomena. Worldview is an aspect then of the learner's conceptual ecology. The worldview a person holds therefore becomes a filter through which he/she views the world.

Researchers have employed both quantitative and qualitative methods in their study of worldviews. The studies deal with cosmological ideas among science teachers and students (Ogunnyi, 1988), conceptualization of nature held by science teachers and students using concept maps and brief narratives derived from naturalistic inquiry (Ogunnyi et al., 1995; Lawrenz and Gray, 1995), the effects of socio-cultural beliefs on school science learning (Jegede et al., 1991), language and conceptual development in science, analyzing classroom discourse or textbooks to determine projected worldviews (Ogunnyi et al., 1995) and children's naive ideas about nature.

The important objective of these studies on worldview is to construct a working hypothesis with which to interpret different perspectives about the universe as they are and not what they should be. According to Cobern (1993) the underlying assumption is that the learning environment for science can be improved if the teacher is more aware of student worldviews as related to science. In his 1993 study, Cobern was intrigued by the apparent lack of influence on students' beliefs about nature even though they had been successful in college level science courses. This research raises important questions with regard to how different people recontextualize science.

Jegede and Okebukalo (1991) surveyed a total of six hundred secondary year-one students from fifteen different schools in Nigeria using the Socio-Cultural Environment Scale (SCES). The SCES is a 30-item instrument with five subscales,
namely, authoritarianism, goal structure, African worldview, societal expectations and sacredness of science. The BAT (Biology Achievement Test), a 50-item multiple choice test, was also administered as a covariate for the attitude change. The pretest-posttest experiment with both experimental and control groups was followed by interviews with a subset of the sample. The findings suggest that instruction in science which deliberately involved discussion of socio-cultural views about science concepts engenders positive socio-cultural attitudes toward the study of science. Jegede et al. (1991), tentatively suggest that the teaching of science using the socio-cultural mode as filter, serves to eliminate the mismatch between traditional ideas brought to the classroom and the scientific explanation of natural occurrences. Jegede considers the determination of students’ epistemological commitments prior to instruction indispensable, especially for learners within the non-western environment where socio-cultural impediments arise in the study of science.

Ogunnyi et al. (1995) identified appropriate categories for an instrument developed by Cobern (1993) to investigate the nature of the worldviews among a group of teachers from non-western cultures (Botswana, Indonesia, Japan, Nigeria, and Philippines). Teachers were asked to rate each of eight fictitious stories on a nominal classificatory scale. Their responses were grouped into four macrothought categories (magic and mysticism; metaphysics, parapsychology and pseudoscience; spiritism; rationalism and science). The results appear to corroborate earlier work; science teachers often hold inadequate viewpoints about the nature of science. They may have entered or left school with several understandings of the nature of science which co-exist and compete with, rather than replace, their worldview presuppositions; science
teachers from non-western cultures do not seem to make a clear demarcation between the scientific and non-scientific worldviews. By implication these views impacted their science teaching which could have served to impact their students’ inadequate notions of science. The findings serve to enrich baseline data for more detailed inquiry into how teachers’ worldview presuppositions might influence the form given to science during instruction. They also call attention to the issue of whether teachers make their students aware of the distinction between what they teach and what they (teachers) actually believe; if there is a difference then it can be assumed that their students will be able to switch from one mental state to another. The danger is that students may come away from science thinking that the scientific worldview is only an abstraction rather than a viewpoint relevant to everyday experience.

A study conducted with prospective science teachers at a South African University (Lawrentz and Gray, 1995) used the data gathering instrument based on Kearney’s model of worldviews. The questionnaire tested student teachers on their understanding of time and distance concepts, the impact of humans on the world, and past, present and future orientation. The results indicate that prospective science teachers have diverse views and that these views often do not incorporate science in the same way. Students’ conceptions of time and distance were nonmechanistic, psychologically bound and authoritarian scientific explanation were sufficient for proof. Their worldviews were related to the course taken (physics or biology major) and home location variables. They recommend that science educators need to be more aware of differences in worldviews and they should structure instruction so as to encourage the recognition and discussion of these views.
Dagher et al. (1997) surveyed 62 biology majors at a private university in Beirut, Lebanon (where English is the language of instruction) about their understandings of the major principles of evolution, whether evolution presents a conflict between science and religion, and whether or not the theory of evolution clashed with their own beliefs.

Their essays were summarized and 15 students were subsequently interviewed to clarify their answers. The study can at best be described as a “snapshot” qualitative study. They found that students had difficulty in accepting scientific evidence for the theory and students' views of science may be intricately connected to religious worldviews. The findings concur with that of earlier studies. Answers yield 27 principles of evolution with “natural selection” and survival of the fittest” being the most frequently mentioned. Many misconceptions were apparent (e.g., “Ape evolved to man”; “Evolution is basically the evolution of man”) and also metaphysical explanations (e.g., “God laid down the basic principles of nature...evolution is an adaptation of these.”).

Answers to question 2 were collapsed into 4 categories: 1) accepted evolution using arguments from an evolutionary or reconciliatory perspective; 2) rejected evolutionary ideas, presenting arguments from a creation or anti-evolutionary perspective; 3) reinterpreted the theory arguing from a compromise perspective (selective); and 4) neutral, espousing either non-committed or confused perspective.

The objections were classified into four themes: conceptual difficulties, alternative interpretations, nature of science, and nature of religion issues.

They concluded that students viewed evolution as a “theory” and not a law; this underscored its speculative nature in their reasoning. Good understanding of the theory
of evolution does not lead to its acceptance. The authors recommend that instruction include discussion of these alternative viewpoints in order to help students resolve their conflicts and prevent students from compartmentalizing their thinking which prevents them from integrating their knowledge.

**Summary of the Literature Review**

In their groundbreaking study linking conceptual change theory with the learning of evolution, Bishop and Anderson (1990) noted that learning this topic is a very difficult process. Subsequent studies support this assertion (Demastes/Southerland, 1994; Demastes/Southerland et al., 1995; 1996).

The presence of other forms of cognitive restructuring (incremental and dual constructions) illustrate a need for research to investigate the patterns of conceptual restructuring within other theoretical frameworks both in biology and other science disciplines. Possible questions which are identified as possible areas for research are: Are these patterns exhaustive of all conceptual restructuring of major organizing conceptions? Are the patterns of change identical for both minor and major conceptions?

With regard to the way instruction aids integration of conceptions, further research is need to identify related (leads to cascade change and requires sequential teaching of these concepts) and independent conceptions in order to devise the most appropriate means of instruction.

Students’ use of teleology and anthropomorphism remains the least well understood facet of students’ conceptions. The means through which teleology and anthropomorphism influence the construction of conceptions remains unclear.
Science has both a product (substantive structure) and process (syntactical structure - the means by which knowledge is generated). Syntactic knowledge entails knowledge of the nature of science (Rudledge & Warden, 2000; Schwabb, 1978). The relationship between nature of science knowledge and understanding of evolutionary concepts should be researched further so that practitioners can evaluate the importance of teaching about the nature of science (and nature of evolution) when teaching evolution.

The application of conceptual change theory to the content area of evolution is in need of research to further explore the limitations of the theory. Research in the evolution laboratory can provide us with insights into the impact of evolution laboratory activities and instruction on conceptual change.
CHAPTER 3: MATERIALS AND RESEARCH METHODS

Chapter Overview

The chapter consists of three sections. Section one describes sampling procedure and procedures followed to obtain exemption from oversight. The final item in this section explains the development of the survey items, the testing of the survey items, and the validation of the items through the pilot study.

Section two deals with the description of the courses, the students, the instructor, the graduate assistant and his role, and the research settings. The rationale for the design of the study, the quantitative and qualitative methods used, and data collection procedures followed are also discussed in this section.

The final section describes the data analysis techniques used to analyze data. The quantitative data analysis methods, such as descriptive data analysis and Independent Means t-test procedure are described. The qualitative data analysis procedure (content analysis) used to analyze interview data and survey data is also described.

Section One

Sampling procedure

The population was a group of college students enrolled in the 3000 level evolution lecture course and laboratory course. Both courses were taught by the same instructor. There were approximately 25 (18) at the end of the semester) students enrolled for the laboratory course and lecture course simultaneously, and 62 enrolled for the lecture course only. In total, the courses together consisted of eighty students at the end of the year as a result of some students dropping out.
The pre-test survey (Appendix D) was used to assess the students' conceptions of evolution at the start of study. This was a whole-class survey.

To ensure maximum variability, extreme groups sampling was utilized to yield the sample (8) for more intensive study. The design for this study was a quasi-experimental design; extreme group sampling substitutes for random sampling (Gall, Borg and Gall, 1996). Based on the survey responses, three students from the upper end and three from the lower end of the lecture and laboratory courses (12 participants in total) constituted this sample. However, 4 students resigned from the study at different stages of the study, and therefore the final number of students in the interview case studies was eight. The upper end included students who used more scientific explanations on the survey, while the lower end consisted of students who used more non-scientific explanations on the survey. The upper limit students scored above 20 (N = 28) and the lower limit students scored below 15 (N = 28) on the pretest survey.

Description of the pilot study

The pilot study was conducted at a small, public southeastern college in Louisiana. Participants were a combination of freshmen and older students who were enrolled either for the laboratory course (6 participants) or for both the lecture and laboratory courses simultaneously (20 participants). Four of the six laboratory course students previously completed the lecture course. The pre-test was administered prior to the course on evolution and the post-test followed 3 weeks later. The purpose of using this group of participants was to test the survey instrument and to get feedback about the survey from the participants. In the main study, however, the lecture and laboratory course students constituted the experimental group. The lecture-only
students constituted the control group. The survey is shown in its revised form in Appendix D. Findings from the pilot study are included in Appendix C.

Adjustments were made to the instrument after discussion with the researcher's major professor. The following changes were made to the instrument and the final form of the survey is contained in Appendix D. Items in the instrument were checked carefully for the way they were worded. Redundant wording was removed from items and the researcher made sure to avoid asking two questions in one item (e.g., items 2 and 3 dealing with mutations are now separate items). Some items were revised or removed, e.g., "The end product of evolution is perfection" was replaced with "Humans are more perfect life forms than lower animals". Item 12 on the original survey was made clearer. The researcher added item 11 to identify how "Darwinian fitness" is defined by students. The researcher added "Darwinian fitness" to item 12 so that students can distinguish between this and the common usage of the word "fitness". Item 20 was added to assess students' understanding of how traits became established in populations. Item 19 looks at how the trait originated. Students in the post-test were reluctant to explain their choices and left that area blank.

The final version of the pretest/posttest survey instrument contained 29 items. The items were two-tiered and students were instructed to select the correct answer on an agree / disagree basis. They were also instructed to provide a reason for their choices in the space below each choice.

Development of the survey

The survey items were a combination of items from two validated tests, namely, the Bishop and Anderson Exam (1985), and Lawson and Worsnop's Questionnaire,
Assessing a Belief in Special Creation or Evolution and Related Beliefs (1992). Some items were adapted from Science and Creationism (NAS, 1984) and McComas’ (1997) fifteen myths about science (nature of science items).

After the content analysis (Lincoln and Guba, 1985) of the pilot study’s open-response data, it became clear that the responses to the items on the survey could be grouped into four categories. The items for each category were dispersed throughout the survey for the pilot study and the main study.

Nature of evolution items

Items 1, 5, 8, 13, and 15 indicate respondents’ opinions about Evolution and items 22, 24, and 28 looked at whether or not it has a valid scientific foundation. These items were also designed to explore whether respondents consider Evolution to be in conflict with their personal and/or religious beliefs. Item 28 refers to the age of the earth; a very old earth (about 4.5 billions years) is required for evolution to have occurred. The alternative conception is that the earth is young; the creation story puts the age of the earth at about 4000 years (NAC, 1999). Item 24 also elicits students’ "acceptance" of either evolution or creationism (Lawson and Worsnop, 1992).

Evolutionary conceptions

Items 2, 3, 11, 12, 16, 18, 19, 20, 21 and 25 were designed to elicit alternative conceptions for evolutionary concepts. Items 11 and 12 deal with the concept “fitness”, that is, Darwinian or genetic fitness. Item 11 was included to afford students the opportunity to identify the alternative conception for “fitness”. According to Bishop and Anderson (1985), item 12 is included for two reasons: to assess their understanding of the word “fitness” as used in evolutionary terminology and to illustrate their
understanding of evolution as a whole. George would be selected by students operating within a naive definition of “fitness” because he was described as healthy, big and strong. Ben would be selected by students who understand that fitness refers to breeding success or longevity. They fail to understand the importance of offspring survival with comments like: “He had the most females”, “he had the largest number of offspring. Sandy is the ideal answer because according to the definition of genetic “fitness”, the concept refers to an organism’s ability to produce surviving offspring.

Items 2, 3, 16, 19, 20 and 21 aim to elicit students’ understanding of the origin and survival of new traits in populations, the role of variation within a population, evolution as the changing proportion of individuals with traits (that is, the differences in breeding success- “faster cheetahs produced more offspring”). The items also would help identify conceptual problems with the concept “adaptation”, the misunderstanding regarding the role of the environment, Lamarckian (use/disuse), teleological (purpose) and anthropomorphic understandings of natural selection and the incorrect conception that the quality of the trait changes from generation to generation (“over the years cheetahs got faster and faster”). Items 19 and 20 focus on the concept of change in trait over time, students’ understanding of mutations, and how traits appear by chance (i.e., mutations occur by chance - items 2 and 3). The incorrect alternative conception that an environmentally imposed need for a trait will influence the appearance of such a trait was also tested. The environment played a role in determining the survival of a trait.

**Evolution and humans**

Items 7, 9, 10, 17, 23, and 29 make reference to how evolution might have affected humans. Items 7 and 23 are anthropocentric in nature. This is a common
misconception (Dagher et al., 1997). Item 9 elicits students’ understanding of genetics and evidence from biochemistry which supports evolution. Items 10 and 29 (Lawson & Worsnop, 1992) are regarded as anthropocentric responses. Item 17 suggests that humans evolved from apes; this is also a common misconception (Dagher et al., 1997) and is held because the student fails to understand that they have a common ancestor and apes did not directly evolve into humans.

Nature of science

Items 4, 6, 14, 26, and 27 test students’ understanding of the Nature of Science (McComas, 1997).

The laboratory course stressed some of these concepts and others not included in the survey instrument. It was the researcher’s aim to look at conceptual change for basic evolutionary concepts like natural selection, adaptation, and mutation.

Permission for study

The researcher and her major professor took the necessary steps to obtain permission to conduct this study with human subjects from the Office of the Dean of the College of Education before proceeding. Permission to conduct the study was granted before the commencement of the pilot study in the Summer of 1998 (Appendix B).

Students in the pilot study and main study were informed of the purpose of the study, they were made aware of their right to withdraw from the study at any time, and were asked to sign a consent form. To maintain confidentiality, pseudonyms were used for the participants in all records, the researcher’s journal, transcriptions and the dissertation. The researcher compensated the interview participants ($5 per interview) for their time spent in interviews (Appendix A).
Validity and reliability

Validity: a quantitative perspective

The instructor who taught the courses in the main study reviewed the survey instrument and confirmed that it had face validity; that is, it appeared that it would measure what it claimed to measure. Two introductory biology students and one graduate student, also confirmed face validity after reviewing the survey. According to Isaac and Michael (1995), face validity in conjunction with other measures of validity (e.g., content validity), reinforces the overall acceptance of an instrument. In the pilot study, the survey was administered to Biology majors (freshman) and retested with the same group three weeks later.

Content validity (a measure of judgmental validity), of the survey instrument was determined by experts in the fields of evolution and science education. They looked at how well the content of the test was related to the research questions and conclusions that were to be drawn. The following people determined content validity: The instructor of the courses used in the pilot study; the graduate assistant/assistant curator who assisted in both courses used in the main study; and a science educator, the major professor for this study. Each of the raters was asked to rate the items on the survey as irrelevant or relevant. The proportion of items that received a high rating were determined by the researcher. Items which were not agreed on were eliminated from the final version of the survey. Other items were revised and badly worded items were also revised. The specific items and the revision of the survey instrument are mentioned under “Description of the pilot study” and “Development of the survey”. Content validity for each item and for the survey instrument as a whole, was established

44
before the start of the main study. The necessary suggestions were noted and taken into account when the researcher made adjustments to the survey instrument.

From a quantitative perspective, some of the threats to inference quality (internal validity) of the research findings, were history and attrition. This was of concern because the researcher would be working with a small number of students for the interviews. The researcher asked students to sign an informed consent form which spelled out clearly their role and responsibilities, the importance of the study, and also their right to withdraw at any time.

Reliability: a quantitative perspective

The surveys were scored by assigning a value of one for a correct answer, and a value of zero for an incorrect answer. The internal-consistency of estimate of reliability of the final twenty nine point pretest/postest survey (Appendix D) was tested by subjecting the posttest scores of the whole class (N=28) to the Kuder-Richardson formula 20. This formula was used because responses were coded on an agree/disagree basis. The correct or appropriate response was scored with the numerical value of one; the incorrect/distorter was assigned a numerical score of zero (Isaac and Michael, 1995). The estimate of reliability for the entire survey was 0.825. Therefore, the reliability (internal-consistency) for the entire test was high (Huck and Cormier, 1996).

Issues of reliability & validity: a qualitative perspective

This study included the collection of qualitative data by means of the survey instrument. The concept “trustworthiness” (incorporates four criteria: credibility, transferability, dependability and confirmability) was introduced to substitute for quantitative design and measurement issues (Lincoln and Guba, 1985; Tashakkori and
Confirmability has been identified in the research literature as the most important component in establishing trustworthiness of results /inferences. To avoid the threats to the validity of the study as a result of the possible roles the informant/respondent can assume ("good", apprehensive, negativistic, suspicious informants), the researcher was able to build relationships of trust with the interviewed students through prolonged engagement with the participants (Tashakori and Teddlie, 1998). The researcher attended the lectures and all laboratory sessions.

Triangulation (that is, data sources, methods, and the use of co-raters/co-observers) and referential adequacy (e.g., adequate storage of audio tapes of interviews) contributed to the credibility of the study. The researcher was involved in this study as a participant observer. The role of the participant observer is described as an active participant in the natural setting and in the interpersonal environment of the unit being observed. Reliability (measurement) or consistency was further enhanced by interrater/interjudge agreement (Tashakkori and Teddlie, 1998). The instructor who taught both lecture and lab courses, is an expert in the area of evolutionary biology. He and his graduate student (schooled in the area of evolutionary biology) rated the data for each student (quantitative and qualitative) included in the summaries of the surveys, interview transcripts, examination scores, and final grades. Each student’s data were reviewed and analyzed by two raters. There was a high degree of agreement between raters for the data analyzed.

Thick description (detailed description of all information) was followed throughout this study and was facilitated by the daily entries in the field journal and by participant observations. Thick description, according to Tashakkori and Teddlie
(1998), is close to the idea of "external validity" of inferences/conclusions. It facilitates replication of the study and is a way to ensure against researcher bias.

Finally, entries were made into the field journal (reflexive journal) regarding methodological shifts, meetings, ideas, and the thinking behind decisions the researcher made. This journal contributed to the overall trustworthiness because it provided information for all four criteria (Tashakkori and Teddlie, 1998).

Section Two

The description of the main study

The pretest survey was administered to the whole class, including those enrolled simultaneously in the Evolution Laboratory course, at the end of August, 1998. Students were informed in a previous lecture of the study and its purposes, and the professor introduced the researcher on more than one occasion to the class. The instructor and his graduate student posted a message on the class homepage on the internet to remind students of the date for the pretest (Hafner, 1998). The professor was out of town for that particular week, and offered the assigned lecture time for administration of the pretest survey. In this study, the pretest survey was initially intended to differentiate between high and low scorers, as a source for selecting students for the interview phase of the study, and as a main posttest instrument.

The interviews were conducted to answer research question 2:

What patterns of conceptual change can be observed in college students and what differences are observed for participants in the lecture-only and the lecture-laboratory groups?

At the presentation of the prospectus to the doctoral committee, it was decided that since the design of the study (the quantitative section) is essentially a quasi-
experimental design, the survey was probably not sufficient for answering research question 1, namely:

What do the whole class data reveal about the overall difference in conceptual change between the lecture and laboratory course groups, and the effect of laboratory learning on their understanding of evolution?

The additional posttest data source was therefore recommended. The instructor included items in the final examination to enable a better comparison between the lecture-laboratory and lecture-only groups. These were identified and prepared by the instructor and were items which he expected the lecture-laboratory participants to perform better on than the lecture-only group. The researcher was an active participant in the classes and therefore did not see the objective final examination before the students sat for the examination. The posttest survey was conducted with only 28 students and was regarded as an additional data source for answering questions about conceptual change. It was also a data source to answer research question number 3:

How does an understanding of the nature of science relate to students’ conceptions of evolutionary concepts?

The courses and the research setting

The study was conducted with students in two 3000-level courses, namely, Evolution Lecture course (BIOL 3040) and Evolution Laboratory course (BIOL 3041). The lecture course was a three-credit course and the laboratory course, a one-credit course. Lectures were held three times per week, Monday, Wednesday, and Friday at 11.30 am to 12.30 p.m. The labs were held once weekly on Tuesdays from 6 p.m. to 9 p.m. Students were enrolled for the lab course on a first-come-first-served basis. The lab course was partly computer-based and students were encouraged to access the homepage in order to keep up with course announcements.
The lecture course is described in the syllabus (Appendix G) as a course on evolutionary biology that uses plant and animal examples to illustrate and clarify fundamental concepts in evolution. It concentrated on basic mechanisms and theory. The course examined the contributions from the history of evolutionary biology, as well as more recent contributions to the understanding of evolution. The professor stressed the understanding of evolution as the unifying concept in biology and he also emphasized the nature of science in the lectures and lab sessions. The lecture course required additional reading from Charles Darwin’s (1859) The Origin of Species, namely the chapters titled Natural Selection and Recapitulation and Conclusion. Another textbook was Mark Ridley’s (1995) Evolution. The chapters from this book are noted in the course syllabus.

Students wrote two, one-hour exams during the semester (2 times 100 points) and sat for a comprehensive final examination (200 points) at the end of the semester. The examination questions were drawn from a question bank and the professor reserved the right to change details in the questions. He wanted students to work to understand the concepts underlying the questions and encouraged them not to try to memorize answers to questions.

The laboratory course is an adjunct to the lectures. The lab syllabus is in Appendix G. This course looked at processes of evolution rather than emphasizing evolutionary patterns. Therefore evidence for evolution and important processes of evolution were seen as integral to a full understanding of evolution.

In the lab course, students were getting a practical understanding of the principles and concepts covered during lectures. Seven of the twelve lab sessions
involved students directly in exercises and experiments. These hands-on activities involved students in stating hypotheses, data collection and recording (e.g., Laboratory 4: Biometry entailed the taking and recording of morphometrics data), they used computer software programs (e.g., Statview was used to analyze morphometric variability) to perform the computation of statistics, they made inferences based on the results, and drew conclusions. Simulation exercises included genetic drift, Natural Selection and biogeography (including factors such as dispersal and vicariance). The simple simulations and demonstrations also brought home the historical nature of evolutionary biology (Hafner et al., 1992). These helped to reinforce lecture concepts and clarify abstract evolutionary concepts which research literature shows even undergraduates fail to comprehend (Brumby, 1984; Bishop and Anderson, 1990; Wandersee, 1985).

In laboratory sessions students were actively involved in discussions and debates about ideas, issues and concepts of evolution. Discussion sessions required that students submit an argumentative essay prior to the discussion. According to the instructor, lab provides an opportunity to elicit misconceptions which can hamper understanding of evolution concepts. Students also had the advantage of direct feedback from the instructor and assistant instructor during lab sessions. Lab discussions included topics such as Evolution and Creation Science, Genetic Engineering and Eugenics, and Human Evolution (Appendix G).

Lab students got practice in writing reports and argumentative essays using a scientific format. Six of the labs which involved students in experimentation or exercises, required brief laboratory reports written according to the format provided in
the course manual. Student groups were graded using a rubric included in the manual. Two two-page argumentative essays were also written by each student prior to a discussion lab. The two discussion labs dealt with Genetic Engineering and Creation Science and Science. Students were given articles based on these topics a week prior to the lab. An example of the readings is the Stephen Jay Gould article, Evolution As Fact and Theory which was published in Discover, May 1981.

The instructor introduced concept mapping as a helpful learning tool to lab students. Concept mapping is a heuristic for teaching and learning to make overt conceptual understandings and linkages/relationships between concepts in a conceptual framework (Trowbridge and Wandersee, 1994; Wandersee, 1990; Hafner and Hafner, 1992; Hafner, 1998).

Prelab talks followed student prelab preparation and aimed to summarize the main focus of the lab session. Finally, postlab talks were scheduled when time permitted (that is, at the end of a lab session or at the start of the next lab session.

The course instructor

The instructor taught both BIOL 3040 and 3041. He has served as Director of the Museum of Natural History at the southeastern state university for over 10 years, and is also Curator of Mammals. He has taught at the institution since 1979 and he currently has a joint appointment in the Department of Biological Sciences and the Museum of Natural Science. The instructor's teaching philosophy and rationale for the laboratory course described in this study, are discussed in Hafner and Hafner (1992) in the EERC proceedings (Baton Rouge, Louisiana in 1992). His research focuses on vertebrate evolution, co-evolution, and systematics with an emphasis on mammals. He
employs a variety of molecular techniques (including protein electrophoresis and DNA/RNA sequencing) to investigate mammalian relationships and to compare rate and pattern of genetic differentiation in hosts and their parasites.

The instructor was interviewed informally on numerous occasions. The researcher consulted with the instructor before the start of the study to get his permission to use his class for the research. They met to discuss the logistics involved, and the researcher consulted with the instructor regarding the survey items (refer to content analysis above) and the final examination being used as a data source. They also discussed the objectives of the courses, his understanding of student conceptions, and ways in which he wanted to address these difficulties before the study began. The course instructor and his graduate assistant were also involved in the analysis stage of this study. They reviewed data for at least four students each, and provided the researcher with feedback.

The graduate assistant

The graduate assistant was pursuing his Ph.D. in evolutionary biology. He monitored all the lectures, taking roll call and assisting the professor in the lectures and the lab course. He co-taught some labs, helped to grade reports and essays, and presented prelab talks and postlab talks. Students consulted with him when they had queries both in the lecture and lab courses. He became a valuable resource and co-observer/co-rater for this study.

The research participants

The posttest instrument was the isolated items on the final examination which was written at the end of the semester. Eighty students sat for this examination.
Eighteen of the eighty were also enrolled for the laboratory course, BIOL 3041.

Twenty eight of the whole class participants responded to a request to complete the posttest survey, which was the same as the pretest survey. Seven of the latter were enrolled for the laboratory course as well. Five students from the lecture-lab group were selected for the interview stage of the research. Three students from the lecture-only group were selected for the interview stage.

**The interview participants**

The eight students who participated in the interview phase were five students from the lecture-laboratory course and three students from the lecture-only course. Four students who were supposed to participate in this phase dropped out before all the interviews were completed, therefore there was not an equal number of students in the two comparison groups. There was a diverse group of participants in the interview phase of this study. Minorities were well represented; four were women, two were African American (females), and one student was of Spanish descent. Their majors in college were Zoology (3), Biochemistry/Premed (2), Plant Biology (2), and one student was a Wildlife and Fisheries major. Their future plans included applied science careers, such as veterinarian, medical doctor, and emergency pediatrician. Four students intended to apply to graduate school to pursue studies in herpetology, evolutionary biology, marine biology and environmental chemistry. Table 1 includes the profiles of the eight students who were interviewed (pre- and posttest interviews were conducted).

The detailed calendar outlining research activities (Table 2) and their intersection with the syllabi for both courses (theory and lab), is included in Appendix M. More details about the interviews are included under “types of interviews.”
Table 1: Profile of interview participants

<table>
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<tr>
<th>Name</th>
<th>Gender</th>
<th>Group</th>
<th>Age</th>
<th>Ethnicity</th>
<th>Major in College</th>
<th>Future Career</th>
<th>Scientist in family</th>
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</tbody>
</table>
### Table 2: Summary of research activities

<table>
<thead>
<tr>
<th>Research activity</th>
<th>Date</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Conceptual Frameworks</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretest survey administered</td>
<td>August 31, 1998</td>
<td>Whole class</td>
</tr>
<tr>
<td>(Evolution &amp; the Nature of Science):</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature of evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evolution concepts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature of Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pretest Interviews:</strong></td>
<td>Week of 9/3-8, 1998</td>
<td>8 Interviewees (3 interviews per participant)</td>
</tr>
<tr>
<td>Open-ended (survey content; personal belief system; demographics)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structured:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interview-about-instances (species content; adaptation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interview about concepts (Evolution: patterns &amp; relationships)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prediction (genetics)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Conceptual Framework at Semester End</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posttest survey administered</td>
<td>December 12, 1998</td>
<td>Whole class</td>
</tr>
<tr>
<td>Evolution &amp; the Nature of Science:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nature of evolution and nature of Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evolution concepts and Human evolution</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Posttest interviews</strong></td>
<td>Week of 12/12-17, 1998</td>
<td>8 Interviewees (2 to 3 interviews per person)</td>
</tr>
<tr>
<td>Open-ended (survey content; personal belief system; demographics)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structured:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prediction (antibiotic; insecticide &amp; skin color variation problems, Brumby, 1984)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing Task ( timelines)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The study design was a quasi-experimental design which approximates the conditions of a true experiment in a setting which does not permit the control or manipulation of all relevant variables (Isaac et al., 1995; The Royal Windsor Society of Nursing Research (RWSNR), 2000). However, quasi-experimental designs introduce some controls over extraneous variables when complete experimental control is lacking. This study made use of the nonequivalent control-group quasi-experimental design (Gall, Borg and Gall, 1996; Huck and Cormier, 1996). Participants were not randomly assigned to the control group (lecture-only) and experimental group (lecture-lab). Both groups took the pretest and posttest as well as the final examination.

Quantitative procedures

The pretest instrument (Appendix D) was administered to select the participants for the interview phase of the study (to answer part of research question 1). The posttest instrument consisted of the isolated final examination items. Examples from the examination items are included in Appendix I. The posttest survey was an additional data source. The survey was completed by only 28 of the 58 people who had completed the pretest survey. The survey was administered to estimate conceptual change for students in the lecture-laboratory and lecture-only courses (to answer research question 1). The survey (pretest and posttest) items were grouped into four sections, namely, nature of evolution, alternative conceptions, human evolution, and the nature of science concepts (to answer research questions 1 and 3).

Qualitative procedures

The survey contained both close-ended and open-ended responses; respondents were encouraged to explain the choice (agree or disagree) they made. This provided the
researcher with an opportunity to assess the reason for the choice and to obtain more accurate pictures of students’ understanding. This also minimized guessing. Interviews were conducted at two intervals at the start and at the end of the semester. Interview participants were interviewed on average three times at each interval. Students were encouraged to “think-aloud” (Ericcson and Simon, 1980) during the interviews (e.g., during the drawing task and the sorting interview). Five of the interview participants were lecture-laboratory members and three were lecture-only members.

Interview types included the clinical (open-ended) interview, sorting interview, drawing task interview, and the prediction interview. The researcher developed profiles of respondents by comparing interval interview data analyzed inductively (to answer primary research question 2). The researcher audited the courses and was involved in the study as a participant observer.

Types of interviews

Open-ended interviews

Open-ended interviews were conducted first and follow-up interviews were scheduled. The initial interview questions were based on the survey questions. Further questions were developed as the study progressed and necessarily came out of previous interviews. According to Isaac and Michael (1995), open-ended interviews allows the participant a frame of reference with which to react, it allows flexibility, clarification, and probing. It might also allow unexpected responses which might reveal significant information.

In this study, these interviews were used to establish a rapport with the students and to clarify their answers in the pre-test questionnaire. Student demographics and
personal information were also gleaned from these interviews. Subsequent interviews concentrated on clarification of previous interview data.

Structured interviews

Each of the students who participated in the interviews was involved in structured interviews similar to the clinical interviews (Lythcott and Duschl, 1990).

In the first type of structured interview students were presented with a series of pictures and they were asked questions pertaining to these pictures. This technique is referred to as an “interview about instances” (White and Gunstone, 1992). It is a useful technique providing a description of the students’ ability to recognize or use a concept and has also been helpful in detecting alternative conceptions of students (Appendix H). It checks whether the student is able to explain his/her decision as well. In this study, photographs and line drawings were used.

The second type of structured interview was used to investigate specific areas including (a) the use of typological species concepts, (b) their understandings of phylogeny, (c) their species concept, and (d) their conceptions of the patterns of evolutionary change (refer to Appendix H). This technique is called “interview about concepts” (White and Gunstone, 1992). It is designed to allow the interviewer to bring out the knowledge a student has about a particular concept.

The third type of structured interview, prediction interviews, assessed students’ abilities to predict the outcome of an inheritance event and a mutation event. White and Gunstone (1992) explain that this technique is more direct than other structured interviews in revealing understanding, because it distinguishes between rote and meaningful learning while assessing the students’ ability to apply the concept. In this
interview the student was presented with a graphic and an explanation of a situation or a problem (Brumby, 1984). Then the student was asked to form a prediction of the outcome and provide a verbal explanation of the prediction. In addition, the technique makes obvious the effects of theories and beliefs on the students’ observations of the graphics and problems (Appendix H).

In the fourth type of the structured interview, the sorting task, the student was shown a series of graphics which displayed the various occurrences in an evolutionary event driven by natural selection. Students sorted the cards and expressed their understanding of the evolutionary process by using the think-aloud interview technique (Ericsson & Simon, 1980). The technique allowed the researcher to investigate the factors the student viewed as necessary for evolution driven by natural selection. The giraffe sorting task required students to differentiate between Lamarckian inheritance of acquired characteristics, and Darwinian natural selection. The graphics used were adapted for this task from Hoagland and Dodson (p. 215, 1995).

In the drawing task interview, students are encouraged to draw or record their thoughts in whatever form they wished (graphic organizers, concept maps, drawings etc.). In the posttest interview students were requested to draw timelines to depict the history of life on earth. The individual timelines are discussed Chapter 5 and are found in Appendix L (redrawn from the original timelines. The drawing task give participants the freedom to “reveal qualities of their understanding that are hidden by other procedures” (White and Gunstone, 1992). According to White and Gunstone (1992), “drawings tap holistic understanding. They allow expression of attitudes or feelings as well as cognition (p.104).” In this way the researcher is able to develop a holistic profile of the interviewed participant.
Observations

The role assumed by the researcher in the natural setting of the person or people being studied is categorized as participant observer, complete observer, observer participant, or complete participant (Patton, 1990). The role assumed by the observer in this study can be characterized as a fluid continuum as the assumed the role of participant observer. This was inevitable; the researcher was in classes and laboratories during the whole semester, and was regarded by the other students as a course member. Lengthy observations enabled the researcher to establish a rapport with the students. The observations helped to establish trustworthiness and credibility of the inferences drawn from the data; that is through prolonged observation and persistent engagement (Patton, 1990; Tashakkori and Teddlie, 1998). In the beginning her role was closer to that of complete observer or onlooker as she surveyed the situation. At the end of the study the researcher assumed this role again. Observations also helped the researcher to select the content for subsequent interviews. The researcher also collected artifacts from the research study for later analysis, namely laboratory reports, student examination scripts, lecture and laboratory handouts, and journal articles.

Observation notes

Observation notes contain a description of what has been observed. If the information has been important in helping you understand the setting, and what went on, it should be entered into the observation notes as soon as possible. Observation notes need to be descriptive. The words used must not be interpretive in the sense that they conceal what actually went on rather than reveal the details of the situation. The notes are a written account of what the researcher hears, sees, experiences and thinks in
the course of collecting and reflecting on the data in a qualitative study (Bogdan and Biklen, 1992). These notes can also contain direct quotations of people or close approximations. The quotations come from what people said during interviews, both formal and informal; they allow for the insider’s perspective on reality to be voiced.

The field notes can have two purposes (Patton, 1990):

• Notes taken during interviews can help the researcher formulate new questions, especially when more clarity is sought as the interviews move along.

• During interviews, note-taking acts as a cue to the respondent, and is a non-verbal behavior which can determine the pace of the interview.

Observation notes helped the researcher to reconstruct events, e.g., particular activities or discussions during labs or lectures, interviews. The observation notes were a source for data triangulation, lending more credibility to interviews. This ensures credibility of inferences drawn from the data by triangulation and thick description (Tashakkori and Teddlie, 1998).

Field journal

The field journal involves a narrative description of the activities of the research day. It allows for reflection on the part of the researcher and is more personal than the observation notes. Events, initial analysis, feelings, biases, ideas and attitudes recorded in the journal. The journal allowed the researcher an informal means of reflecting on the method(s) of data collection and analysis, changes implemented, and the researcher’s attitude toward the research (Bogdan and Biklen, 1992). This became a valuable source of information for the researcher as she started the writing process, and
during the research as well. The researcher also recorded the names of people who were invaluable to the research process and dated all entries. Discussions on method and procedure for data analysis and other discussions with the major professor were also recorded in the journal. These entries were crucial to the development of the dissertation.

Section Three

Data Analysis

Data analysis of the original Bishop and Anderson test (1985) is problematic because it does not reflect students’ use of alternative conceptions for a conceptual issue; it only provides information on students’ use of scientific conceptions. Demastes/Southerland (1994) used a scoring method which provided a better way of learning about students’ alternative and scientific conceptions. This proved to be useful in my study. In this method students’ conceptions are first categorized (for example, into teleological explanations, the species concept, the unit of evolutionary change) and then analogous pre- and posttest conceptions are compared for each category so that the pathway of conceptual change can be described.

In this study, concepts were categorized into categories, namely the nature of evolution and the nature of science, evolutionary conceptions (including species concept, natural selection, unit of evolutionary change), and human evolution. In the initial pre-analysis stage, the pretest was scored (1 for the scientific concept and zero for the non-scientific concept) and scores were tabulated to give a picture of students’ initial conceptions which facilitated the selection of a sample for the qualitative study.
(interviews). The posttest surveys were scored the same way. Fifty-eight students completed the pretest survey. Only those students who completed both surveys were included and the total number of surveys for this study was twenty eight. The lecture-only students who completed the surveys totaled twenty one (about one-third of the total number) and only seven lecture-lab students (less than half of the total number) completed the survey. The survey results were used to make preliminary inferences about the effect of the laboratory on students’ understanding, but also to provide insight into student conceptual change as a whole (namely, “implications for conceptual change”, contained in the title of this study). The interview results elaborated on this in more detail.

The isolated items on the instructor-developed final examination, were scored as indicated in the final examination (Appendix I). The final examination items (posttest instrument) were data sources to answer research question 1. The results from this data source were intended to assess the effects of the lab on students’ understanding of evolutionary concepts (that is, the first part of the title of this study).

Qualitative data analysis

The interviews were transcribed and data triangulation was ensured by making audio recordings of the interviews and collecting hard copies of the drawings (timelines), and artifacts related to these interviews. In this way data collection and analysis were both ongoing.

The Constant Comparative Analysis associated with Lincoln and Guba (1985) was used to conduct content analysis of all the data sources for each student. This method involved unitizing and categorizing the transcripts and then establishing
coding categories for the data. The latter emerging themes were determined during the pilot study stage of the research study, that is, nature of science, evolutionary concepts, human evolution and nature of science. The NUD*ST software program (Roberts and Roberts, 1996), which was originally to be used to analyze qualitative data, was eventually not used in this study. The researcher decided to substitute the Lincoln and Guba (1985) method because, after coding the data for each student, it became clear that using the software would be somewhat repetitive. The researcher was able to trace students' conceptual change adequately without the software.

In this way a fluid profile of the students was developed as they developed and changed explanations during the period of the research. By constructing an individual conceptual profile inventory for evolution for each student based on the emerging themes, the researcher was able to compare and document conceptual change at the end of the semester. A conceptual inventory profile worksheet was developed for each participant in the comparison groups (lecture only and lecture-laboratory). In this way the researcher was able to compare and contrast students from each level.

Time frame

Longitudinal, panel studies allow for a fuller understanding to be gained and it entails following the same subjects over an extended time frame (Gall et al., 1996). To establish a rapport with participants and to provide an opportunity to do a longitudinal study, the researcher was actively engaged for an entire semester with students in both lecture and laboratory courses. The researcher was assigned to a lab group and participated in the experiments, writing of the lab reports and discussions held in the lab. The pre-test survey was administered on August 31, 1998 during one of the lecture
periods. Interview participants were selected following analysis of the survey data. The preinstruction interviews with individual participants followed as soon as students were available (within the first week of September, 1998). The post-test survey was administered on the same day (December 12, 1998) as the final examination. Posttest interviews were conducted the week of the final examination and three posttest interviews were conducted the week following the examination. Details of the lecture and laboratory courses are outlined in the calendar (Appendix M) and in detail in Appendix G. The interviews and survey dates are also indicated in the calendar.
Chapter Overview

Chapter 4 contains the descriptive statistical analysis of pretest and posttest data, and the results from the independent means t-tests for the isolated items on the objective final examination. These results answer research questions 1 and 3. That is, the patterns of conceptual change for the whole class (research question 1) is reported in this section. Results for research question 3, which reveal the relationship between the nature-of-science knowledge and understanding of evolutionary conceptions, are also reported.

Whole class conceptual change

The whole class conceptual frameworks were arrived at by adapting the scoring method proposed by Demastes/Southerland and Good (1993) and Demastes/Southerland (1994) which allows for categorization of students’ conceptions and comparison of pretest and posttest conceptions. In this way, conceptual change pathways are made visible and can be described. The conceptual grouping proposed by the above method is retained and includes also other conceptions relating to evolution. These concepts are: the species concept, the unit of evolutionary change, and the origin and of new traits. Other concepts included in the analysis of data sources were: nature of science and nature of evolution, evolutionary conceptions, human evolution, natural selection,* allometry,* phylogeny,* and biogeography* (* indicates the concepts covered in the isolated examination questions which would be used to compare lecture and lecture-laboratory groups).

This study included examination of students’ alternative conceptions which could interfere with the understanding of the major concepts mentioned above.
In this way the researcher hoped to shed further light on patterns of conceptual change which other studies have brought to our attention (Bishop and Anderson, 1990; Demastes/Southerland et al., 1995; Demastes/Southerland et al., 1996; Southerland, 1997). This section will answer research question 1.

Species concept

Item 18 on the survey demonstrated that students generally held a typological species concept. This indicates that they understood “species” to be defined in terms of similar characteristics or traits. It also implies that they did not understand that a population consists of a group of individuals and that variation exists among them. In other words, they were unaware of the significance of variation. The cheetah problem (item 21), the definition for “species” (item 18), and duck webbing problem (items 19 & 20) on the surveys illustrate students’ use of the typological species concept.

Lecture-lab participant (cheetah problem): Maybe a change in prey caused the necessity for all the cheetahs to get faster.
Species item: More often than not species are very similar phenotypically and genetically.

The two comparison groups showed a shift in this concept from non-scientific to the scientific conception, the variable species concept.

Lecture-only participant: The cheetahs whose muscles and bones were built at running later made those animals better at capturing their prey (were faster), surviving to reproduce this trait would spread through the population after many generations and selection acting on them.

The two groups performed equally well in this shift, with the lecture-only group shifting from 38% on the pretest to 67% on the posttest, and the lecture-lab group shifted from 40% to 71% (figure 1). Other authors have reported that the alternative conception in this case prevents the student from constructing a scientific conception of
natural selection (Bishop and Anderson, 1990; Demastes/Southerland et al., 1996).

Student responses are included in Appendix K.

**Unit of evolutionary change**

Students who were generally not using the variable species concept were not understanding the importance of variation, or the unit of evolutionary change. This concept appeared to be a difficult one for both the lecture-only and the lecture-lab groups to understand. The lecture-only group did not perform very well on the items on the survey which tested for this concept (the cheetah problem, duck webbing problem, and the cave salamander problem; Appendix D). It is noteworthy that two conceptions were identified for the unit of evolutionary change. The first conception was that evolution of the trait occurred in all individuals.

Lecture-only participant (cheetah problem): Their bones and muscles adapted to allow the population to run faster.

The second conception among the participants was that evolution changes the proportion of the population or species with a specific trait. This is the scientific conception. A lecture-only participant was able to answer the conception correctly:

Lecture-only participant (Cheetah problem): The cheetahs whose muscles and bones were better built; this made them better at capturing prey, surviving to reproduce, feeding their offspring which would have the same genes. The latter would be more fit, and this trait would spread throughout the population after many generations and selection acting on it.

Students in the lecture-only group moved toward the alternative conception for the unit of evolutionary change. The lecture-lab group moved toward the scientific concept (biological species concept).

When her species concept was analyzed, it was clear that she held a biological species concept. She had the following to say about this concept:
Figure 1: Comparison of pre- and posttest scores on the species concept for lecture-only and lecture-lab groups
(Lecture-only N=21; Lecture-lab N=7)

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Mayr's biological species concept: while members of a species may have similar traits, the important thing is whether they are able to produce fertile, viable offspring.

Figure 2 illustrates the pre- and posttest conceptions of the lecture-only group for the unit of evolutionary change, and figure 3 that of the lecture-lab group. The lecture-only group shifted toward the alternative conception (from 58% to 32%), and the lecture-lab group improved from 27% to 57%. Only 29% held the alternative conception; that is, the whole population is the unit of evolutionary change. Forty-seven percent in the lecture-only group held the alternative conception.

Two participants in each of the comparison groups selected the individual as the unit of evolutionary change. One participant in the lecture-only group retained this alternative conception, and one in the lecture-lab group also retained this conception. One other participant in the lecture-lab group selected the individual as the unit of evolutionary change on the posttest. The individual as the unit of evolutionary change is not represented in figure 2. Selected student responses related to this conception are included in Appendix K.

Origin of variation

Figures 4 and 5 compare the two groups on their conceptions for origin of variation. Responses for the origin of variation were grouped in the following categories: need (teleological), use/disuse (Lamarckism), mutations, and other. Selected student responses for each of these categories is included in Appendix K.

In the following example, need is built in as a mechanism for evolutionary change or as a source of new traits.

Lecture-only participant (cave salamander problem) The eyes were not needed therefore they became (over time) non-functional.
Figure 2: Lecture-only participants' (N=21) conceptions for the unit of evolutionary change. (Note: The total percentage does not add up to 100; those alternative conceptions which were not held by a large number, were excluded.)

Figure 3: Lecture-lab participants' (N=7) conceptions for the unit of evolutionary change. (Note: The total percentage does not add up to 100; those alternative conceptions which were not held by a large number, were excluded.)
The student held a typological species concept. This student shifted to a use/disuse mechanism after instruction. The cheetah problem was answered in a similar way. Fourteen percent of the lecture-only group held this conception; this shifted to 10% after instruction. The lecture-lab group shifted from 14% to 0 after instruction, but the 14% shifted to the use/disuse mechanism of change.

Lecture-lab participant: (cheetah problem) This might be because in order to survive cheetahs needed to gain speed so they did.

Associated with “need” is the use/disuse conception which was held by 62% of the lecture-only group and 43% of the lecture-lab group. After instruction, three (14%) of the first group shifted to the scientific conception of mutation, and the rest retained the use/disuse conception. In the lecture-lab group 23% shifted to the “need” mechanism, 14% retained this conception.

Mutation as the origin of variation was represented. In the lecture-only group, two students (10%) were placed in the “other” category. After instruction, one of the latter moved to the use/disuse mechanism. In the lecture-lab group Special Creation surfaced as a mechanism for production of variation in one student’s response. This student’s conceptual change is discussed in detail in the qualitative section of this chapter (Brianna). The most surprising result after instruction was that she shifted to a scientific conception and identified mutation as a source of variation (14% moved to the scientific conception). Another surprising development is that in the lecture-only group one student moved from a scientific conception for this concept to a use/disuse conception. In this group, three (14%) students shifted to a scientific conception. This trend was also noted in the Demastes/Southerland study (1994).
Origin of Variation
Lecture-only Group

- Other
- Mutation
- Use/disuse
- Need

Percentage holding conception

Figure 4: Lecture-only participants’ (N=21) conceptions for origin of variation

Origin of Variation
Lecture-Lab Group

- Other
- Mutation
- Use/disuse
- Need

Percentage holding conception

Figure 5: Lecture-lab participants’ (N=7) conceptions for origin of variation
The lecture-lab group did not show a shift from “need” or “use/disuse” to the scientific mutation. None of the “need” group moved to the scientific conception in either comparison group.

Other conceptual shifts occurred from one to another alternative conception. This was observed in studies done by Demastes/Southerland (1994) and Demastes/Southerland et al. (1996). This occurred equally in both groups. Figure 3 illustrates the comparison of pretest and posttest scores for this conception for the lecture-only and lecture-lab groups.

It appeared that college students were mostly aware that the use of teleology and anthropomorphism in their explanations was non-scientific. They apparently used these explanations as a heuristic. The topic of teleology was raised during a lecture by the instructor. Students were therefore made aware of this alternative point of view. The interview phase of this study will elaborate more on this topic. It is also important to note that the instructor spent at least three lectures talking about theories such as Lamarckism, teleology, and other concepts which were once regarded as scientific, in his teaching about the history of evolution (Appendix G).

Appendix J (whole-class conceptual change inventory about evolution and the nature of science) illustrates that for the duck webbing (item 19 on the survey) and cheetah (items 21 on the survey) problems the lecture-laboratory group showed a substantial increase on the posttest in selecting the scientific conception; that is that mutations play a role in the origin of variation in a population (total increase of 23% and 30% respectively). The lecture-only group showed a drop in their scores (Appendix J).
Summary of conceptual change pathways

Conceptual change pathways for the comparison groups on the major organizing concepts mentioned above are illustrated in Table 3.

After instruction, there was a large increase in the shift toward the variable species concept. The lecture-only group showed an increase of 29%, and the lecture-lab group showed a slightly larger shift (plus 31%).

Participants in the lecture-lab group showed a shift toward the scientific conception for the unit of evolutionary change (plus 30%). The lecture-only group showed a surprising shift toward the alternative conception, that is that all individuals in a population are the unit of evolutionary change. A small percentage of the lecture-only group moved toward the scientific concept.

The results for the origin of variation conception showed the most surprising shifts, not always toward the scientific conception. Demastes/Southerland and Good (1993) also showed this trend in their study. One category not mentioned in the literature which surveyed college students is the conception that variation arises through creation by a supreme being. This was observed in the answer one student in the lecture-lab group provided for the origin of new traits. This student underwent conceptual change toward the scientific conception (i.e., mutation as the origin of variation). Her conceptual change pattern is described in the interview section in more detail and is summarized in a conceptual profile inventory (included in Chapter 5: Brianna).

Other important shifts were toward the scientific conception (14% for both groups), from the scientific conception toward an alternative conception (5% in lecture-only group), and even from one alternative conception to another (see below).
Table 3: Conceptual change pathways of the comparison groups for the major conceptions of evolution.

<table>
<thead>
<tr>
<th></th>
<th>Alternative Conception</th>
<th>Scientific Conception</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Species concept</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lecture-only</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typological</td>
<td>38%</td>
<td>+29%</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>67%</td>
</tr>
<tr>
<td><strong>Lecture-lab</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typological</td>
<td>40%</td>
<td>+31%</td>
</tr>
<tr>
<td></td>
<td>Variable</td>
<td>71%</td>
</tr>
<tr>
<td><strong>B. Unit of evolutionary change</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lecture-only</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole population</td>
<td>47%</td>
<td>-15%</td>
</tr>
<tr>
<td></td>
<td>Part of population</td>
<td>32%</td>
</tr>
<tr>
<td><strong>Lecture-lab</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole population</td>
<td>27%</td>
<td>+30%</td>
</tr>
<tr>
<td></td>
<td>Part of population</td>
<td>57%</td>
</tr>
</tbody>
</table>

Table continued
C. Origin of variation

Lecture-only group

Need

\[ \begin{align*}
10\% & \quad 14\% & \quad 14\% & \quad \text{Mutation} \\
\downarrow & & \downarrow & \\
10\% & \quad 5\% & \quad \text{Use/disuse} \\
\downarrow & & \\
10\% & \quad 5\% & \quad \text{Other}
\end{align*} \]

Lecture-lab group

Need

\[ \begin{align*}
14\% & \quad 29\% & \quad \text{Mutation} \\
\downarrow & & \\
\text{Use/disuse} & \downarrow & \\
\text{Other} & & 14\% \\
& \quad \text{(special creation)}
\end{align*} \]

This is similar to what was observed by Demastes/Southerland et al. (1993). This movement from one to another alternative conception, was the most common type of conceptual change. There were shifts in conceptual change from the need conception toward the use/disuse conception. Fourteen percent in lecture-lab group and the same percent in the lecture-only group shifted in this way. The shift use/disuse to need were 29% in the lecture-lab group and 10% in the lecture only group. The use/disuse
conception was the largest for the lecture-only participants. Need and mutation are equally represented in the lecture-lab group.

**The final examination and isolated exam items**

In addition to the survey data, isolated questions (relating to evolution) from the final objective examination were also analyzed, and they served as an additional posttest data source to discriminate further between the lecture-only and lecture-laboratory groups. Summary statistics for all quantitative data sources are included in Table 4, that is, pretest and posttests, final grade scores, and the final examination.

**Table 4: Summary statistics for data sources (quantitative)**

<table>
<thead>
<tr>
<th>Data Source</th>
<th>N</th>
<th>M</th>
<th>S.D.</th>
<th>Significance</th>
<th>Effect Size</th>
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<td>Pretest Survey</td>
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<tr>
<td>Lecture-only</td>
<td>28</td>
<td>68.1</td>
<td>10.69</td>
<td>N.S. (p=0.470)</td>
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<tr>
<td>Lecture-Lab</td>
<td>21</td>
<td>69</td>
<td>12.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>62</td>
<td>14.47</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lecture-only</td>
<td>28</td>
<td>73.8</td>
<td>17.54</td>
<td>N.S. (0.255)</td>
<td>0.49</td>
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<tr>
<td>Lecture-Lab</td>
<td>21</td>
<td>76</td>
<td>16.84</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>67</td>
<td>19.22</td>
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<td></td>
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<td>Final Examination</td>
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</tr>
<tr>
<td>Lecture-only</td>
<td>80</td>
<td>83.9</td>
<td>9.95</td>
<td>N.S. (p=0.142)</td>
<td>0.42</td>
</tr>
<tr>
<td>Lecture-Lab</td>
<td>62</td>
<td>84.3</td>
<td>10.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>80.3</td>
<td>8.93</td>
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<td>Final Grade Score</td>
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<tr>
<td>Lecture-only</td>
<td>80</td>
<td>84.4</td>
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<td>Lecture-Lab</td>
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<td>84.53</td>
<td>9.32</td>
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<tr>
<td></td>
<td>18</td>
<td>84.06</td>
<td>7.01</td>
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</table>

Independent means tests revealed that there was no significant difference between the means of the lecture-only and lecture-lab groups on the pre- and posttests, the final examination, and the final grade score. Descriptive statistical analysis, effect sizes, and significance levels are illustrated in Table 5.
Figure 6 shows the results from descriptive statistical analysis of the isolated items on the final examination, illustrating the mean performance of participants in the two comparison groups. Although the differences are not statistically significant for all items, the lecture-lab participants understood certain concepts better, namely questions testing understanding of biometry and biogeography. These concepts were enriched in the laboratory (Appendix G) and involved hands-on simulations of dispersal and vicariance. In the case of the biometry lab, activities included measurement, data recording, and data analysis using computer software. The biogeography lab was completed before the instructor covered it in the lecture because of scheduling problems. Rhonda, one of the lab participants, mentioned this particular lab as making the most sense because she had covered it in a hands-on way in the lab before the lecture.

The seven isolated items on the final objective examination were developed by the instructor in order to differentiate between the lecture-only and lecture-lab groups (N=80). The researcher collapsed these isolated items into four categories, namely natural selection, biogeography, biometry/allometry, and phylogeny, based on the laboratories the concepts were drawn from (syllabus found in Appendix G). An independent means t-test revealed no significant difference between the lecture-only and lecture-lab groups for two of the areas tested (namely, natural selection and phylogeny), and a statistically significant difference for two other areas tested, both in favor of the lecture-lab group. The biogeography items showed a significant difference at the 0.05 level and the null hypothesis was rejected (t=2.652; p=0.010). The allometry (biometry) items showed a significant difference at the 0.05 level of
Figure 6: Comparison of lecture-only and lecture-lab participants' mean scores for the isolated examination items

Table 5: Summary statistics for isolated exam items for comparison groups

<table>
<thead>
<tr>
<th>Items on Exam</th>
<th>N</th>
<th>M</th>
<th>SD</th>
<th>Statistical Significance</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Phylogeny</td>
<td>80</td>
<td>87.48</td>
<td>18.23</td>
<td>N.S. (p=0.56)</td>
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<td>86.90</td>
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<td>18</td>
<td>89.44</td>
<td>14.87</td>
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<td></td>
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<td>2. Allometry</td>
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<td>89.79</td>
<td>17.7</td>
<td>p &lt; 0.05</td>
<td>0.68</td>
</tr>
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<td>81.5</td>
<td>18.5</td>
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<td>Lecture-lab</td>
<td>18</td>
<td>92.89</td>
<td>15.23</td>
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</tr>
<tr>
<td>3. Biogeography</td>
<td>80</td>
<td>86.18</td>
<td>22.01</td>
<td>p &lt; 0.05</td>
<td>0.65</td>
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<tr>
<td>Lecture-only</td>
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<td>74.50</td>
<td>26.38</td>
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<td>Lecture-lab</td>
<td>18</td>
<td>89.50</td>
<td>19.53</td>
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<td>4. Natural Selection</td>
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<td>28.01</td>
<td>N.S. (p=0.25)</td>
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<td>Lecture-lab</td>
<td>18</td>
<td>63.22</td>
<td>29.40</td>
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</table>
significance, hence the null hypothesis was also rejected (t=2.46; p=0.03). The final examination as a whole did not show a significant difference, nor did the final grade scores, nor pretest and posttest scores between lecture-only and lecture-laboratory groups. Summary statistics are included in Table 4 in which effect sizes are reported as well.

**The rest of the conceptual framework**

The surveys were developed also to assess students' understanding of other conceptions associated with evolution. Areas probed were nature of evolution, human evolution, nature of science, and evolutionary conceptions. Appendix J includes a summary of the percentage of students answering correctly.

The issue of human evolution proved to be a very important issue affecting student acceptance of evolution. In the posttest survey the lecture-only group showed a drop in the number of people who agreed with the incorrect item (7) “Humans are more perfect life forms than lower animals.” Fourteen percent changed their incorrect conception here. In the lecture-lab group, there was no change, with 29% of respondents still holding this conception. On the pretest survey, 85% of the lecture-only group agreed with the incorrect item (17), “Human being evolved from apes.” Twenty nine percent of the lecture-lab group agreed with it. After instruction there was a change for both groups; the lecture-only group improved by 5% and the lecture-lab group changed by 29%. This topic was briefly mentioned in the lecture class. The lecture-lab group however, had the opportunity to discuss it and read an article on the topic during a lab session. They therefore had more exposure to this concept, and the correct scientific conception was pointed out to them as well during the lecture the following period.
The age of the earth was a controversial topic as well. Ninety-one percent of the students in the lecture-only group agreed with the correct item on the survey (item 28), that is, that the earth is older than 4.5 billion years. In the lecture-lab group, this number was 71% which was the same as on the pretest survey.

Some participants, especially the “creationists,” were adamant that they “believed microevolution, but not macroevolution.” This is a typical “young-earth” creationist viewpoint. Three of the interview participants will be discussed later in this regard. This concept appeared to be related to students’ religious orientation.

The question as to whether or not evolution and scientific creationism should get equal time received a mixed reaction in the two groups. The Lecture group shifted toward agreement on this topic (from 6% to 18% after instruction agreed). The lecture-lab group chose not to include scientific creationism in high school alongside evolution (100% disagreed with this item). The lecture-lab group had the benefit of discussing this topic and reading articles on it in a laboratory session (refer to Appendix G). The laboratory session covered the reasons for the incompatibility of science and scientific creationism and the non-scientific status of scientific creationism. Students asked the instructor for literature dealing with the differences.

The nature of science

The following results answer the secondary research question (number 3) which asked the following question:

How does an understanding of the nature of science (and the nature of evolution) relate to students’ understanding of evolutionary concepts?

With regard to the nature of science items, the lecture-lab group performed better on average for the nature of science theme on the survey (Appendix J). They
seemed to understand as a group the importance of communication among scientists (item 26); one hundred percent understood that science is not a solitary pursuit. This was stressed in the lab sessions where students were actively engaged in experiments, observations and other exercises (including discussions). This engagement probably influenced their choice of the correct conception on the survey. The instructor stressed nature of science issues during lecture classes and lab sessions.

There was a high level of agreement in both groups for the other nature of science items on the survey, for example, that scientific knowledge is tentative, that science does not claim to provide absolute proof, and that science and technology are not the same. However, in both groups, low percentage of students agreed that scientists did not follow a general and universal “scientific method.” Examples of student open-ended responses are found in Appendix K.

The relationship between nature of science and understanding of evolutionary concepts was assessed using the final grade scores and the final exam results. The nature-of-science scores on the posttest survey were used (Appendix J). There is positive correlation between the nature-of-science scores gained and the final examination score, which is significant at the 0.01 level of significance (Pearson’s correlation = 0.376), and the nature-of-science scores and the final examination score (Pearson’s correlation = 0.404). Although the correlation scores are low and moderate respectively, the relationship is positive in each case. The relationship is direct; the higher the score on the nature-of-science section on the survey, the higher the final grade score and final examination score. It appears that students who had a good understanding of evolution (assessed by means of the objective final examination) also had a good understanding of the nature of science. Because of the small sample (N=28),
these results are not generalizable to the whole class. Therefore, students’
understanding of the nature of science is explored further in the interview phase of this
study.

Summary of whole class conceptual change

The students entered the course with varied understandings of the scientific
conceptions associated with evolution. They showed conceptual change toward
scientific conceptions for some of the conceptual groups on the survey. That is, the
lecture-only group showed a positive conceptual shift for the nature of evolution,
human evolution, and evolutionary conceptions, and it remained the same for the nature
of science. The lecture-lab group showed a positive conceptual shift for the
evolutionary concepts, human evolution and the nature-of-science concepts. They
showed a negative conceptual shift for nature-of-evolution concepts.

The lecture-only group showed a larger shift from a scientific conception to an
alternative conception for specific items contained in these conceptual groups on the
survey. They also showed the largest percentage of use/disuse (Lamarckian)
conceptions after instruction. This was shown in two of the three major conceptual
groups, namely, the unit of evolutionary change and the origin of traits (variation). The
lecture-lab group showed this trend only for the origin of variation conceptual group.

The common conceptions held by participants before instruction were the use of
the typological species concept, the whole population as the unit of evolutionary
change, and variation as produced by use/disuse are. After instruction, the most
important changes are seen in the shift to a variable species concept, the decrease in the
use of need and use/disuse, and the substitution of mutation as the origin of new traits
(variation). The unit of evolutionary change was a problematic conception among the
lecture-only group; they showed a shift to the alternative conception (the whole population is the unit of evolutionary change), and the lecture-lab group showed a shift of 20% to the scientific conception (the unit of evolutionary change is part of the population).
CHAPTER 5: INTERVIEW RESULTS AND DISCUSSIONS

Chapter Overview

This chapter contains the qualitative results which resulted from the content analysis of the interviews and survey data of the eight selected participants (Lincoln and Guba, 1985). That is, the conceptual change of the eight interview participants is reported individually in this section. The purpose of the interviews was to get an in-depth look at the students' understanding of evolution concepts. In terms of conceptual change, this is critical (conceptual change is alluded to in the second part of the title of this study). Due to the attrition of 4 students from the study at different stages, there are unequal numbers of participants in the two comparison groups; there are 5 in the lecture-lab group and 3 in the lecture-only group. The researcher does not claim that these 8 students are fully representative of the whole class. However, since comparison groups (which are at two extremes of a score distribution on one variable) were selected using extreme-group sampling, the assumption is that they are more likely to differ on other measured variables (Gall et al., 1996).

Overall summaries of conceptual change for each of the comparison groups as well as individual conceptual change summaries are reported in this chapter. Individual students' conceptual change is discussed below and includes the analysis of interview data, pre- and posttest survey data, and data from the final examination. Data sources for each of the interviewed students were analyzed by two people, namely the researcher and an expert in the area of evolutionary biology. The two experts who served as the co-raters were the instructor, an evolutionary biologist, and his research assistant, a doctoral student in evolutionary biology.
Previous research (Demastes/Southerland, 1994; Demastes/Southerland, 1995; 1996) suggested further study to investigate conceptual change patterns which deviate from the Posner et al. (1982) Conceptual Change Model.

Conceptual ecology has been defined by many researchers as that aspect of knowledge which is most affected by the learner’s culture. Conceptual ecology includes the fundamental organizing knowledge which controls and modifies conceptual change. Preliminary data analysis indicated that certain aspects of conceptual ecology can affect conceptual change profoundly. Implicated in this regard are the learner’s religious framework, acceptance or rejection of evolution, scientific epistemology, and scientific orientation. The emergent themes from the pilot study data, namely “nature of science and nature of evolution”, “evolutionary concepts”, and “human evolution” were used to organize students’ conceptions. The three major conceptual groups, namely species concept, unit of evolutionary change, and origin of new traits (Demastes/Southerland, et al., 1993; Demastes/Southerland, 1994), are included under the subheading “evolutionary concepts.”

This section describes the qualitative results obtained from the interviews and traces the changes in student understanding of evolution. It answers primary research question 2.

**Lecture-only Participants’ Conceptual Change**

**Ian - atheistic, scientific realist**

**Preinstruction phase**

Conceptual ecology and background

Ian was a 21 year old male whose major was Zoology. He had been in college for 4 years at the time of this study and would graduate the next semester. After college
he planned to pursue a career in medicine. Ian was a very articulate, soft-spoken, and confident young man. He appeared to think before he spoke and seemed to be using effective metacognitive strategies when answering questions.

He did not have science related hobbies, nor did he read science related literature, or watch science related TV programs. He had family in science careers (NASA engineers). Ian did not enroll for the lab course (because he did not have to), and enrolled for the lecture course to fulfill a degree requirement.

He had a positive scientific orientation and a non-theistic religious orientation (he acknowledged that he was not religious). He held a non-confrontational, distinct model for the science-religion issue (McGrath, 1999) and he had a realist scientific epistemology. He accepted that evolution had occurred, but felt that geological evidence was equivalent to natural selection as far as describing the history of the natural world. In this regard, he was a relativist.

Nature of evolution and nature of science

In the preinstruction survey he disagreed that natural selection had a valid scientific foundation; he claimed it was not based on the testing of hypotheses, but that it was based on observation and inference. This is an alternative conception because most of what we study about evolution is based on testable hypotheses. Another faulty conception held at the start of the study is that geological theories are equal and as important as evolution in explaining the history of the natural world. He agreed that organisms have evolved from common ancestors going back to the simplest one-celled (item 8 included in Appendix D) organisms and accepted that the earth is very old (at least 4.5 billion years).
Evolutionary conceptions

Mutations are chance events (random) and are not willed by the organism. He understood that mutations are not necessarily advantageous; they could also be deleterious or even neutral.

He was unable to recognize the prediction problems which dealt with natural selection. He failed to recognize the incorrect elements in the cave salamander problem (Appendix D). He agreed with the use/disuse mechanism of evolutionary change (origin of mutation). He disagreed with the cheetah problem (correctly) but for the incorrect reason. He stated that muscles and bones changed first; therefore he did not recognize the teleological reasoning in the way the problem was stated. The unit of evolutionary change was the whole population. The fact that the trait improved with each generation (albeit gradually) was another instance of Lamarckism included in this problem which he was unaware of.

The concept of fitness had two meanings for Ian; it was associated with the capacity for producing offspring which reach reproductive age, and it included the ability to adapt to new situations (a “desirable trait” - Bishop and Anderson; 1990). Therefore he selected an incorrect choice for the fittest lion, namely, Spot because this lion was “more adaptive.” However, during the interview he selected Sandy because most of his offspring reached adulthood. He did not change his definition of fitness during the interview.

Ian understood that a species was a group of organisms that can reproduce. He did not recognize that the offspring needed to be viable. He did not have a full understanding of the biological species concept. He was able to rearrange the
vertebrates in the correct phylogenetic relationships, and selected diagram C (Appendix H) to describe the process of evolution (this was the correct choice).

Human evolution

With regard to human evolution, he accepted the incorrect item that humans are derived from (modern) apes. He rejected the idea of humans or other life forms having a soul because no proof existed to the contrary. His reasoning was rational; he based his answer on the availability of evidence. He did not regard humans as more perfect, he accepted that humans are classified as animals, and that they are primates. Humans, as well as other life forms, evolved and were not created.

Postinstruction phase

Conceptual ecology

Ian maintained his non-theistic religious orientation, and an acceptance of evolution. He also maintained a positive scientific orientation and a realist epistemology for science. He rejected pseudoscience which he stated made for a good story since there was no proof that it was true. Ian understood many of the major concepts for evolution better after instruction and he had a better understanding of the history of evolution and history of the natural world as is evident in his time line and responses in the interview. At the end of the semester he had a historical/biological view or mechanistic view of evolution and the natural world. During the interview he demonstrated that he also understood the evidence for evolution and expanded on this:

**Interviewer:** What evidence can you provide for evolution?

**Ian:** Probably a combination of geological and fossil remains, for example, fossil remains from different parts of the stratigraph, DNA, and homology.

**Interviewer:** What did you know about the history of evolution before this course?
Ian: I knew about Lamarck and Darwin and Lyell, but from an anthropological standpoint...It was the first time I had ever heard of the new synthesis, and classical versus neo-Darwinism, I got more detail in this course, and its the first time I had heard of micro- versus macroevolution.

The time line (drawing task) confirmed his understanding of the history of the natural world (Appendix L). This detailed time line indicates that he had a good understanding of phylogeny and history of life, and that he accepted evolution as a valid scientific theory. His thinking did not indicate any conflicts with regard to the science/evolution-religion controversy and appeared to remain non-confrontational and distinct throughout the semester (McGrath, 1999).

Ian scored an A plus on the final examination and he scored full points for each of the four isolated items on the final examination.

Nature of evolution and nature of science

He understood that natural selection did have a scientific foundation and that the study of evolutionary biology is based on testable hypotheses. His responses in the open-ended part of the items were much stronger and much more scientific. In the pretest Ian thought that geological theories and evolution were equally valid explanations for the history of the natural world; in the posttest he acknowledged that evolution is the single most valid explanation.

His answers on the posttest for the nature of science items did not change and he maintained a good understanding of these concepts. There were only subtle changes in his reasoning as reflected in the open response sections. Like six of the other interview participants, Ian still retained the alternative conception of a general and universal scientific method.
Evolutionary conceptions

The concept mutation was refined somewhat to include the idea that mutations happen in individual organisms rather than populations. More detail was provided in the interview where he stated that during a mutation there was a change in the code of an allele. He shifted to the use of the variable species concept.

He changed from using a use/disuse conception for the origin of variation to an understanding of mutation as the origin of variation. In the blind cave salamander item, blindness was not a disadvantageous trait in the dark and was therefore not selected against. He explained that a random mutation and not the environment was probably responsible for blindness. For the cheetah problem he stated that a mutation was probably responsible for the change in body size, muscle and bone development, and that with this physical increase came a physical capacity for speed. He appeared to stop short of explaining for this example and the cave salamander problem, that the trait does not improve and get passed on, the proportion of individuals with the trait increases from generation to generation. He did not have a complete understanding of the mechanism of evolution by natural selection.

The prediction interviews (Appendix H) afforded further opportunity to explore this topic. For the antibiotic problem he failed to explain the significance of variation in the bacterial population, but he did speak of subsequent mutation in the population (of bacteria), which would mean resistance in the new strains. He spoke vaguely of immunity (Brumby, 1984).

In the insect problem, mutations could have afforded some insects resistance and hence protect them against the insecticide. Some insects were already resistant. He
did not mention natural selection, nor did he mention that the resistant ones were able to reproduce and pass on this trait to their offspring. His explanation did not include how this becomes established in the population.

Ian recognized that the skin problem dealt with natural selection; mutations might have caused different skin colors and that lighter skin was probably more selected against inside Africa and was not selected against outside Africa. In Africa they were exposed to high levels of UV light and therefore darker skin was more beneficial there. He correctly explained all the predictions.

His understanding of fitness changed after instruction; fitness referred to the ability to pass on genes. Sandy was the fittest because he produced the most offspring which reached adulthood.

Human evolution

For human evolution his answers were similar to his pretest answers, with explanations given in the posttest being stronger. He understood that humans did not evolve from modern day apes or chimps, but that humans share a common ancestor with apes. Most of the students who completed a posttest survey, used this correct scientific conception.

Conceptual change at the end of the semester

From a socio-affective perspective, Ian was interested in evolution and had a mechanistic, naturalist view of the natural world. He was a non-theistic evolutionist and was motivated to pursue his career in applied science (medicine). He maintained his rational outlook and based his beliefs about science and theories about science and the natural world, on testable hypotheses and the availability of evidence. His
Preinstruction Phase

Scientific conceptions
Natural Selection has a valid scientific foundation.
An old earth (plus 4.5 billion years)
Organisms have common ancestors, back to simple one-celled organisms
Mutations and variation are chance events.
Mutations can be deleterious, advantageous or neutral.
Fitness as a capacity to produce offspring which reach reproductive age.
Humans are classified under animal kingdom.
Humans are not more perfect than other animals.
Evolution does not have a purpose nor direction.

Alternative conceptions
Natural Selection is based on observation and inferences.
Geological and evolution are equally important in explaining the history of the natural world.
Scientists all follow a universal general scientific method.
Use/Disuse as a mechanism of evolutionary change.
Unit of evolutionary change is the whole population.
Fitness is the ability to adapt to new situations.
Humans are derived from apes.

Postinstruction Phase

Scientific conceptions
Natural Selection has a valid scientific foundation
Evolution is the main theory explaining the history of the natural world.
An old earth (plus 4.5 billion years)
Organisms have common ancestors, back to simple one-celled organisms
Mutations and variation are chance events.
Mutations can be deleterious, advantageous or neutral.
Fitness as a capacity to produce offspring which reach reproductive age.
Humans are classified under animal kingdom.
Humans are not more perfect than other animals.
Evolution does not have a purpose nor direction.
Natural Selection is based on testable hypotheses.
Natural selection acts on variation.
Unit of evolutionary change is part of the population.
Humans and apes share a common ancestor.
Humans cannot evolve from modern apes, chimps etc.
Selection acts to remove traits selected against.
Fitness is the measure of how many offspring reach adulthood.

Alternative conceptions
Scientists all follow a universal general scientific method.
The trait increases and improves over time (not proportion of individuals with the trait).

Figure 7: Ian’s conceptual inventory profile and conceptual change instances
scientific orientation was made clearer after instruction. After instruction his explanations of major conceptions were stronger and clearer.

Ian made some ontological shifts at the end of the semester. He understood natural selection as having a valid scientific foundation, based on testable hypothesis, from the previous belief that it was only based on observation and inferences. Evolution is the most important theory for explaining the natural world. The shift to a mechanistic understanding of natural selection (mutation as an origin of variation and selection acting on the latter) is an example of what Thagard (1992) called replacement of an incorrect central rule. Branch jumping (Thagard, 1992) is illustrated in the change in conception about the relationship between humans and apes; a shift in the relationship structure is illustrated as humans and apes have a common ancestor, humans did not evolve from apes. He understood how humans and apes share a common ancestor, and that humans did not evolve from modern day apes. This conception was intelligible, as he was able to explain the relationship, it was believable to him (plausible) and also fruitful. This was also a concept for which many students experienced conceptual change. Dissatisfaction with this conception probably occurred during the last lecture on human evolution when it was proposed to students how apes and humans are related by a common ancestor. One-hundred percent of the lecture-lab group and 95 % of the lecture-only group experienced conceptual change in this conception (survey data).

Ian experienced conceptual change for the mechanism of evolution; it was intelligible, plausible, and fruitful. He was able to apply this theory to explain other examples during the interview (cave salamander, cheetah problem, skin problem), but
he was not able to articulate how change occurs in the proportion of individuals and not
the trait itself. The latter represents a dual construction. Conceptual change was
wholesale for the species concept, unit of evolutionary change, and origin of variation /
new traits. He experienced conceptual change for various other concepts. This is
illustrated in Figure 7 (conceptual inventory profile and conceptual change instances).

Adrian - theistic evolutionist and scientific realist

Preinstruction phase

Background and conceptual ecology

This participant was a 20 year old male and former hospital worker. He was a
Biochemistry major and one of 4 males in this study. His alternative career choice
would be that of evolutionary biologist. Adrian was a very quiet person and was not
enrolled for the laboratory course because he did not get a seat (limited to 25). He
planned to pursue a career in Emergency Pediatric Medicine because he thrived on the
“excitement”, and because kids are more susceptible to new medication, hence he
would not have many patients dying on him. His earliest influence was his
pediatrician; he pretty much knew what career he would pursue the first time he met his
pediatrician. He did not have family in science careers nor did he have a science related
hobby because he worked and time was a constraint. He read Discover Magazine and
Natural History, and enjoyed TLC (The Learning Channel) and the Discovery Channel.
He was interested in, and fascinated by evolution and therefore enrolled for the lecture
course. He was the product of a Baptist church school (2 years pre-med) where a
particular professor had had an influence on him because he “believed” in evolution (it
had caused a stir at that time). The instructor had taught his viewpoint and what others
think about evolution. His also drew inspiration from a movie (Relic) in which the main character is an evolutionary biologist; this was his alternative career choice.

Adrian collected human “evolution memorabilia” (e.g., National Geographic series map on human evolution) and designed a wood burning depicting the ape to man scale from a display in the National Geographic. He did the latter as extra credit project. Adrian accepted evolution but he maintained a strong religious belief system.

His scientific orientation was distinct and contrasted with an equally distinct religious orientation. Adrian held an old-earth / intelligent-design view of evolution. He was not an authority seeker, but based his understanding of natural phenomena on whether or not he considered these explanations to be rational or plausible. He believed that teaching evolution in high school was too controversial. Evolution is as an important part of biology, but it should not be taught in depth; natural selection and Darwin would suffice (“keep it small time”). He also suggested that the discussion of evolution be kept on an animal basis and not include humans. This indicated that he understood that the controversy about evolution entailed macroevolution (large scale evolution) and human evolution.

Adrian accepted evolution as a way of explaining the natural world and evolutionary changes; that is a rational view of most of the natural world. His view of religion is distinct (McGrath, 1999), but is not a literal interpretation of the Bible and religious discourse. He accepted a view that organisms may have changed over time, but attributes evolution to God. His answer to item 8 (The earth’s present day life forms have evolved from common ancestors going back to the simplest one-celled organisms), read as follows:
I can’t explain why, I just feel that this may have been God’s plan; (the item) does seem valid and plausible.

However, he stated that the Bible provided an alternative theory more useful than evolution in explaining the history of the natural world. At the start of this study it was clear that Adrian had a good understanding of the science/religion conflict, and that he understood the multiple meanings of the word “Creationism. He held a non-confrontational, convergent view of the science/religion issue (McGrath, 1999). Adrian was a “old-earth” creationist (Larson & Witham, 1999).

With regard to his scientific epistemology, he was a realist because his view of science implied that he understood that science operated to explain reality, that scientific knowledge is tentative, and that evidence is needed to support scientific hypotheses. In short, he accepted evolution but only as directed by God. He rejected the notion that the mechanism of evolutionary change is a result of a “blind” act like natural selection. He was a scientific realist and was a gradual creationist (he believed that God created life forms on earth and directed evolution as part of his plan). In addition he believed in an old earth which is essentially orderly in accordance with God’s plan.

Nature of evolution and the nature of science

He agreed that evolution has a valid scientific foundation and supported this with science knowledge, for example, in Origin of the Species, Darwin stated that there are many examples of evolution by natural selection. He felt that both evolution and Scientific Creationism should be taught in school because high school students are mature enough to consider both sides and decide for themselves. The fact that earth’s
present day life forms have evolved from single-cell organisms was valid and plausible to him, because he felt it was God’s plan. Evolution therefore had a purpose (God’s purpose). However, he did not regard evolutionary change as leading to perfection. He regarded the Bible as an alternative authority to the explaining the history of the natural world. He initially stated that evolution conflicted with the Biblical account of creation. The nature of science conceptions were more or less congruent with his scientific orientation. Adrian recognized the tentative nature of scientific knowledge, and that acceptance of scientific knowledge is not always straightforward. He also stated that science cannot offer absolute proof and he was able to distinguish between science and technology. However, he held an alternative conception with regard to the “scientific method” (he agreed that scientists follow a scientific method):

I agree with there being a scientific method because scientists have to follow a scientific method so that there findings can be reproduced.

Human evolution

Adrian did not consider human beings to be more perfect than “lower” life forms. In his opinion humans possess a soul, other animals do not because humans are the chosen to worship in fellowship, and live eternally with God. There existed an evolutionary relationship between humans and apes because they have a common ancestor. He explained the origin of human and all other life as an act of creation by God, but said that:

We were created by God, but not as we are today. I believe we evolved to what we are today.

Therefore human beings are special only because they have been chosen to worship with God, but they like, other animals, have evolved, and they are descendent from a
common ancestor to apes. He was disappointed that the course did not deal with more human evolution as that was the reason he had enrolled in this course.

Evolutionary conceptions

Adrian did not explain the chance or random aspect of mutation. He confused the chance aspect of it. It is possible that he understood what mutations were, and that they happened by chance. He mentioned that mutations and variations occur too frequently in nature and are part of nature. Mutations could better equip an organism to survive in its environment, but that they could also accomplish the reverse - they could be neutral or detrimental. He also stated that a mutation is “a physical change in a being or creature or a population.” It appeared that he knew that a mutation would be expressed in the phenotype and could result in intraspecific variation.

He did not understand the origin of new traits (variation). He understood evolutionary change in terms of use/disuse as was evident in his written response to the cave salamander problem. Adrian also agreed with the incorrect statement in the cheetah problem which implied that need drove the development of speed in cheetahs. In the cave salamander problem, he explained during the interview that sight was weeded out because it was not a necessity when the other senses became more enhanced.

Use/disuse is then the mechanism which drives change in a trait, or survival or removal of a trait. He mentioned that light (the environment) caused blindness as well as lack of use (of the eyes / sight) and that it occurred “over a long period of time.” His answer for the cheetah probe agreed with the incorrect item. He reasoned that a “gradual adaptation is plausible.” In the interview he used the use/disuse mechanism explain how cheetahs were faster than their ancestors. Through use and enhancement these
cheetahs built up endurance and eventually ran as fast as 60 miles per hour. He mentioned that they “have the genetics” for speed. Therefore, with regard to evolutionary change at the preinstruction stage, he held the following conceptions: evolutionary change is gradual, it occurs as a result of an environmental cue and therefore use/disuse determined the survival, or removal of a trait. Examples of alternative conceptions that he held are: the unit of evolutionary change is the whole population and variation is produced in the population by need.

Adrian was not sure exactly how to define fitness. He however disagreed correctly with the incorrect item and stated that he was not sure. However, his selection of Sandy as the fittest lion (correct choice) because more his offspring reached adulthood, implies that he understood that fitness had to do with reproductive potential and perpetuation of the species. He mentioned that Sandy’s death would not affect his genetic fitness. He understood biological fitness and did not use a collage conception of fitness (Demastes/Southerland, 1994; Bishop and Anderson, 1990).

Adrian confused the issue of adaptive radiation by not being able to separate the origin of variation from the act of natural selection. It appeared that he used a Lamarckian explanation for the mechanism of change; the environment provides the cue for mutation and adaptation (need). He did not understand that mutations arise by chance, and are a source of variation. He knew that mutation, variation and natural selection were the conceptions involved but he could not articulate an explanation. There was evidence that Adrian was experiencing dissatisfaction with his explanation and was aware of gaps in his understanding at this point.

His written response agreed with the typological species concept. In the interview, he expanded on this concept to include reproductive potential in his answer:
It’s a group of animals which have isolating breeding...that are isolated and breed only with their own and have their own gene pool.

The interview about instances further probed the species concept (e.g., the kitten graphic and wild cats graphic) which he answered correctly. The outcome was that he had a scientifically acceptable conception of species; he held a biological species concept.

He selected diagram C as the graphic depicting evolutionary change (Appendix H) because it was the only one explaining how a common ancestor could give rise to different lineages. He did not have a good understanding of vertebrate taxonomy; he incorrectly placed the amphibian first on the vertebrate phylogeny chart. The only correct relationship was reptile to bird. He omitted humans from the relationship tree probably because he did not understand evolutionary relationships among the vertebrates. Although these are basic ideas explored during introductory biology courses, it has to be noted that Adrian was a biochemistry major.

Prediction interviews using the mice graphics indicated that he understood genetics in terms of Mendelian genetics. He understood what an allele is and was able to recognize that Lamarckian inheritance would be incorrect to explain the inheritance event.

Postinstruction phase

Conceptual ecology

Adrian did not change his belief that God created mankind (life) and directed evolution. He included microevolution and macroevolution in his “acceptance” of the
theory of evolution. He retained his religious framework but stated that the Biblical stories are analogies which are not to be taken literally. Humans were animals too but they differed from other animals because they had souls. He improved his understanding of nature of science and nature of evolution. His positive scientific orientation reflects his acceptance of evolution even though he did not reject his religious beliefs. He interpreted his personal beliefs through his religious framework but his activities (reading, projects, interests) revolve around science and medicine. His realist epistemology coincided with his scientific orientation, and acceptance of evolution despite his religious framework. He also rejected pseudoscience ideas, understood other theories of evolution (punctuated equilibrium theory), used biological terminology, and provided examples of evidence for evolution.

Adrian ended the semester with a B grade and a good understanding of evolution. He understood that the biological evidence for evolution is overwhelming and adapted his religious beliefs, over time, around this knowledge. He would probably always hold this dual construction.

Nature of evolution and nature of science

Adrian showed a shift in understanding for many of the nature-of-evolution items on the written survey. He regarded Scientific Creationism as “religious” and without a scientific foundation. He concluded that it should not be taught alongside evolution. Adrian also changed his answer to item 15; he regarded evolution (not the Bible as in the preinstruction survey) as primary in explaining the history of the natural world. He still did not see a conflict between the Bible and evolution regarding creation. He also indicated a keen interest in an alternative career as an evolutionary
The nature of science items showed that he still thought of scientists as following a scientific method. His score on nature-of-science items and nature-of-evolution items are very similar. With regard to the process of science, he acknowledged that theories needed to be tested and evidence should be gathered before theories could be accepted. With regard to human evolution, he showed a surprising shift. Although he still said humans had a soul and other animals did not, he now acknowledged that humans are animals too. This indicates an ontological shift. He understood the evolutionary relationship between humans and apes, and understood that humans are not derived from present day apes, but from a common ancestor. He retained his position that humans and all life forms were created. Therefore he regarded the role of religion as discussing creation of life forms, and evolution as dealing with changes after creation. In the interview he identified human evolution as the issue which interested him the most. His interest in evolution concerned “mankind and creation.” It is evident that once he sorted out the conception that evolution did not elaborate or speak to creation and origins and that they were not in conflict on this issue, he was able to expand on his narrow conception/consideration of the scope of evolution and include other animals. He did acknowledge macroevolution. He had a Lamarckian-Creationist framework for evolution where use (Lamarckian conception) is the driven force behind adaptation to new environmental cues. However, the overarching idea of God creating life forms and directing evolutionary change is still more prevalent.

I believe that God created man but not in the literal sense of which the Bible says. I think he said: “let there be man” and Adam was there...I believe he created life, he did not take my rib and create Eve out of the dirt and stuff. I
believe his purpose was to create mankind. Evolution is part of the design of God. Humans are not the most perfect life forms. As far as us being the end product (of evolution)...you can't say end-product because we are still evolving.

In the survey he stated that because cave salamanders did not use their eyes, this resulted in blindness. The environment (darkness) played a role and other features like smell, touch became more enhanced. Disuse of one led to the use or enhancement of another feature and gradually over time the salamanders with the newly developed/enhanced trait (smell, touch):

Since they could not see in the first place since it was completely dark, so those that could either sense or smell or touch or feel what's around them, they were more successful, their offspring even more so being born into darkness and so forth.

He hinted at variation but said that a chance mutation could have occurred. Adrian never explained how mutations could be the source of variation. In the survey he shifted to an understanding that mutations are not always beneficial. Natural selection is not mentioned; the mechanism for evolutionary change in this example is therefore use/disuse because they needed to adapt to the new environment of darkness. He was more successful with the cheetah problem; he mentioned the concept "variation" and described how, like in the giraffe sorting task, there were cheetahs in the initial population that were faster than others. Adrian failed to mention the origin of variation. He was able to understand that the trait did not improve over time, but that there were more cheetahs with the trait over time (differential reproduction).

The prediction interviews provided another opportunity for the researcher to probe his understanding of natural selection. In the bacteria problem, he correctly identified the bacteria as the target of antibiotics, but implied that mutations are
purposeful. He used anthropomorphism in his response by indicating that bacteria strive to survive. He used the same reasoning in the insecticide problem. The latter indicates that he is unable to distinguish between functional and causal explanations; he therefore provided a functional explanation and did not sufficiently describe how a trait evolved. Here he also indicated that like in the giraffe problem, some flies died (he did not mention variation in the population, that is, that some flies were resistant to the insecticide, nor did he mention natural selection) and their gene pools were wiped out. Those that survived passed on their genes became more numerous. Although he did not mention variation, he implied this in his answer (some flies died), he also implied selection but did not separate it from the production of variation.

The skin problem showed that he had a basic understanding of genetics and that he understood the change in skin coloration to be a result of mutation. He was able to identify the unit of evolutionary change as the population and not the individual. He indicated that this change happened over a long period of time.

Adrian understood that adaptations can be behavioral and genetic, and that some are only behavioral. Adaptation was defined in the everyday context of the word and therefore he retained the alternative conception of an environmentally-directed influence on the appearance, development or enhancement of a trait:

That’s (adaptation) gonna be a...change in behavior or feature to make them more suited to an environment.

The conception of adaptation is the concept which affected how he conceptualized the non-random act of natural selection. It appeared to affect his ability to separate natural selection from the production of variation.
His understanding of fitness changed. He selected Sandy as the most fit, because most of his cubs reached adulthood. He acknowledged that the species concept entailed more than just having similar traits; species members needed to enable to reproduce successfully.

His time line depicts a creationist version of evolutionary theory (Appendix L). It illustrates that Adrian regarded evolution and the creation of the world as directed by God as part of His plan. Mankind evolved from simpler life and was not created exactly as described in the literal interpretation of Genesis. The marks of Christianity, the appearance of Jesus and the “second coming,” appear on his time line.

With regard to his religious orientation at the end of the semester, he was a gradual creationist. However, there was also evidence of non-theistic evolutionary elements in his responses. The former is evident in his timeline and his acceptance of an old earth. The non-theistic evolution framework is evident in his opinion that Scientific creationism does not have a valid scientific foundation (previously thought both should be taught) and that evolution explained the history of the natural world (he selected the Bible in the preinstruction survey). Adrian maintained his non-confrontational, convergent approach throughout the semester. He could therefore be described as a “theistic evolutionist” (Moore, 2000); one that believes that evolution is God’s way of explaining life’s diversity. Moore (2000) regards theistic evolution as a euphemism for creationism.

Conceptual change at the end of semester

From a social/affective perspective he enjoyed science in his personal life and was interested in applied science (medicine). Adrian was interested in human evolution.
in particular and was disappointed that the lectures did not cover this as much. He thought the course would focus on human evolution. This knowledge was important for him especially in his future career as well as in his personal life. He asserted that it was directed by God, it was God's plan.

From an ontological perspective, he moved toward a scientific conception for the origin of variation and the role of mutation, as well as the unit of evolutionary change. He understood the relationship between humans and apes (branch jumping), the fitness concept, and the variable species concept. An important instance of conceptual change is observed in the final prediction interview; he understood that there is an increase in the proportion of individuals with a trait over time and that the trait did not improve over time. However, he also held the use/disuse alternative conception (see cave salamander explanation). This is an instance of dual construction. It is related to his dual construction about the nature of mutations (i.e., they are beneficial).

From an epistemological perspective, he regarded the major concepts mentioned above intelligible, plausible (believable) and fruitful. However, the nature of mutations got blurred from time to time, and he appeared not to understand that mutations can be deleterious, beneficial or neutral. He did not understand this fully and therefore the use/disuse conception was retained. This was not totally intelligible, plausible nor fruitful to him.

Preinstruction Phase

Scientific conceptions
Nature of evolution
Natural Selection has a valid scientific foundation.
An old earth (plus 4.5 billion years)
Organisms have common ancestors, back to simple

Figure 8: Adrian's conceptual profile inventory and conceptual change instances

Figure continued
One-celled organisms.
Everything evolved.
Evolutionary change is gradual.

**Evolutionary concepts**
- Variable species concept.
- Mutations can be deleterious or advantageous.
- Fitness as a capacity to produce offspring which reach reproductive age.

**Human evolution**
- Humans are classified under animal kingdom.
- Humans are not more perfect than other animals.
- Humans and other organisms evolve.
- Humans and apes have a common ancestor.

**Nature of science**
- Scientific knowledge is tentative.
- Cannot offer absolute proof.
- Acceptance is not straightforward.

**Alternative conceptions**
- Nature of evolution
  - Mutations and variation are not chance events.
  - Bible provided an alternative explanation more useful in explaining the history of the natural world.
  - Orderly and harmonious earth in accordance with God's plan.
  - Evolution has a purpose
  - Evolution is directed by God.

**Evolutionary concepts**
- Use/Disuse and need as mechanisms of evolutionary change.
- Unit of evolutionary change is the whole population.
- The trait improves gradually from generation to generation.

**Human evolution**
- After creation all organisms evolve.

**Nature of science**
- Scientists all follow a universal general scientific method.

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**Postinstruction Phase**

**Scientific conceptions**

**Nature of evolution**
- Natural Selection has a valid scientific foundation
- Evolution is the main theory explaining the history of the natural world.
- An old earth (plus 4.5 billion years)
- Organisms have common ancestors, back to simple one-celled organisms
- Evolution does not have a purpose nor direction.
- Natural Selection is based on testable hypotheses.
- Scientific Creationism has not scientific foundation.

**Evolutionary concepts**
- Evolution as Micro- and macroevolution
- Mutations can be deleterious or advantageous.
- Fitness as a capacity to produce offspring which reach reproductive age.
- Natural selection acts on variation.
- Use/disuse as a mechanism for evolutionary change.

Figure continued
Unit of evolutionary change is part of the population. The trait increases and improves over time (not proportion of individuals with the trait). Selection acts to remove traits selected against. Fitness is the measure of how many offspring reach adulthood.

**Human evolution**
- Humans are classified under animal kingdom.
- Humans are not more perfect than other animals.
- Humans and apes share a common ancestor.
- Humans cannot evolve from modern apes, chimps etc.

**Alternative conceptions**

**Evolutionary concepts**
- Mutations are beneficial.
- Mutations cannot be neutral.
- Use/disuse as a mechanism for evolutionary change.
- Fitness is the ability to adapt to new situations.
- The environment induces the appearance of a trait.

**Nature of science**
- Scientists all follow a universal general scientific method.

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**Patricia - creationist and scientific relativist and skeptic**

**Preinstruction phase**

**Conceptual ecology and background**

Patricia was a 19 year old African American female, a Biochemistry or Pre-med major who would graduate in May 2000. She planned on pursuing a medical career after graduation. Her family members in applied science careers appeared to be her role models. She enrolled for the lecture course to fulfill a credit requirement. She planned to take the lab course later. At the start of the course she felt that evolution was just a way to disagree with creationism.

With regard to her religious orientation she was a quick creationist at the start of the study and clearly did not accept evolution, but learned what she could about it for the purposes of the course and to “get out of college.” She was willing to put her beliefs aside for that purpose. In this regard she was consciously operating under a dual
construction framework for evolution. Although she did not explain the items in the interview and survey in religious terms, she is somewhat of an authority seeker as she did not always weigh evidence or knowledge claims based on how rational or logical they were. She interpreted some items by first looking at it from a Biblical perspective. Patricia started out the semester in a conflicted position with regard to the science/religion debate (McGrath, 1999).

Patricia was a scientific relativist (Tashakkori and Teddlie, 1998) and also a skeptic. She interpreted the natural world through a sociological perspective. It appeared that she was not overly interested in either science or evolution, but she realized she needed these subjects to get into medical school. It was a means to the career she wanted to pursue and she would endure it, but not “believe” it.

Nature of science and nature of evolution

Patricia compartmentalized her knowledge into scientific and personal/religious knowledge. She gave the scientifically acceptable answer on the survey, but in the interviews she stated her personal belief. She answered the survey items as if she were being tested and answered in the way she would be assured of a “good grade.” In this regard then she agreed that evolution has a valid scientific foundation, that life forms have evolved from a single-celled organism, and that the earth is about 4.5 billion years old (an old earth). She did however held some alternative conceptions about the nature of evolution.

Alternative conceptions included that there are other theories which can explain the history of the natural world, that all living things were created, and that evolution conflicted with the Biblical account of creation.
With regard to the nature of science items, she held the alternative conceptions that there is one “scientific method” and that science and technology are the same. She was not sure that science provided absolute proof. It was clear that Patricia did not have a good understanding of the nature of science and the nature of evolution.

Human evolution

Patricia felt that human beings were more perfect than lower animals. She agreed on the survey that humans and apes shared a common ancestor but admitted that she had “learned” this information. Humans and all living animals possess souls and that humans beings did not come from apes (item 17), because “human beings were created by God!!” and “all living things were created by God not just human beings.” However, she held a dual construction for the conception. She disagreed that “evolution is basically the evolution of humans” (item 23) because “evolution includes animals as well.” This is directly opposite to her conviction that God created all living.

Patricia therefore held a dual construction for the evolution of humans and other life forms; she was a quick creationist and essentially a biblical literalist. She believed firmly that God created humans and the world.

Patricia was consciously dichotomizing her religious knowledge framework and scientific knowledge for this course. She used the evolutionary conception when probed during interviews and surveys, except when it came to human evolution and the origins of organisms.

Evolutionary conceptions

She understood that mutations were chance events, but held the alternative conception that mutations were always beneficial equipping the organism with a better...
means of surviving in its environment. It is clear that she separated her personal belief from her scientific conception of the concept and that she appears capable of developing a scientific framework for evolution. Her understanding of natural selection, the mechanism for evolution was limited and she held alternative conceptions with regard to this concept. She maintained a macro-evolutionary framework for evolutionary change; it was essentially Lamarckian where the environment determined the change in trait and it was passed on to the next generation. Natural selection was therefore a purposeful act that selected the appropriate adaptation. In the cave salamander problem, she also used the use/disuse alternative conception to explain how the trait of blindness developed:

Gradually over time salamanders lose their sight and become blind; natural selection is involved. If you don’t use your arm, you will have no arm, just so salamanders were not using their eyes, and natural selection will select blindness—this is a gradual thing. It also has to do with the cave being dark. In light they are not blind, but in the cave they are blind.

In this example she used the conception of evolutionary change as a gradual change.

She had the following to say about the cheetah problem:

The dominant cheetahs ran faster, this is inherited. Prey got faster so as to survive and therefore cheetahs got faster to survive too.

The new trait (speed) was produced in response to a need for the beneficial trait of speed. She implied that mutation is involved ("the dominant cheetah...inherited) but she did not make this explicit. The fact that need is built into her answer, makes it difficult for her to see that a random mutation was involved in the production of variation. Patricia held a collage conception of fitness (Demastes/Southerland, 1994). She was an authority seeker. In answer to the item on which lion is the fittest, she
agreed that George was the fittest. However her reason was that “scientists say so!!” (her emphasis). She added number of males to the definition of fitness and changed her answer, that is Ben was the fittest lion. He lived longer and he produced the most cubs even though all of the cubs did not reach adulthood. She therefore defined fitness in terms of survivability, number of males, health and strength. This is referred to as a collage conception of fitness.

In the interviews, she maintained the conception that similarity in traits determine a species, that is she held a typological species concept.

The adaptive radiation probe was explained in terms of the finches adapting to the specific environment they had dispersed to in order survive. Therefore need (to survive) in response to the environmental cue is the mechanism through which evolution operated.

They dispersed, developed by adapting to surroundings to survive, the woodpecker can’t be a woodpecker if it is using the cactus.

She chose the correct lineage, C, which explained how evolutionary change could have taken place (Appendix H). She made this choice because this was the only one which showed the different lineages arising from the single ancestor. Patricia did not understand vertebrate taxonomy; she indicated that fish gave rise to humans, and amphibia and reptiles “go together.” She was unsure where birds “fitted in” and was experiencing a conflict between the taxonomy and the creation story.

Postinstruction phase

Patricia showed some change in her conceptual ecology at the end of the semester, but she held on firmly to many alternative conceptions. She maintained a
belief in creationism, but admitted that she did not think that her beliefs had become stronger, and indicated that "it has been shaken a little." She attributed this to the fact that she had been shown physical evidence (e.g., fossils). She questioned "how can we prove creation. But evolution ...they are trying to prove it." This shows that she had gained knowledge about evolution and the nature of science during the course. She, however, maintained her creationist framework for evolution. In the drawing task, she illustrated this framework (Appendix L). The timeline is an interesting mixture of both scientific and non-scientific (creationist) conceptions. The biblical sequence and evolutionary relationships are both depicted on her timeline. Her timeline included Dinosaurs, an evolutionary conception, and the sequence from fish to land animals which illustrate evolutionary relationships.

In the survey she said that humans are more perfect life forms than lower animals because:

Not only in creation were we made in God's own image, but in evolution we are more intelligent thus making us more intelligent.

She maintained her dichotomy of science conceptions and her personal belief system. With regard to the age of the earth (more than 4.5 billion years old), she agreed with the item and then qualified this as follows:

I agree to some point because that is what I have been taught in school but if creation and evolution were given equal time in school, 4.5 billion would not be the first age that comes to mind. I would have a choice.

This indicates is that she was a quick creationist (for the origin of life forms) and somewhat of a progressive creationist (for the mechanism of evolutionary change), but that the authority of her personal beliefs outweighed what she understood about the
natural world. Extra-logical reasoning surfaced here. She therefore viewed the natural
world from a literal biblical perspective. This was not surprising and was not a
unique viewpoint. Two other participants (interviews) and a number of students who
completed the surveys expressed similar opinions. Many students, when placed in a
conflicted situation, will opt for religion over science (McGrath, 1999). In Patricia’s
case, she shifted even further to a non-scientific understanding of the age of the earth.

Preinstruction Phase
Scientific conceptions
Nature of science
Natural Selection has a valid scientific foundation.
An old earth (plus 4.5 billion years)
Organisms have common ancestors, back to simple
One-celled organisms
Evolutionary concepts
Mutations and variation are chance events.
Human Evolution
Humans are classified under animal kingdom.
Humans did not evolve from apes.
Alternative conceptions
There are other theories important in explaining the history of the natural world.
Mutations were always beneficial equipping the organism with a better means of surviving in
its environment.
All living things were created.
Humans were created.
Humans are more perfect than other life forms.
Scientists all follow a universal general scientific method.
Typological species concept.
Use/Disuse and need as mechanisms of evolutionary change.
Environment determined the change in trait.
Unit of evolutionary change is the whole population.
Fitness defined in terms of survivability, number of males, and other desirable traits.
Evolution has a purpose and is directional.
The trait increases and improves over time (not proportion of individuals with the trait).

Postinstruction Phase
Scientific conceptions
Natural Selection has a valid scientific foundation
An old earth (plus 4.5 billion years)(learned)

Figure 9: Patricia’s conceptual inventory and conceptual change instances
Humans are classified under animal kingdom. Natural selection acts on variation.
Humans and apes share a common ancestor.
Humans cannot evolve from modern apes, chimps etc.

Alternative conceptions
Humans are more perfect than other animals, in evolution and intelligence.
Evolution does have a purpose and is directional.
There are other theories important in explaining the history of the natural world (creationism!).
Mutations are not chance events.
Mutations were always beneficial equipping the organism with a better means of surviving in its environment.
All living things were created.
Humans were created.
Scientists all follow a universal general scientific method.
Typological species concept.
Use/Disuse and need as mechanisms of evolutionary change.
Environment determined the change in trait.
Unit of evolutionary change is the whole population.
Fitness defined in terms of survivability, number of males, desirable traits.

Nature of science and nature of evolution

Patricia operated through a dual construction framework for many of her ideas about evolution. She regarded the earth as old, because she did not have an alternative from her personal belief to rely on; she regarded the nature of evolution as gradual, directed, purposeful, and driven by use/disuse and need (mechanism). She continued to describe evolutionary change as the acquisition of desirable traits which arose as a result of whether the organism used it or need.

Human evolution

It appeared that at the end of the semester Patricia was trying to clarify her alternative conceptions about humans. She accepted that natural selection had a valid scientific foundation, but maintained the position that humans were more intelligent and perfect. Humans were the most perfect of all created life forms. However she cleared up one alternative conception regarding the relationship between humans and apes. In
the posttest survey she said that:

We are more related to chimps than apes, and we did not evolve from chimps; we just have a common ancestor.

This was mentioned in the last lecture and was stressed by the professor. Many (95% in the lecture only group) of the other students who completed a posttest survey had a very similar answer. This might have been one aspect of human evolution which made her feel that she was not rejecting evolution completely.

Evolutionary conceptions

Linked to her conception of the nature and mechanism of evolution was her alternative conceptions about the mechanism of evolutionary change. She held a macro-evolutionary framework (Samarapungavan and Wiers, 1997) for the mechanism of evolutionary change. The alternative conception she held here was related to her alternative conception about mutation. She held the view that mutations are not chance events, that they are selected to “help better organisms” and to better equip them for their environments. In her explanation for the cave salamander need and use/disuse (because of the environmental cue) cause cave salamanders to become blind.

She chose one incorrect card in the sorting task, but understood enough of the two theories, Lamarckism and Darwinian natural selection to explain the difference between the two albeit very vaguely. She did not respond when the researcher cued her about variation nor did she attempt to include it in her answer. For the cheetah problem, she claimed that the new trait (cheetahs ran faster) occurred in the cheetah population because of the need to keep up with their prey. This was therefore a beneficial trait and the bones and muscles adapted in order for them to get faster.
Because the prey got faster in order to survive, the cheetahs got faster and the bones adapted to this speed. I still agree with this answer.

She did not mention variation, and clearly used need as the agent for change in the trait.

When cued about how she would apply the sorting task (giraffe probe) she became a little frustrated:

The slower ones dying off and the faster ones able to survive? That’s the kinda answer I have!

The prediction interviews were intended to further probe this concept. In the antibiotics problem (Appendix H) the antibiotics were medicine which could cause “something” (in humans). The human body is the target of antibiotics. She did not mention bacteria, selection, variation. She did not recognize that the conceptual basis of the problem was natural selection. In the insecticide problem (Appendix H) she failed to see or mention variation again and that the problem involved natural selection.

The skin problem elicited the conception of evolutionary change operating through adaptation; skin color changes in response to an environmental cue:

When the light skinned couple go to Africa and have children, the children will have the same skin color as the parents. Then they will develop darker skin color as well as their parents.

She did not understand that skin color has a genetic basis and that she was discussing tanning as an explanation for evolutionary changes which developed since the first man.

There is no mention of mutation or co-dominance in the case of skin color.

Therefore, for natural selection, she did not understand how variation played a role. However, she appeared to understand this in the interview (“I think natural selection operates on variation”) but still held firmly to the her alternative conceptions. She did not understand the role of random mutation (“something in our genes is altered...but it is not a chance event...there is a reason, I guess, some of our genes are
altered”) and variation, nor did she understand that non-random natural selection operated separately from the development of variation. She held the alternative conception that the quality of the trait improved over time.

Related to this concept are the concepts fitness, adaptation, and the species concept. She had a collage conception of fitness (Demastes/Southerland, 1994). In her definition of fitness she included the number of males, strength, health and size:

I choose George because of the fitness, he is healthy, stronger. But if it said how many males he would have produced and how many females, I would probably have picked the one with the most males.

She retained a collage conception of fitness in the final interview. She removed survival as being the most important trait; strength and “maleness” became dominant in her semester-end interview. Adaptation was another concept where the need to change in response to an environmental cue (Lamarckism) became the causal agent.

Adaptation is where an animal adapts to its way of life and an animal adapts to its surroundings in order to survive. I mean if I’m not using my arm...for some reason...let me use another example. I’m getting confused. It is just so you can better survive in your surroundings.

Patricia was not aware of using different kinds of explanations for this concept. She was also not aware that she was explaining her example in terms of the everyday use of the word. She retained a typological species concept and added that species have similar genetic traits. However, she did not understand a variable species concept. This is linked to her failure to understand how natural selection acts on variation in a group / species / population.

**Conceptual change at the end of the semester**

From a social / affective perspective, she definitely enjoyed the lectures and felt that she had learned something from the course. Although she had not changed her
personal beliefs, her beliefs were shaken a little and she felt that evolution was believable because of the physical evidence (e.g., fossils). She was reasoning rationally. She also questioned the ability of creationists to prove creation.

At the end of the semester Patricia had maintained her essentially Lamarckian framework for evolutionary change. This is seen in the time line she constructed; Lamarckians construct linear time lines with organisms emerging in sequence from simple to more complex (Samarapungavan & Wiers, 1997). She explained the emergence of specific traits in terms of the Lamarckian mechanism of use/disuse. She did not make any ontological shifts to scientific conceptions for mutation, variation, natural selection, fitness, adaptation and species concepts. However, she experienced a shift toward understanding that natural selection acts on variation.

Patricia found the old-earth theory intelligible and plausible, but not fruitful. She was unable to reason on a rational basis because her personal beliefs and scientific knowledge conflicted. There was one instance where it appeared that she was changing her conception about evolution, or at least her rejection of evolution. With regard to the other evolutionary concepts, for example mutation, variation, and natural selection, she found these intelligible, but not plausible nor fruitful concepts. This was because she did not understand the random nature of mutation, the origin and significance of variation, and she could not explain the mechanism of evolutionary change (natural selection). Need was the mechanism by which organisms changed and adapted to the cues from their changing environments (Lamarckian framework).

Patricia’s thinking could be described as confrontational with regard to the science and religion debate. Elements of conflict were apparent in her discourse.

121

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The issue of human evolution and that of animals in general were not fruitful to her because of her belief system. Religion “defeated” evolution because, to “accept” evolution would mean excluding important elements of her belief system. This aspect of the conceptual ecology exercised a strong influence on Patricia’s thinking. She operated under a dual construction for most evolution concepts.

Lecture-Laboratory Participants’ Conceptual Change

Martin - scientific realist and atheistic evolutionist

Preinstruction phase

Conceptual change and background

Martin was a 22 year old white male, student athlete, majoring in Plant Biology. He would graduate the next semester. Martin was in his 5th year in college and planned to pursue graduate school after graduation. He was enrolled in the lecture and laboratory courses because he was interested in the topic and because they were degree requirements.

It appeared that Martin was a very serious student who spent much of his time on the practice field and the plant biology lab where he worked as a student worker. The rest of the time his spent doing school assignments. He was talkative and voiced his opinion during discussion labs. He appeared to be very interested in this study and asked questions about the study design.

Martin had a positive orientation toward science and had a realist epistemology of science. He read science fiction, Mycologia, Discover Magazine, Science News, and had science related hobbies. His parents both had science related careers. His particular interest was mycology.
Martin subscribed to an atheistic evolutionary view and accepted evolution as an all encompassing description of the natural world and of life. According to Martin, Evolution, is a unifying concept. He asserted that there is overwhelming evidence supporting its claims. He accepted on “faith” that the age of the earth is about 4.5 billion years but would not commit himself to a particular date (“I heard of that anyway. I’m not sure why”).

Nature of evolution and nature of science

Martin was unsure of whether there was a conflict between evolution and Biblical creation. He disagreed with the teaching of scientific creationism in schools as it did not have a valid foundation; that is it did not have observable repeatable data to support its claims. Natural selection had a valid foundation for its claims. He understood that evolution is not goal-directed, it did not have perfection as its ultimate aim, it is the best theory to explain the natural world and the earth is very old.

He regarded science as his personal philosophy about life; because he believed in what could be observed.

Martin clearly understood the nature of science and this mirrored his understanding of the nature of evolution. He accepted the fallibility of scientific knowledge, and that science cannot offer absolute proof. He agreed that scientific knowledge is not just accepted but that ideas are ideally challenged and tested. Science and technology were different fields; science is observation and understanding, and technology is building or “making stuff.” However, he believed that scientists follow a universal scientific method:

To be a scientist, one must follow a rigorous course of observation and verification and report these.
Human evolution

Martin recognized that humans were classified as animals, and he recognized that they were not the most perfect life forms. He was ambivalent about the existence of a soul. This was probably linked to his refusal to reject anything for which he did not have evidence. He asserted that humans are apes, and clearly believed that all life forms had evolved. He held an alternative conception regarding humans and apes, and that perfection had a place in biology:

Bacteria are more perfect life forms (than humans). They evolve faster, are ubiquitous now and forever.

Evolutionary conceptions

Martin spoke about mutations being induced but that they were mostly chance events, and that some organisms were able to induce mutation because they have mechanisms to induce mutation. The notion that mutations equip an organism to better survive in its environment was rejected. He understood mutations were random events and that mutation was the genesis of variation. Martin understood that the cave salamander problem involved natural selection, although he did not say it was. It would select the disadvantageous traits from the population. This meant that blindness was not a disadvantage in a dark cave therefore it was not selected against. He did not indicate how blindness first occurred in the population nor how it got established. He could not explain why he chose the correct item for the cheetah problem other than indicating that use/disuse was not a valid explanation. In the interview he clearly understood what natural selection was:

Mutation is part of the genesis of variation; natural selection acts on that variation by eliminating things that are deleterious, that can’t survive, eliminating unfavorable variation.
He understood that possessing desirable traits like health, strength and so forth were not what biological fitness entailed. The unit of evolutionary change is a proportion of the population, and viability of the offspring is what mattered in “fitness”.

He selected Ben as the fittest lion (item 12) because he produced the most cubs, but failed to see that not as many reached reproductive age. Species are organisms capable of interbreeding. He did not mention that the viability of offspring (reaching reproductive age) would play a role in determining whether these organisms were a species.

He was unsure of the phylogeny of vertebrates especially whether frogs were related to fish or reptiles. This was not totally unexpected as Martin was a plant biology major. However, this was a very basic item which is covered in freshman biology courses. With regard to evolutionary patterns of change, he selected C because of one speciation event depicted in the graphic (Appendix H).

With regard to the adaptive radiation problem, he recognized that dispersal played a role in the birds occupying different niches. However, he asserted that dispersal and availability of the niches caused the birds to have different bills shapes form the ancestor. He recognized that variation was significant here, but did not explain that its origin is separate from the act of natural selection. He appeared to be using a Lamarckian explanation for the initial dispersal of the birds.

Postinstruction phase

Conceptual ecology

Martin did not experience any change with regard to his religious orientation, his acceptance of evolution, his scientific orientation and scientific epistemology. He
still asserted an uncertainty about the actual age of the earth, although it was clear he believed in an old earth. He retained his uncertainty of the concept of "soul" and refused to reject the existence of a soul for humans and non-humans. He had a realist epistemology for science. His timeline clearly depicts that he understood evolution and that he believed in a very old earth, evolutionary change and the evolution of all life forms (Appendix L).

Nature of evolution and nature of science

After instruction he had a very clear understanding of the nature of evolution. He understood that natural selection as a theory had been accepted because it had been tested and observed many times; that is there was sufficient evidence to accept it as having a valid foundation. A literal interpretation of the bible would conflict with evolution and that perfection did not have a place in biology. He asserted that scientific creationism had no place in science and served to undermine science:

Interviewer: I see that you don’t think it should be taught in school?
Martin: Not in science class. Fine in philosophy class. To call it creation science is a misnomer. Any other place but science class. If someone brings it up in science class, if you discuss it in biology we would talk about why it is not a science, we would talk about the science part.

His overall view of the nature of evolution was that it is not goal-directed, nor purposeful, that it required a very old earth and that all life forms evolved.

Furthermore, evolution by natural selection was a gradual process. With regard to the science/religion debate, he understood that evolution did not conflict with biblical creation. He held a non-confrontational, distinct view of the debate; he regarded the two areas as being separate entities based on different assumptions (McGrath, 1999).
He showed a vast improvement in the nature of science items. This was especially true for the open ended responses. Although he still accepted a universal scientific method, he indicated that scientists all follow a rigorous course of observation and verification, and that they report their data. This indicates that he knew that there is not "a scientific method." He also understood that science is a shared pursuit. This was stressed in the labs by the providing opportunities for students to work in groups to collect data, and to collate and report their findings by the next laboratory session. He recognized that scientific knowledge is not absolute proof and that it should always be questioned. Martin therefore had a good understanding of the nature of science at the end of the semester.

Evolutionary Conceptions

Martin could explain mutation and its significance much clearer. He stated that mutations arise by chance, and made a distinction between types of mutations; some did not do anything (neutral), many are deleterious to the organisms, and some help the survival of an organism. When he explained that some mutations are "caused," he was speaking about the specificity of the site selected by DNA segments.

He provided a more sophisticated explanation for natural selection:

**Interviewer:** So it acts on the phenotype?  
**Martin:** Yes it acts on the phenotype; although...indirectly acts on the genotype. Sometimes it gets confusing as to where the phenotype ends and genotype ends because the genotype is still a physical structure that can be a phenotype on a molecular level.  
**Interviewer:** Does variation have anything to do with natural selection?  
**Martin:** If there is not variation, or it could have nothing to do with it too. But in order for natural selection to act as an evolutionary force, there has to be variation.
He was able to answer both cave salamander and cheetah problems correctly. With regard to the cave salamander problem he stated the following:

I say that there’s some salamanders now that are not in caves but sometimes might be blind or have different vision than other salamanders, or there might be other developmental changes, there is some variation in the population, the original population. When they go into the caves, they are subject to different pressure, selective pressure, so that being blind is no longer a disadvantage like outside. Besides if all salamanders here went blind (outside), they’d be killed, they could not eat, it would be a big disadvantage.

It is clear that he understood the significance of variation and that he separated this from the action of natural selection. He understood the cheetah problem in similar terms. There was variation in the original cheetah population and not all ran 20 miles per hour. The faster ones, could catch the prey and produce more offspring and hence their genes are more represented in the successive generations. The rate of change is discussed below:

It does not have to be a gradual change, it could be anything...there are lots of developmental changes that can make dramatic shifts, there could be strong selective pressure to make a dramatic shift, like all the slow prey are gone and only the fast cheetahs survive. ...It does not have to be a very gradual change either. The last part: muscles etc. that is stupid. They are running faster and the bones and muscles probably developed before they ran faster. It could also happen gradually.

He clearly understood the development of stronger bones and muscles in non-teleological, non-Lamarckian terms. He was also able to distinguish between Darwinian natural selection and Lamarckian inheritance of acquired characteristics.

The prediction interviews helped to clarify his understanding of natural selection. He recognized that the antibiotic problem and the insecticide problem were about the same issue:

This is a good example for what I learned in lab. If natural selection acts fitness increases, so generally if you are putting a strong selection, which would be
antibiotics, you are increasing the fitness level of the bacteria, and every time you do that you are increasing the fitness more and more. A more fit population are those that are resistant or sort of resistant live better, have more offspring, are increasing their fitness very high. So soon the whole population is resistant. The insecticide problem...some of the same reasoning.

It is clear that he understood the role of variation, that natural selection acts on variation, and that more bacteria/insects build resistance in successive generations. For the skin problem, he also recognized variation in skin color in the population and that a mutation might have caused a variation. He was able to correctly answer all of the prediction probes.

He understood fitness in terms of the greatest number of viable offspring reaching reproductive maturity. He correctly selected Sandy as the fittest lion and his genes are passed on in higher frequency than the rest. He recognized that species are genetically isolated populations which would remain isolated because they cannot share genetic material. This represents an improvement over the pretest survey answer. He held a variable species concept at the end of the semester. He distinguished between behavioral, genetic or biological adaptation:

Martin: It is a character that’s beneficial to “fitness” of the population. How much of that genotype that produces that adaptation increases in frequency in the future generation.

Interviewer: Then it’s genetically based?

Martin: On some level it has to be. It could be subtle.

Interviewer: And behavioral adaptations, are they genetically based?

Martin: They could be and they are also cultural. I would not call that adaptation, I would call that a culture.

Human evolution

He recognized that apes and humans share similarities such as genetic and morphological similarities. He learned that humans and apes have a common ancestor
and that humans did not evolve from modern apes. Evolution does not have a purpose (it does not result in more perfect organisms) and that it is therefore not goal-directed.

**Conceptual change at the end of the semester**

From a social / affective perspective, he enjoyed learning about evolution and was very interested in the topic since his chosen career was evolutionary biology. He was the only interviewed student who showed an explicit interest in the process of this study and the process of learning about evolution. He was involved on a daily basis with career scientists as a student worker and in his personal life because both his parents are scientists. Martin thought like a scientist because he reasoned from a rational basis. Martin experienced a shift in his understanding regarding the nature of evolution; he understood that evolution is based on testable hypotheses. Perfection was removed as having a place in biology. Both conceptions required deletion of old, and the addition of new concepts (Thagard, 1992). He also further showed an ontological shift for mutation; it is random, and can be deleterious, neutral or beneficial (addition). The same happened with variation; it was what natural selection acted on. The rate of evolutionary change, can be speeded up by differential development rates (addition). Branch jumping is seen in the ontological shift to understanding that the proportion of individuals with a trait increases every generation. Tree switching is seen in the ontological shift that humans did not evolve from apes, they shared a common ancestor (Thagard, 1992).

From an epistemological perspective, he showed holistic (wholesale) conceptual change for the concepts discussed above. These concepts intelligible, plausible and fruitful. For the major conceptual groups (species concept, unit of evolutionary change
and origin of variation) he experienced wholesale conceptual change. He was able to explain that mutations are random, that they give rise to variation and natural selection acts on variation. He found the new conceptions to be believable and he was able to explain other examples using the new conceptions. This was especially true for the origin of mutation, the species concept, unit of evolutionary change and the fact that evolutionary change operates through the increase in the proportion of individuals with a trait.

**Preinstruction Phase**

**Scientific conceptions**
- Natural Selection has a valid scientific foundation.
- An old earth (plus 4.5 billion years)(on “faith”)
- Organisms have common ancestors, back to simple one-celled organisms.
- All life has evolved, evolves.
- Mutations and variation are chance events.
- Mutations can be deleterious, advantageous or neutral.
- Mutation as a source of variation.
- Mutations do not equip organism to better survive in its environment.
- Fitness as a capacity to produce offspring which reach reproductive age.
- Humans are classified under animal kingdom.
- Humans are not more perfect than other animals.
- Evolution is the best theory to explain the history of the natural world.
- Evolution does not have a purpose nor direction.
- Natural selection will select the disadvantageous traits from the population.
- Use /disuse is not a valid explanation.
- Biological species concept.
- Fitness is the attributed to viability of offspring.

**Alternative conceptions**
- Perfection has a place in biology, evolution.
- Scientists all follow a universal general scientific method.
- Unit of evolutionary change is the whole population.
- Human are derived from apes, they are apes.

**Postinstruction Phase**

**Scientific conceptions**
- Nature of evolution
- Natural Selection has a valid scientific foundation, tested and observed.
- Perfection does not have role in biology.

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**Figure 10:** Martin's conceptual inventory profile and conceptual change instances

Figure continued
Evolution does not conflict with biblical creation. Rate of change not always gradual, influenced by developmental rates. Evolution is the main theory explaining the history of the natural world. An old earth (plus 4.5 billion years) Organisms have common ancestors, back to simple one-celled organisms Evolution does not have a purpose nor direction, therefore no role for perfection in biology/evolution. Natural Selection is based on testable hypotheses. 

Evolutionary concepts Mutations and variation are chance events. Mutations can be deleterious, advantageous or neutral. Natural selection acts on variation. Unit of evolutionary change is part of the population. The trait increases and improves over time (not proportion of individuals with the trait). Selection acts to remove traits selected against. Fitness is the measure of how many offspring reach adulthood. Variable species concept.

Human evolution Humans and apes share a common ancestor. Humans cannot evolve from modern apes, chimps etc. Humans are classified under animal kingdom. Humans are not more perfect than other animals.

Nature of science Science is necessarily a shared pursuit. Scientific knowledge does not provide absolute proof, tentative. 

Alternative conceptions Scientists all follow a universal general scientific method.

Mary - creationist and scientific relativist

Preinstruction phase

Conceptual change and background

Mary (M) was a 23 year old white female, Zoology major who would graduate the next semester after 5.5 years in college. She planned to enroll in graduate school to pursue a career in herpetology. Her overall score was a B letter grade for the theory course. She did not have time for science related hobbies and did not read or watch science topics on television very much. She enrolled for the courses because she enjoyed the way the instructor teaches and because she needed the course credit.
It became apparent from reading her responses on the pretest survey that this participant had very strong religious beliefs and that human evolution was a moot point for her. Therefore her conceptual ecology for evolution was distinctly influenced by her religious orientation. She admitted that her opinion of evolution had changed since school which had taught her that evolution was "bad," "horrible," and "don't listen to it." She was however still concerned with issues like man having a soul, man being created, and man being related to apes and amphibians. She was unaware of the alternative conceptions she held in this regard and it became obvious during the interview that she had bought into much of the anti-evolution propaganda. Therefore her religious framework was congruent with her rejection of evolution, or parts of it.

She was also under the misconception that evolutionists want to convert people and that "being in the science field, it is very hard to keep your faith." Mary found herself in a conflicted situation because she thought that she had to exclude her religious beliefs in order to accept evolution. Important aspects of her conceptual ecology for evolution is her appeal to authority, her sensitivity about her belief, and her respect for authority figures in science and evolution:

It really depends on what evolutionist you're talking to and which creationist you're talking to. Some evolutionists believe that all Christianity is stupid and then with a lot of them ...(Bible-beaters) they won't listen either. Both sides are not willing to give any because they're both stubborn. But I think there are people that ...I think that ...I've talked to scientists that are Christian and they have been the best mentors I guess because they see both sides. And they believe both sides. Certain things do conflict, but I think a lot of things really go together.

It appeared that she wanted the two fields to converge and she wanted to "accept" evolution without sacrificing her religious beliefs. Another example which supports this analysis comes from the interview. When asked how science and religion differ she said that:
I don’t know, the thing is I have some tape I’ve been meaning to watch. A scientist, I can’t remember his name now but he was a scientist for his whole life. He became a Christian when he was in his 70s or 80s, and he spent the rest of his life trying to answer questions like...make...physical evidence for Christianity. And also certain things to disprove evolution you know. Back and forth and vice versa. And I’ve been meaning to watch this...that...I think I really need to watch those, those would help a lot. But...I don’t know if I know enough about evolution yet to really answer (this question).

Mary had a positive orientation toward science. Her orientation toward evolution was notably different from that toward biology. She admitted that most of evolution was pertinent to biology, but she did not mention that evolution was central to biology or was a unifying principle. She was more interested in zoology and more specifically, in herpetology. Evolution was definitely controversial to her. Her understanding of evolution at the start of this course was a sociological one connected to her experiences at school and living in the Bible Belt in the South. She was the most skeptical and forthright participant who also held many alternative conceptions in other areas of the topic.

According to Mary, there were some “flaws” in the evidence for evolution, namely, that humans evolved from apes, the age of the earth, and that we all evolved from one single organism (she was not sure about this issue). She mentioned the issue of pine tree evolution as an example of such a “flaw”:

I read a paper a while back...they were talking about the time when pine trees evolved and one strata had pine trees and then layers and layers below they had pine pollen. Which is impossible because...the only explanation scientists had for it is that there had to be some huge flood that mixed up all the layers and they settled back down. So there’s a certain things like that...that kinda shows that Christianity is involved. If you believe in Noah and the great flood, then that could be what that was.
It was clear that she had bought into creationist propaganda about evolution and that the propaganda was clouding her judgment. Her epistemology toward science could best be described as relativist and, with regard to her religious orientation, she was a quick creationist. She held a theistic view for evolution of humans and a naturalistic view for the rest of nature.

Nature of evolution and nature of science

She was confused about the nature of evolution and saw it as a direct challenge to her religious beliefs. She agreed with scientific items on the survey and then would qualify her choices with a disclaimer:

I agree with parts of this theory (evolution), but some of it is hard for me to agree with because I was raised on creation (Creationism).

It is clear that Mary was experiencing cognitive conflict with this issue. She was of the opinion that both sides (evolution and scientific creationism) should be taught at schools. They should get equal time and be taught “fairly” so that students could make an educated choice.

She could not conceive that all organisms evolved from a one-celled organism, and believed that creationism was an alternative and useful theory to evolution. However, she did see a lot of similarity between evolution and the Bible.

Her understanding of evolutionary change was that organisms evolve to be perfectly suited to their environment, that organisms have to adapt to their environments, and that the ones that adapt the best will survive. This is therefore a Lamarckian view of evolutionary change. Evolution was directional and purposeful. She clearly did not believe in an old earth. This conception is linked to her religious belief system.
Evolutionary Conceptions

Mary understood that mutations arose for a particular reason and that favorable mutations would be an advantage to the organism. At this stage she was not clear about the role of mutation in evolutionary change. This alternative conception affected the way she understood other evolution concepts.

She understood evolutionary change as operating through use/disuse (e.g., the cave salamanders problem) and through need (teleology), as was the case for the cheetah problem. In both cases the environment was the cue for evolutionary change.

For the cheetah problem she explained the following:

Mary: I would say it is kinda the same thing as with the eyes (of the salamander) and it the fact that they needed to use their muscles more and the needed to run faster in order to survive. So they adapted to the fact that their prey got faster. And so...that was gradual also.

Interviewer: So the entire population got faster? Faster over time?
Mary: Yes. Because I'm sure the prey did not one day all of a sudden get faster than they were. They probably got faster and faster also.

Interviewer: What would the impetus for change be?
Mary: I would say both the prey and the environment. Because the prey got faster for some reason also.

It is clear that the quality of the trait is regarded as improving over time, that variation is not considered as important and that need governed the process of evolutionary change. The conception of evolutionary change is therefore essentially Lamarckian.

Mary held a collage conception of fitness; considered all the “desirable traits” mentioned in item 11 on the survey (Appendix D) as essential for fitness. Fitness was connected with perfection; the more fit the animal, the more his genes would be passed on. This understanding was linked to her inability to understand the nature of
mutations. Adaptation was regarded as more immediate following the birth of offspring. Sandy was the fittest lion (correct) based on the number of offspring reaching adulthood.

This is having the best offspring going on and producing more offspring. I would think that it’s also important to have offspring adapt to the environment at that point. One thing that’s important is to have, in some species, more females than males because the fact of the ratio and the fact that she can actually have...be the breeder.

She disagreed with the typological species concept item on the survey. This was clearly the influence of the lab at this stage, because her interview followed the lab on Classification (Appendix G), where a video was shown on the species concept. She had a variable species conceptA species can breed and produce viable offspring that can go and breed again. The kittens graphics (Appendix H) did not confuse her. Even though they were phenotypically different, she recognized this and agreed that they were still one species. The wild cats on the other hand were different species, even though they might be able to breed, she recognized that their offspring would not be viable.

She used a Mendelian explanation for the mice prediction interview. Mary correctly rearranged the phylogenetic tree of the vertebrates. She had taken a number of courses in vertebrate zoology (herpetology and ichthyology). She selected the correct phylogenetic tree depicting evolutionary change (C) for changes like adaptive radiation of the finches. Consistent with her belief system, she selected B for evolutionary change of humans:

Humans will stay humans forever. I don’t think we’ll change into anything else or anything has changed into humans.

Mary managed the conflict between her personal belief system and evolution by incorporating selective elements of evolutionary theory and creationism. She accepted
many of the elements of evolution but could not apply these to humans. At the start of the semester, she was in a conflicted situation (McGrath, 1999).

The example of adaptation indicate that she used the everyday understanding of “adapt.” The environment was the casual agent in adaptation. She recognized that there were adaptations that were genetically based. From her explanation of adaptive radiation, it was clear that she understood that speciation could occur when members of a species become isolated (e.g., geographically isolated) and that this could lead to speciation (through reproductive isolation). However, she did not expand on the mechanism of this change. She mentioned chance but not how it connected to the different bill shapes; she explained the change in bill shape in terms of need. She did not understand that variation existed in the initial population and that selection acted on that variation.

Human evolution

Mary believed that humans were special, that they were the only life forms that possess a soul, and that we did not share a common ancestor with apes.

I strongly disagree. We are similar, but...so why are apes not still evolving into humans today???

Mary made a clear distinction between creation and evolution; everything was created and evolution affected all living things. Therefore she accepted that all life forms, including humans, did not stay the same. She believed in a literal interpretation of the creation story and therefore in a young earth. In the interview she explained that animals did not have a souls and that when they die, their lives end. Humans were special and when they died, they possibly transcended to something else. She asserted
that evolution affected humans and animals in a similar way, and that evolution was reversible.

Postinstruction
Conceptual ecology

She would be described as a quick creationist for her religious orientation, because she retained the alternative conception of a young earth (albeit between 10 and 100,000 years old) and special creation for humans. The age for the earth that she selected was indicative of the fact that she knew that evolution takes a long time. It also indicated her reluctance to abandon her beliefs. This was clear in her statements that “apes and humans don’t share a common ancestor,” “all things were created,” and her opinion that creation (ism) is a more useful theory than evolution for explaining the history of the natural world. This was clear too in the time line she constructed which depicts a literal biblical interpretation of the creation story (Appendix L).

With regard to her rejection of macroevolution it became clear that this was equated with the broad view of evolution which is very controversial for creationists. Macroevolution, according to Mary, is “just the general theory that humans evolved from apes.” Therefore this was clearly the reason for her not accepting evolution as a plausible explanation for the history of the natural world.

She had a realist epistemology of science and a distinct scientific orientation (McGrath, 1999). This characterization contrasted sharply with her essentially creationist belief system. Toward the end of the semester Mary showed some signs of attempts to integrate the two world views. Her views bordered on confrontational and convergent categories (McGrath, 1999) for the science-religion conflict. It appeared
that Mary was, on the one hand trying to reconcile the two views, and on the other hand, attempting to hold on to her beliefs. She felt that evolution threatened her beliefs.

Nature of evolution and nature of science

In the pretest, it was clear that Mary did not understand the error of goal-directedness in evolution. In the posttest she appeared to have a better grasp of the process of evolution, but she maintained the notion that evolution had a goal so that animals are better adapted to their environments. The changes are to better serve them and their offspring.

She understood when she was using teleological explanations. She ended the semester with a better understanding of the nature of evolution. Although she maintained her views regarding an old earth and humans as special creations, she changed her opinion about the teaching of special creation as an equal alternative to evolution. Mary greed that scientific creationism should not be taught as an equal alternative to evolution. This issue was discussed during a lab session.

She indicated in the posttest that organisms are immutable; this indicates a reversal in her conception. It appears that this was another point at which she could not separate her religious beliefs from her understanding of evolution. This item is linked to item 8 which speaks to the relationship organisms have as a result of evolution from common ancestors going back to the simplest one-celled organisms. She disagreed with this. This indicates that she was being consistent in her rejection of large scale evolution. When asked whether her opinion about evolution had changed:

A little. I still don’t believe much about macroevolution, but I do believe in microevolution. I don’t believe anything that’s macroevolution not because that’s not true, but a lot of it I find very, I find very skeptical...
She demonstrated a better understanding of the nature of science items on the posttest. Science does not provide absolute proof. Science and technology are two different fields of study. However she maintained a view that scientists follow "a universal scientific method."

Evolutionary conceptions

After instruction she understood that mutations are chance events, and she understood that, depending on whether or not the mutation is beneficial, it could equip the organism with a better chance of surviving in its environment. She expanded on this in the interview:

Mary: The fact that there is a genetic mishap and an animal either takes on characteristics that are...I mean the next generation either takes on characteristics that are better for its species worse...depending on whether the mutation is beneficial or not.
Interviewer: How would variation tie into that?
Mary: I would say that mutation is the number one source of variation

From this discussion it is clear that she has a good understanding of the randomness of mutation and that mutation is one source of variation.

Her concept of natural selection underwent a drastic change. After instruction she understood that natural selection acted to remove deleterious traits:

I think that natural selection would select for organisms...mutations that were most beneficial and then would select against mutations that did not enable the animal to get ahead.

In the sorting task (Darwinian natural selection versus Lamarckian acquired characteristics) she successfully explained her choices based on her previous explanation. However, she had a dual conception for the mechanism of evolution. For the cave salamander and cheetah problems she explained the mechanism of change as
operating through need (the cave salamanders did not need eyes, and other senses were enhanced; the cheetahs got faster in order to keep up with their prey). The researcher would explain this as follows: Mary needed to know that this example involved natural selection, then she would be able to explain it in terms of natural selection. When faced with novel examples like these, she was unable to fit it with a particular algorithm. She could explain the giraffe problem in terms of natural selection because she recognized it as an example of natural selection. It was also a question on the final examination.

Further probing on this topic was afforded by the prediction interview. She (incorrectly) understood that the antibiotic worked on the human body which would build resistance toward it. The antibiotic would be needed for major disease and resistance builds through generations. The antibiotic would then not be useful and the person could die from the disease. In the insecticide problem, the insects also built resistance to the insecticide. The skin problem elicited a Biblical explanation:

Interviewer: Humans arose in Africa, how do you explain for skin color which exits around the world today?
Mary: I take that from the Bible. I think that it was in Jerusalem. I don't know the exact story (Tower of Babel). Yes, yes I would use that to explain this.

For the rest of the predictions on skin color, she did give a rational explanation, but she did not give a plausible explanation for variation in skin color. In general, she did not recognize any of these problems as natural selection problems.

She did not change her conception of fitness and adaptation after instruction. She held a dual conception for the species concept after instruction; the typological as well as the biological species concept. Natural selection, adaptation and evolution are concepts which got blurred from time to time. She appeared to have a dual conception
for evolution. Although she regarded all things as changing she maintained that all things were created. She contradicted herself by stating that life forms look essentially the same today as when life first appeared on Earth. This would be an instance of conflict between religious belief and scientific understanding of a conception.

**Conceptual change at the semester’s end**

From a social/affective perspective she continued to be interested in evolution but was clearly only interested in microevolution. She did not accept macroevolution. She maintained that humans were special and that all things were created. Mary subscribed to the view that creationism is a more useful theory for explaining the history of the natural world. She ended the course with a sociological orientation toward evolution.

Mary was able to understand that mutations are chance events (deletion and central rule change; Thagard, 1992), that mutations can be beneficial, deleterious, or neutral (central rule change, addition). This was a significant ontological shift from an alternative to a scientific category. It is crucial to the understanding that evolution is not directional or does not have a purpose, and it facilitates an understanding of how variation arises and the significance of variation.

She also understood natural selection as one of the main mechanisms of evolutionary change after instruction. This is a instance of deletion of a central rule and the replacement with the scientific conception (Thagard, 1992). However, she also held the alternative conceptions of need and use/disuse. She operated under a dual conception for the origin and mechanism of evolutionary change. Her understanding of natural selection and mutation and variation went were linked to her understanding of
the variable species concept (deletion and addition). It is clear that she experienced
conceptual change for mutation, variation, the significance of variation, and the action
of natural selection on variation. She understood how natural selection selected the
individuals/mutations from the population that were not beneficial to suiting the
organism to its environment. She found these concepts to be intelligible, plausible and
fruitful.

She found the concept of natural selection to be intelligible and plausible but not
entirely fruitful; she also accepted need and use/disuse as alternatives to explaining
evolutionary change. She therefore did not find natural selection to be a fruitful model
to explain all the examples dealing with natural selection. In this sense she had a dual
construction for this concept.

<table>
<thead>
<tr>
<th>Preinstruction Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific conceptions</td>
</tr>
<tr>
<td>Nature of evolution</td>
</tr>
<tr>
<td>Natural Selection has a valid scientific foundation.</td>
</tr>
<tr>
<td>Everything evolved.</td>
</tr>
<tr>
<td>Evolutionary change is gradual.</td>
</tr>
<tr>
<td>Evolutionary concepts</td>
</tr>
<tr>
<td>Variable species concept.</td>
</tr>
<tr>
<td>Mutations can be deleterious or advantageous.</td>
</tr>
<tr>
<td>Fitness as a capacity to produce offspring which reach reproductive age.</td>
</tr>
<tr>
<td>Human evolution</td>
</tr>
<tr>
<td>Humans are not classified under animal kingdom.</td>
</tr>
<tr>
<td>Humans are not more perfect than other animals.</td>
</tr>
<tr>
<td>Other organisms evolve.</td>
</tr>
<tr>
<td>Humans and apes have a common ancestor.</td>
</tr>
<tr>
<td>Nature of science</td>
</tr>
<tr>
<td>Scientific knowledge is tentative.</td>
</tr>
<tr>
<td>Cannot offer absolute proof.</td>
</tr>
<tr>
<td>Acceptance is not straightforward.</td>
</tr>
<tr>
<td>Alternative conceptions</td>
</tr>
<tr>
<td>Nature of evolution</td>
</tr>
<tr>
<td>Mutations and variation are not chance events.</td>
</tr>
<tr>
<td>Mutations arise for a reason.</td>
</tr>
</tbody>
</table>

**Figure 11: Mary’s conceptual inventory profile and conceptual change instances**
Organisms do not have common ancestors, back to simple one-celled organisms.
Organisms evolve to be perfectly suited to their environment.
Creationism provided an alternative explanation more useful in explaining the history of the
natural world.
A young earth.
Evolution is reversible.
Evolution has a purpose
Evolution is directed by God.

Evolutionary concepts
Use/Disuse and need as mechanisms of evolutionary change.
Unit of evolutionary change is the whole population.
Fitness defined in terms of “desirable traits”.
The trait improves gradually from generation to generation.

Human evolution
After creation, humans do not evolve.
Humans have not evolved to their present state.
Humans were special.
Humans did not share a common ancestor.

Nature of science
Scientists all follow a universal general scientific method.

Postinstruction Phase
Scientific conceptions
Nature of evolution
Natural Selection has a valid scientific foundation (?)
Evolution is the main theory explaining the history of the natural world. (?)
Evolution does not have a purpose nor direction. (?)
Scientific Creationism has no scientific foundation.

Evolutionary concepts
Mutations can be deleterious or advantageous.
Mutations and variation are chance events.
Fitness as a capacity to produce offspring which reach reproductive age.
Mutation is a source of variation.
Natural selection acts on variation
Unit of evolutionary change is not the whole population; but part of it.
Natural selection as a mechanism for evolutionary change.
The trait increases and improves over time (not (?!) proportion of individuals with the trait).
Selection acts to remove traits selected against.

Human evolution
Humans cannot evolve from modern apes, chimps etc.

Nature of science
Science cannot offer absolute proof.
Science and technology are not the same.

Alternative conceptions
Nature of evolution
Organisms do not have common ancestors, back to simple one-celled organisms
Life forms look the same today as when they first appeared on earth.
Rejection of macroevolution.

Figure continued
Evolutionary concepts
Fitness is the ability to adapt to new situations.
The trait increases and improves over time (not proportion of individuals with the trait).
Evolution operates through need, use/disuse, special creation.
Species are immutable.

Human evolution
Humans are not classified under animal kingdom.
Humans are more perfect than other animals.
Humans and apes do not share a common ancestor.

Juan - gradual creationist and scientific realist

Preinstructional phase

Conceptual ecology and background

Juan was a 23 year old Spanish-speaking male who spoke English as a second language. He was a Wildlife and Fisheries (Forestry) major and he intended to enter an applied science career after graduation. He enrolled for the lab and lecture courses to meet degree requirements. He did not have family in science careers nor did he have a science related hobby. He had a positive orientation toward science and he regularly read science columns in various magazines. Juan also enjoyed science fiction (Star Wars). With regard to his scientific epistemology, he was a realist because he recognized that a “scientific method” followed strictly by all scientists cannot exist, he acknowledged that science could not provide absolute proof, and that scientific knowledge is fallible and acceptance of such knowledge is not straightforward.

Juan was not very religious and did not make a firm statement about the role of a divine being in evolution. However, it was obvious during the interview that he operated through a religious framework some of the time and a scientific framework at other times. He did not consider the conflict between religion and science to be valid. He acknowledged that other people did but to him “religion is religion and nature is
nature." Juan therefore held a view that religion and science are distinct, but also showed signs of convergent thinking at the start of the semester (McGrath, 1999). He recognized that science and religion spoke to different things but he also held the view that they should “just be together, just to make things better”. This is indicative of convergent thinking. He was probably referring to an end in conflict between the two.

Juan mentioned that he did not attend church but did not elaborate on this issue. He appeared to be a nominal Christian who attended church on special occasions and whenever he was around his family. However, he mentioned that he believed in creation and that God created man in his own image. He could not commit to the idea of an old earth but he understood (or maybe learned) that evolutionary change according to the Darwinian model takes place gradually. He was classified as a gradual creationist at the start of the study. He accepted a modified version of evolution and entered the courses with many alternative conceptions.

Nature of evolution and nature of science

He was unable to answer the item regarding the evolution of life forms from common ancestors going back to single-celled organisms (survey item 8). He understood evolution to be gradual, purposeful, and directional, and engineered; that is, he saw perfection as a goal of evolution.

Evolution is meant to make something perfect. More perfect and more suitable for that environment so they can reproduce and still live and keep going on.

He also considered evolution important for connecting biological facts. He incorrectly indicated that the individual not the population is the unit of evolution.
Juan demonstrated a number of alternative conceptions with regard to the nature of science. He probably did not understand that science proceeds due to many small steps after falsifying hypotheses. That is trial and error is part of the process of science. He understood that science and technology are different and that acceptance of new scientific knowledge is not straightforward. He also viewed disagreement among scientists the same way he saw disagreement between two religious sects. It appeared that he did not recognize that the difference would be that the scientists should be seeking the best hypothesis not the most politically correct or appealing one.

Evolutionary Conceptions

Juan did not understand the meaning of “chance” hence he assumed that everything happened for a reason. He did not understand that mutations are random. According to Juan, mutations had to have a purpose. This was linked to the alternative conception that change in organisms over time is goal-directed or purposeful.

He understood natural selection to be a purposeful act and he anthropomorphized it. He held the alternative conception that the bones of cheetahs became adapted to run faster. He added that the change was a gradual change. The causal agent was the prey which got faster. The rest of his response indicated that he did not understand the role of mutation in this example and that he did not clearly see the significance of variation. He appeared to imply that something changes in some individuals in the population but he was not clear and did not use the term mutation. He did not mention natural selection but did imply this (“some get all the meat and the others die, or they could not make it”). This indicated that he did not separate the origin of the trait (speed) from the act of selection (non-random). Therefore he
proposed that the cheetahs got faster because their prey got faster. Hence need was the mechanism whereby evolution proceeded.

Use/disuse (Lamarckism) played a role in his answer for the cave salamander problem. The dark (environment) was the causal agent in this problem. He also mentioned the enhancement of other senses like hearing and smell. He equated this process to how blind people use their hearing to compensate for their blindness. This is an instance where he used anthropomorphism. Therefore evolution proceeded toward the enhancement of beneficial traits to compensate the loss of another trait (sight). He again did not make the connection between a random mutation that arise by chance and variation upon which natural selection would act. Fitness was defined in terms of the “desirable” traits of health, youth, strength and how organisms pass it (possibly the change/trait) to their offspring. He correctly identified Sandy as the fittest lion but added that Sandy was younger than George as well. He portrayed a collage conception of fitness (Bishop and Anderson, 1990; Demastes/Southerland, 1994). This was common among a large percentage of the whole-class participants.

He agreed with the typological species concept and this is linked to his inability to understand the significance of variation. The typological species concept ignores the existence of variation as well as the role of random mutation in developing variation. Need or use became the causal agents for change. In the interview he could not expand effectively on his preinstruction survey answer. He identified the phenotypically different domestic cats as belonging to the same species even if they were different colors (Appendix H). He did not mention the fact that they interbreed and produce viable offspring (reproductively isolated from other groups). Morphological similarity
defined a species (typological species). The wild cats were morphologically different therefore they were not in the same species. However he also mentioned that they can interbreed, but he did not mention that the offspring would not be viable. He did not have a clear understanding of the biological species concept.

He used the word adaptation in its everyday context; an individual changing by its own will. In the adaptive radiation problem (Darwin’s finches graphic was used as a probe), he explained the different types of finches as developing different beak structures due to their diet. The birds adapted slowly to things around them and the environment then provided the cues for change in beaks and coloration. He did not understand mutation, variation, and the gradual increase in proportion of individuals with the trait (beak structure differing from the ancestor) over successive generations.

Juan chose the correct phylogenetic tree (diagram C in Appendix H) which depicts evolutionary change. He hesitated about whether evolution in humans had followed a similar path.

He was grappling with human evolution during the pretest phase period of this study. He rearranged the scrambled vertebrate phylogenetic tree correctly, (Appendix H) but he removed humans from the list because he did not “see” humans in this scheme. From this example it appeared that he held the conception that humans were special creatures and that they were the product of a special creation event. It appeared that for this concept at least he was a quick creationist.

He understood genetics in terms of Mendelian genetics as was uncovered by the mice probes (found in Appendix H). However, it appeared that he held an oversimplified understanding of genetics.
Human evolution

Juan did not see humans as any different from other animals with regard to evolution but he indicated that they might have been the product of special creation. He understood that humans were not more perfect than lower animals and he indicated that every living thing possessed a soul. He was not able to answer the item about whether humans and apes share a more recent ancestor than humans and dogs. He held the alternative conception that humans evolved from apes. From the interview data it is clear that he was not sure about the issue of the presence of a soul but that he was appealing to authority (religion). He would not commit to an answer either way. He also questioned the creation story of mankind, but conceded that humans came from something else (evolved) and that they might not have looked like they do now. It appeared that Juan was struggling to reconcile his beliefs and his understanding.

Postinstruction phase

Conceptual ecology

Juan showed a shift in his conceptual ecology with respect to his religious orientation. He shifted in his understanding and moved closer to an acceptance of evolution. Like Adrian he showed evidence of straddling the categories of gradual creationism and non-theistic evolution. His scientific orientation remained unchanged and his epistemology for science also remained about the same.

He understood evolution at best very modestly; he scored a C plus in the final examination and a D in the last exam. Scores for the isolated items indicate that he understood natural selection modestly (C) and that he failed to understand biogeography (less than 50%) as well as phylogeny. He scored above 90% for the allometry items.

151
Nature of evolution and nature of science

Juan changed his opinion about scientific creationism being taught in schools because he now regarded it as non-scientific because it could not be falsified. He still could not answer the item related to origins from a single-celled organism. He tentatively agreed that evolution could explain most of the natural world although it did not cover everything. He considered science and the Biblical account of creation to be in conflict with regard to quick creationism ("because the earth was not created in one week"). This is linked to his shift from progressive creationism to gradual creationism. By the end of the semester, Juan had shifted to a view that separated evolution (science) and religion as two distinct fields (McGrath, 1999). This represented a major shift in his thinking because it appeared to hold him back in the pretest stage of this study.

Evolutionary conceptions

The unit of evolution changed after instruction from the individual to the population. Juan also shifted his conception of fitness from a collage conception which included strength, survival, health and number of females, to a much narrower one. He chose Sandy this time for the correct reason; the production of viable offspring to perpetuate his genes.

Preinstruction Phase
Scientific conceptions
Natural Selection has a valid scientific foundation.
Humans are not more perfect than other animals.
Evolution involves gradual change.

Alternative conceptions
Nature of evolution
Evolution is meant to make something perfect.
Evolution has a purpose and direction.

Figure 12: Juan's conceptual inventory profile and conceptual change instances

Figure continued
Evolutionary concepts
Mutations are not random, they have a purpose.
Mutations are advantageous to the organism.
Use/Disuse and need as a mechanism of evolutionary change.
Natural selection is a purposeful act.
Typological species concept.
Unit of evolutionary change is the whole population.
Fitness: desirable traits and adaptations are passed on.

Human evolution
Human are derived from apes.
Human beings are not animals.
Special creation for humans.

Nature of science
Scientists all follow a universal general scientific method.

Postinstruction Phase
Scientific conceptions

Nature of science
Natural Selection has a valid scientific foundation
Natural Selection is based on testable hypotheses.
Scientists do not all follow a universal general scientific method.
Evolution is the main theory explaining the history of the natural world.
An old earth (plus 4.5 billion years)
Organisms have common ancestors, back to simple one-celled organisms
Evolution does not have a purpose nor direction.

Evolutionary concepts
Unit of evolutionary change is part of the population.
Mutations do not necessarily equip the organism with a better means of surviving in its environment.
Variation exists in a population.
Fitness as a capacity to produce offspring which reach reproductive age.

Human evolution
Humans are classified under animal kingdom.
Humans are not more perfect than other animals.
Humans and apes share a common ancestor.
Humans cannot evolve from modern apes, chimps etc.

Alternative conceptions
Nature of science
Evolutionary concepts
Typological species concept.
Mutations and variation are not chance events.
Origin of variation unsure.
The trait increases and improves over time.

Juan retained the alternative conception that mutations are purposeful.

However, he understood that mutations did not necessarily equip the organism with a better means of surviving in its environment.
Juan failed to see the possibility of a mutation causing blindness in the cave salamander problem. He continued to regard the development of blindness in terms of loss through disuse. In the cheetah problem, he stated that the slower cheetahs were selected against; this implies that he knew that there was variation in the population even though he did not verbalize it. However, he again did not see the significance of mutation in this probe. Selection was mentioned, but Juan did not separate natural selection from the first stage (origin of the new trait). He also did not explain that the trait became established through the changing proportion of individuals with discrete traits with each successive generation. This final step in explaining evolutionary change is missing in all his explanations of natural selection and evolutionary change. Hence in the cave salamander probe, he views the trait (sight) as deteriorating because the salamander did not "need" it in the dark cave (the trait itself deteriorates from one generation to the next).

At the end of the semester he still held the typological species concept. This is despite the lectures and lab session on the species concept. The lab session included a video which showed how a species is defined by the production of viable offspring (biological species concept). This lab on taxonomy and classification pointed out the different species concepts. The video showed examples of non-viable crosses.

Human evolution

Juan shifted in his understanding of how humans and apes are related. He was more unsure of whether humans possess a soul, and whether everything had a soul ("who knows"). He appeared to be questioning whether this could be true. This represents a point of cognitive conflict for this participant.
Conceptual change at the semester's end

From a social-affective perspective, Juan accepted that evolution had occurred and is occurring, and he enjoyed learning about it. Although he was not overly religious, he was a Christian who reasoned about evolution as if it were designed and orchestrated by a supreme being. It appeared that he was experiencing dissatisfaction with his personal understanding of evolution and its implications. For example, he was unsure of the concept of "soul" at the end of the semester.

He experienced a number of ontological shifts after instruction in the lecture and lab courses. However he retained alternative conceptions of certain very important concepts. He accepted the old earth theory for evolution, because earth was "not created in a week." This ontological shift involved the deletion of a central rule of creationism and its replacement with a scientific evolutionary concept. Another important ontological shift, was the replacement of the individual as the unit of evolutionary change, with a proportion of the population as the unit of evolutionary change.

Human evolution concepts changed most dramatically. For example, he understood that humans and apes have common ancestors; that humans did not evolve from apes; that humans are not perfect and humans are classified as animals. These are examples of deletion, addition and the last example illustrates an instance of "branch jumping" (Thagard, 1992). He asserted that humans are not special, but belong to the animal kingdom.

The fact that evolution is not directional nor purposeful was an ontological shift probably influenced by conceptual change with regard to human evolution. The former
involved the deletion of a central rule and its replacement with a scientific conception of the nature of evolution. Juan experienced conceptual change for many of his alternative conceptions, but these included many "minor" conceptions. The concepts discussed above are intelligible to him (he was able to explain them accurately), they are plausible because they were believable to him, and they were fruitful as well.

The major conception that he found intelligible and plausible but not fruitful is the variable species concept. He understood that mutations and variation arise by chance. However, the fact that mutations give rise to variation, and the proportion of individuals with a trait increases with each generation, are not intelligible, plausible nor fruitful. He did not accept them as believable, and he mentioned that he was unsure about the origin of variation. He did not experience wholesale conceptual change. He held dual constructions for many concepts.

**Rhonda - atheistic evolutionist and scientific realist**

**Preinstruction phase**

Conceptual ecology and background

Rhonda was very different from the other three females who participated in this study. She was a 24 year old white female and a Zoology major who had been at college for 5 years. She would graduate that semester. She wanted to enroll in graduate school after graduation. She mentioned her interest in marine biology and she enjoyed watching Animal Planet, Discovery Channel, Nova, and read Discover Magazine. She had enrolled for the lecture and lab courses because she was interested in anthropology and evolution and because it was a required course. From the beginning it was clear that she was not religious (atheistic evolutionist) and was very
skeptical of religion. She fully accepted evolution. Rhonda had a bubbly personality, she was talkative and was very interested in the lecture and lab courses. She participated in lab discussions and would stay behind after lecture and lab to clear up an issue with the instructor or graduate assistant. She was involved in trying to expand her learning of this topic. Her scientific orientation coincided with her realist epistemology, but it could be characterized as a naive realist epistemology. She understood evolution and natural phenomena in a mechanistic way and the most noticeable aspect of her conceptual ecology was her “support” of evolution and her rejection of religion:

I am a strong believer of evolution-fact or law-most other explanations are questionable. The Bible believes that God created man in the image of himself---what created God?

However, as a naive realist she did not always use rational criteria in her understanding of science, she often interjected her comments with appeals to authority (science) and appeared to buy into scientific dogma. For example, in her answer to the item about the age of the earth, she answers affirmatively that the earth is older than 4.5 billion years, but qualifies this response with “check the books.” It became clear that a lot of her knowledge about science, evolution, and the natural world came from the courses she had done at college. She provided examples from human evolution and anthropology during the interviews and confirmed that she enjoyed human evolution and related issues. This was visible too in her time line drawing which depicted the major events of life on earth.

Nature of evolution and nature of science

Rhonda was a strong supporter of evolution and she disagreed with the notion that there are alternative theories that can explain the history of the natural world. She
was under the misapprehension that the goal of evolutionists is to have people “believe” in evolution. It was her assertion that evolution is in conflict with the Biblical account of creation and she understood the scientific conception of an old earth.

She did not have a very good understanding of the nature of science; her open-ended responses were not always based on rational criteria and she held alternative conceptions in this regard. Her response to whether science provides absolute proof was that science provided proof and that science teaches things that have been proven. This response is congruent with her tendency to rely on the opinion of authorities (science in this case) instead of basing her answers on the plausibility of an event/item. However, despite her classification as a naive realist, she had a very strong orientation to science, evolution and anthropology.

Evolutionary Conceptions

Rhonda accepted tentatively that mutation and variations arose by chance. Like Adrian, she believed that since mutations can be induced (in the laboratory) the origin of mutations did not constitute a chance event. Further probing during the interviews, made it clear that she did not fully understand the randomness of mutations. She agreed with an incorrect item that stated that mutations equip organisms with better means of surviving in its environment. But she indicated in the open-ended response that “not all mutations are good.”

From her explanation in the interview, it became clear that Rhonda had a poor understanding of natural selection. Rhonda tended to explain evolutionary change in terms of the environment. She stated that blindness occurred because cave salamanders found themselves in a dark cave, and hence the environment made it unnecessary for
sight. She therefore held alternative conceptions namely, that all the individuals (cave salamanders) became blind at one time, she used need (need to keep up with their prey in the case of the cheetahs) and the environment (darkness in the case of the cave salamanders) as the causal agents of change. She did not indicate the role and significance of variation. She also did not understand the origin and significance of variation. Nor did she understand how selection acts on this variation.

Even though she correctly disagreed with the incorrect item 12 (George is the fittest lion) she did not understand the concept of biological fitness and she indicated that she was unsure of her answer. Ben (the lion which fathered the most cubs, had the most females and died at an old age) as the fittest lion. It appeared that she associated fitness with longevity which in turn was connected with the ability to produce offspring. She subscribed to the typological species concept. This is connected to the dismissal of the role and significance of variation in natural selection. Proponents of the typological species concept dismiss the importance of variation in evolutionary change.

Rhonda had good understanding of phylogeny and taxonomy in the preinstruction interview. Humans were included in the vertebrate phylogenetic tree. She selected the correct phylogenetic diagram, diagram C, which depicted evolutionary change (Appendix H).

She explained adaptation in the everyday context of the word and did not understand how variation provides the raw material for natural selection. She explained how finches developed different beak shapes in terms of adaptation to a changing environment.
Human evolution

Rhonda held alternative conceptions with regard to humans such as, humans have souls and humans evolved from apes. She regarded all organisms including humans as having evolved from a common ancestor. Like Adrian, she expressed her interest in human evolution. She was looking forward to the topic on human evolution near the end of the semester.

Postinstruction phase
Conceptual ecology

After the course she still felt the same about evolution; that is, she was interested in it. She did not change her orientation toward science nor did she change her mind about the rejection of religion. Rhonda was an anti-theistic evolutionist with regard to her religious orientation. She did not maintain her tendency to appeal to authority, instead she based her support for or against an issue on rational criteria:

I just...this creation story boggles my mind. And until somebody shows me proof...says look at this, this is your ancestor ...I have to have evidence before I throw my money in a collection plate.

The time line she constructed during the drawing task interview indicated that human evolution was a central issue in her conceptual ecology. She accepted that humans have evolved and she accepted a common ancestor for humans and apes. By her own admission, she had gaps in her knowledge about the evolution of other animals, plants and life forms (Appendix L).

Nature of evolution and nature of science

Rhonda shifted her understanding of the nature of science and the nature of evolution by the end of the semester. However, these shifts were not dramatic and she
also held on to some of her alternative conceptions. In the survey she changed her opinion regarding how perfection is built into natural selection. She agreed with the item (incorrect) which claimed that evolution is goal-directed and culminates in perfect adaptation to an organism's environment. Her answer to the item 15 (There are other alternative theories that can explain the natural world better than evolution) also changed. She previously held the view that "belief in evolution" is a goal of evolution education. She held the view that evolution conflicts with Biblical creation.

In the interview she expanded on the nature-of-evolution ideas. Rhonda explained that the lab and lectures had provided her with knowledge which enabled her to make more sense of evolution. She based her answer here on rational criteria including evidence and proof for evolution. She rejected the creation story on the grounds that it did not have physical proof or evidence for its claims. This illustrates a shift in her understanding of the nature of science.

At the start of this study, she appeared to have a weak understanding about the nature of science as is evident in her open-response answers. This changed slightly after instruction.

Evolutionary conceptions

There appeared to be a discrepancy between her answers on the survey and those in the interview. She did not understand the mutations are chance events. She maintained her original answer during the interview. It was clear that she was referring to induced mutations, but she could not explain what happens in nature. Rhonda was able to understand that not all mutations are beneficial; this was a change over her preinstruction answer.
Her posttest survey did not expand on her (incorrect) choices for the cave salamander and cheetah problems. In the interview the cave salamander problem, which is an example of a “non-beneficial trait” (blindness - recessive trait), proved to be a stumbling block for her. She was unable to understand that this example involved variation and natural selection. She could not conceive that mutation was involved. Because she did not understand the essence of biological fitness, she was therefore unable to solve this problem.

However she immediately recognized the cheetah problem as a natural selection problem. When asked if she could explain this problem in terms the sorting task (Appendix H), she went back to the cave salamander without prompting. The latter indicated that she was experiencing dissatisfaction with her conception for this example.

The faster ...the variation of fastness in cats, the faster cats got more food/better food, reproduced more viable offspring. And therefore passed on their trait. The salamanders I still don’t ...because I don’t think eyesight doesn’t seem to me...it’s necessary for survival. So blind one’s and the one’s that had eyes still ate, still would be able to reproduce just as much. It’s not...to run slow and not to catch food that’s a big deal because you won’t live yourself much less produce offspring or they’d be weak. You have the giraffes with the higher necks were able to eat more, the cheetahs who catch their prey were able to eat more...so that’s what I make of that. The eyes would not make a difference to me though. Cause if they all went blind they were still able to eat but even the ones that had eyes were able to eat too.

The examples used, giraffe and cheetah problems, deal with “beneficial” traits such as longer necks to reach leaves and speed to catch prey respectively. The cave salamander problem deals with the loss of a “non-beneficial” trait (a recessive trait) because sight would not matter in a dark cave (it was more adaptive in that environment than having sight). It is clear that Rhonda was defining evolutionary change, and in particular the
mechanism of natural selection, as operating through need and the acquisition of beneficial traits. With regard to traits that are “non-beneficial”, they were not needed, therefore loss of such a trait (e.g., sight) would not count as natural selection. She did not understand completely the significance of natural selection and how it operated. Further probing through the prediction interviews indicated that Rhonda did understand in a broad sense how natural selection operated. For the insecticide problem, she spoke about insects building immunity against the insecticide. This indicated that she did not understand that natural selection was at work. Rhonda understood that the skin problem entailed a mutation in the original population. She correctly answered the prediction questions related to this problem.

It was clear that she understood that there was an increase in numbers of individuals in each generation with a trait, and that it was not the quality of the trait that improved with each generation. She did not understand the origin of variation but did understand its importance; therefore she was able to understand that natural selection acts on variation. This also contributed to the conceptual shift away from using need as a mechanism for evolutionary change.

Her conception of fitness changed to a scientific conception; she disagreed with the definition in the survey (item 11), and seemed to be negating the importance of robust health which she stated sounded “chauvinistic”. She selected Sandy as the fittest lion and this was based on a narrower definition related to reproductive potential.

Her conception for species also changed from typological to at least a consideration of genetic compatibility. She referred to the fact that members of the same species are able to interbreed because they were not genetically isolated. She
shifted therefore from a typological species concept to a variable species concept. This is linked to her understanding of fitness and the importance of variation in species.

She had a good understanding of how organisms were related and understood evolutionary relationships between various groups. Her special interest was the phylogenetic relationship of humans. This is linked to her interest in anthropology.

She linked adaptation to mutation and regarded adaptation as an act which is crucial after a mutation had occurred. Adaptation was therefore a step which was necessary in order for a species to carry on and was connected to natural selection.

Human evolution

In the postinstruction interview and survey she appeared to have a reasonably good understanding of human evolution. This was still the area of evolution she was most interested in and she appeared to have the most examples, anecdotes and knowledge on this topic. She changed her conception that humans evolved from apes; she now mentioned that we have a common ancestor. Her response to item 9 indicated that she had discovered her alternative conception on this topic, because she mentioned the fossil record (that is comparisons with a common ancestor) and DNA analysis. In her time line she almost exclusively mapped the relationship of humans to their primate relatives when asked to draw a time line showing the major events in the history of life on earth (Appendix L).

Conceptual change at semester end

Rhonda was very interested in evolution and enjoyed the labs and the lectures. She sat near the front of the class in both courses and could always be seen talking with the instructor and the assistant. She particularly enjoyed human evolution. She maintained an anti-theistic evolutionary view and rejected religion on rational grounds.
Rhonda held a dual conception for mutation; she was unsure whether it was a chance event at the beginning of the study. At the end of the semester, she gradually changed her understanding of mutations and the origin of variation. She made an ontological shift for these conceptions because she understood that mutations are a source of variation. Together with this shift she understood that (chance) mutations could not always be beneficial (addition of a rule; Thagard, 1992). However, she held onto the alternative conception as well. Therefore she could not understand that the mutation in the blind cave salamander (blindness) could have been neutral. She held a dual construction therefore for the nature of mutations. This implies that conceptual change was not wholesale. She understood natural selection acted on variation (addition), and that the unit of evolutionary change was not the whole population (deletion and addition). Her conception of the importance of variation helped her to make an ontological shift toward the scientific conception for the mechanism of evolutionary change. After these ontological shifts came together, she was able to define adaptation as well. Like everyone else in the lecture-lab group (100% in the posttest survey), she understood that humans did not evolve from apes but that they had a common ancestor. Other shifts included the move toward a variable species concept and her understanding of fitness as a measure of the number of offspring reaching adulthood. Rhonda experienced conceptual change, but not the kind explained by the wholesale model. She held dual constructions for certain concepts such as, the nature of mutations. At the end of the semester Rhonda accepted evolution although she held alternative conceptions, and she believed that science provided absolute proof and that science teaches what has been proven.
Preinstruction Phase

**Scientific conceptions**

**Nature of science**

Natural Selection has a valid scientific foundation.
Humans are not more perfect than other animals.
The earth is older than 4.5 billion years old.
All organisms are related through evolution to a common ancestor.
There are no alternative theories to explain the history of the natural world.

**Evolutionary concepts**

Mutations and variations arise by chance.
Not all mutations are good.

**Alternative conceptions**

**Nature of evolution**

Evolution is meant to make something perfect.
Science provides proof. It teaches things that have been proven.
Evolution has a purpose and direction.

**Evolutionary concepts**

Mutations are advantageous to the organism.
Use/Disuse and need as a mechanism of evolutionary change.
Natural selection is a purposeful act.
Typological species concept.
Unit of evolutionary change is the whole population.
Fitness: associated with longevity and ability to produce offspring.

**Human evolution**

Humans are derived from apes.

**Nature of science**

Scientists all follow a universal general scientific method.

Postinstruction Phase

**Scientific conceptions**

**Nature of science**

Natural Selection has a valid scientific foundation.
Natural Selection is based on testable hypotheses.
Scientists do not all follow a universal general scientific method.
Evolution is the main theory explaining the history of the natural world.
An old earth (plus 4.5 billion years)
Creationism does not have proof/evidence.
Evolution does not have a purpose nor direction.
Organisms have common ancestors, back to simple one-celled organisms.

**Evolutionary concepts**

Unit of evolutionary change is part of the population, not whole population.
Mutations do not necessarily equip the organism with a better means of surviving.
Not all mutations are beneficial.
Variation exists in a population.
Natural selection acts on variation.

**Evolutionary change operates through an increase, over successive generations, in the number**

Figure 13: Rhonda's conceptual inventory profile and conceptual change instances

Figure continued
of individuals with the trait.
Fitness as a capacity to produce offspring which reach reproductive age.

**Human evolution**
Humans are classified under animal kingdom.
Humans are not more perfect than other animals.
Humans and apes share a common ancestor.
Humans cannot evolve from modern apes, chimps etc.

**Alternative conceptions**

**Nature of evolution**
Evolution is meant to make something perfect.
Evolution has a purpose and direction.

**Evolutionary concepts**
Variable species concept.
Use/disuse and need as mechanisms for evolutionary change.
The trait increases and improves over time.

**Nature of science**
Scientists follow a scientific method.
Science provides absolute proof.

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**Brianna - quick creationist and scientific relativist**

**Pre-instruction phase**

Conceptual ecology and background

This student was a 22 year old African American female and she was a plant
biology major. She had been in college for 4.5 yrs at the time of the study. She
planned to pursue graduate studies in Environmental Chemistry after graduation. She
registered for both Evolution lecture and laboratory courses; evolution was one of her
majors and she had always been interested in it. She had a very strong religious
orientation at the time of the initial interviews.

She was very quiet and kept to herself in class and in the laboratory course. In
the lab she worked in her group, but one never actually heard her talking much. In class
she did not stand out from other students. There was very little interaction during
lectures; students did not ask many questions. The lab sessions involved more student-
to-student interaction and discussion especially in the assigned lab groups.
Brianna acknowledged her very deep religious convictions early on in the study. In fact it could be deduced from the open-ended responses on the preinstruction survey. Although she believed firmly in the creation story for humans, she did not give a clear indication of whether she believed in creation or evolution for other species. Humans were special and all other animals were there for their (human) use. She was initially a "quick creationist" (Nelson, 1986). Although she was interested in evolution she "would not really accept it." She believed in a literal interpretation of the Bible story of creation especially for humans and acknowledged that her Biblical understanding was in conflict with evolution. She did not believe in evolution for humans, but when probed about evolution in animals she offered a Lamarckian explanation for the mechanism of evolution (see cheetah probe below) or reverted to a creationist explanation (see blind cave salamander probe below). With regard to her scientific orientation, she was a pragmatist and a skeptic. The latter largely due to her religious belief system. She was skeptical of evolution, she also sought out authority figures who shared these views and religious convictions. She never seemed to question any of her convictions and appeared accepting of these. Because she viewed much of nature through her religious frame of reference, she had difficulty defining the concepts in scientific terms. Almost every aspect of evolution probed during interviews was answered with a reference to a divine being. Most everything else was "man made stuff." Her opinion about evolution and her inability to explain certain concepts (e.g., mutation), were viewed through the filter she used to view the world, namely religion.

Another important influence on her conceptual ecology was her inability to think critically about issues of which she was unsure. For example, she refers to her family and preacher as very significant in her thinking process and her decisions.

168
Nature of science and nature of evolution

Brianna knew that science claimed that evolution has a scientific foundation, but she was skeptical of this. She disagreed that life forms evolved, and therefore rejected the notion that any life form could have evolved from a single-celled organism. Furthermore she found that there were other theories which were more useful than evolution in describing the natural world. Her other conceptions about evolution were not congruent with the scientific conceptions. She proposed a young earth and she believed that there was a conflict between evolution and the Biblical account of creation. Responses on the survey indicated that she held alternative conceptions about nature of science issues as well. She adhered to the notion of a “scientific method,” she asserted that science and technology were the same, and that acceptance of scientific knowledge was straightforward. She rejected macroevolution and asserted that the earth was very young. In addition, she correctly rejected the idea that science provided absolute proof, but her reasoning was not scientific. It was instead related to her religious framework which she felt could provide answers as well. In the pretest she did not understand item 26 (Science is a solitary pursuit). She was an authority seeker; she relied on authority figures to inform her about what she should believe/accept.

Human Evolution

The issue of human evolution was most the controversial aspect of evolution for Brianna. Her opinions about this issue held her back from fully understanding evolution and its mechanisms. She held a religious view for everything and especially with regard to humans. She was a biblical literalist for the creation of humans, and she believed that animals were also created, but undergo some changes over their life time (“microevolution”). She did not think that humans were “animals” or that they “came
from apes (this was a common misconception mentioned by many of the students included in the whole class data). In this regard she mentioned the following:

I don’t believe humans came from apes; they are two separate things. All stand alone; human, dog and ape are all different.

On the survey she indicated that humans have a soul and all living things as well. It was obviously a puzzling question and she sought her preacher’s advise after she completed the survey on this matter. During the pretest interview she related to the interviewer that based on her preacher’s advice, animals do not have a soul but that humans do. Therefore she definitely appealed to authority and did not judge the validity of this claim for herself.

Evolutionary conceptions

Mutation is a process that plays a critical role in production of variation or new traits in a population, and variation is the raw material for natural selection (a non-random process). Mutation is a chance event and this was a difficult concept for her to understand. It means essentially that she failed to understand the origin of new traits and the survival of new traits (due to selection), which are two separate processes. Hence she did not understand the importance of variation within populations. She also did not understand that natural selection works on the population and results in an increase in the proportion of individuals possessing a trait with successive generations (more of the organism with this trait).

She agreed on the survey that mutations are random, chance events, but in the interview she admitted that she was not sure. She was filtering the information through her religious framework.

It think it is hard for me to actually see the idea of evolution period. I think everything happens by the biblical way so it cannot happen by chance. I think
He (God) knows...it s gonna happen before it happens. Its...not by chance its in His hands...His work.

Therefore, mutations were directed by a supreme being and were not chance events. Mutations were also considered to be a means for organisms to better survive in their environments and “something is what it is so it can better survive.”

The concept of natural selection was probed more than any other concept because the researcher considered it to be one of the most important concepts in evolution. One of the major stumbling blocks to understanding microevolution or evolutionary change is the failure of the learner to see the importance of intraspecific variation for the mechanism of evolution, that is, natural selection (Rudolph and Stewart, 1998). It is the raw material on which natural selection (a non-random, selection process among varied individuals) works (Rudolph and Stewart, 1998).

Her understanding of evolution was rather limited and was at best a broad understanding fraught with many alternative conceptions. She also did not have a sound understanding of the nature of evolutionary change nor of the mechanism of evolutionary change, natural selection. Her epistemological orientation was definitely non-scientific and creationist.

(Natural selection) is a man made way of describing how different organisms are on earth, how change occurs in different organisms, it describes evolution and individual random mating. It’s just a man made view of the way the life cycle occurs; that is some of them will be chosen and some will not. It is a man made mechanism.

Brianna did not mention the importance of variation, she confused random mating and random mutations, and she seemed to equate evolution with natural selection. She regarded this mechanism as a man made fabrication. This is a result of her religious framework and her acceptance of a literal creation story. She understood species as
static, immutable entities. She understood that the process of selection is non-random and that it is not the quality of the trait which changes over time, but the proportion of individuals with the trait (change in allelic frequencies, differential reproduction) which changes.

The blind cave salamander problem (item 16) elicited various alternative conceptions. She (correctly) disagreed with the statement but when she elaborated on her reason in the interview it became clear that she was reasoning from a non-evolutionary framework. She stated the following:

I feel that once again...it once again goes back to what I said before: the supreme being knows who is gonna be blind from the go. It is not because you lost your sight. If he has...before he knows how many offspring you will have, which one is gonna have a mutation, which is gonna be blind, healthy.

In response to what the role of mutations might be:

I don't know, He just said this one is gonna be blind, it happened among them. He just wanted it.

The cheetah problem (Appendix D) was difficult for her to answer. She first disagreed with the item (incorrect item) and then changed her mind during the interview. Her explanation had a Lamarckian flavor; speed, bones, and muscles changed and were passed on. Here again the lack of understanding about intraspecific variation was the stumbling block to her understanding how the process occurred.

Brianna used an everyday understanding of “fitness.” In the survey, she omitted a choice for this item. In the interview she mentioned that she would agree (incorrect item) and also add to it that survival and number of offspring were important. She thought George was not the fittest just because he was strong. In the interview she selected Sandy because of the number of surviving cubs and stated that “strength you can gain.” She did not refer to viability of the offspring or their reproductive potential.
(differential reproductive success) which could result in a change in allele frequencies in the population. Over time these microevolutionary processes would lead to macroevolutionary changes.

She mentioned a number of different criteria for fitness, namely strength, survival, number of females, and number of offspring. Demastes/Southerland (1994) calls this a collage conception for fitness.

Her use of the typological species concept is congruent with her view that God directed the creation of discrete groups/species. According to Brianna, “they (species) all stand alone” because those in one species have similar traits. Species once created do not change. When probed about different wild cats (lion, tiger), she said they were in different species, because “they don’t look similar.” This conception is definitely typological and did not include any reference to the Darwinian variable species concept (if they can mate and produce viable offspring, they are the same species). This is surprising because at the time of the interview, she had done a lab in which a video showed how a species is defined in accordance with the Biological Species Concept. This alternative conception might have been a result of her creationist, non-evolutionary framework.

She chose a diagram (D, Appendix H) which depicted the original species splitting into many species and then still surviving. She probably did not understand this illustration. She mentioned along with choosing this illustration that:

Species are in different environments they look different. They change around the environment.

She incorrectly placed the vertebrates in the following order:

frogs---->reptiles------>fish----->birds
This probe indicated that she did not have a good understanding of vertebrate taxonomy (perhaps because she is a plant biology major), and that she did not regard humans as animals (she chose to exclude humans from the taxonomy). This further supports the researcher's analysis that the participant views species as created, immutable organisms and that she had a Lamarckian understanding for the mechanism of evolution. She regarded humans as special. She had a clear understanding of the inheritance of traits as defined in the Mendelian conception of inheritance. This was probed in the prediction interview where she reasoned logically about the scenarios with the mice and their tails. She correctly identified the dominant traits, heterozygous traits and she explained the scenarios correctly. However, this could indicate that she compartmentalized her knowledge.

Post instruction

Conceptual ecology

Brianna did not show change her opinions about evolution at the end of the semester nor did she resolve or clarify the alternative conceptions she held at entry level. She still exhibited a quick creationist framework and viewed evolution through her creationist lens as “man made stuff.”

The posttest survey and interview data provided evidence that the participant had moved more toward the non-scientific knowledge framework for many evolutionary concepts; in fact she shifted more toward her religious framework. She did not believe evolution had a valid scientific foundation and she indicated that there is no proof for macroevolution. In one of the labs that had looked at whether creationism and science should both be taught in school, she had not really given her true opinion.

174

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She appeared to be afraid of voicing her opinion. She reasoned from a purely non-objective stance:

Large scale evolution is fictitious for me; there really is no proof, there are gaps in the fossil record. There is no solid evidence for me that things come from other things. The Bible is the justification for origins (Genesis) as it goes step by step. I understand their (evolutionists) argument, but I do not believe it.

It is clear that Brianna is a Biblical literalist. With regard to the age of the earth, she maintained that it is a young earth. She also maintained her belief that life forms have not evolved from a single-celled organism.

The participant operated under a creationist framework. The drawing task further supports this analysis (Appendix L). She hesitated about where the dinosaur would be placed:

Where would they be placed with reference to humans? Does the Bible mention Dinosaurs? I don’t know where to place dinosaurs?

It can be inferred from her timeline that she was attempting to draw her timeline in accordance with the Biblical account and not an evolutionary account. The timeline shows the sequence of the creation of the earth and life as described in Genesis, that is a literal interpretation. She placed apes (which seem to be a problem issue for her because of their supposed links to humans) and other animals before humans. Man and woman were created at different times; this depicts the Adam and Eve story in Genesis. She maintained her conviction that humans are the most perfect life forms and that animals were put on earth for them. Humans are the top of the hierarchy.

At the end of the interview, she added that she just had a thought that maybe apes were like cave men: the cave man was the ape which she considered to be the second most intelligent in the hierarchy (clearly she held a ladder-like Lamarckian
concept of the tree of life). These cave men had not fully developed to be as perfect as humans:

Maybe apes were like cave men; maybe that was the ape. I think they are the second most intelligent in the hierarchy. So maybe they had not fully evolved to be as perfect as humans; they were then the second thing. On my timeline then I would now put animals at the end because I feel apes are second to humans. But they have not evolved from the same species.

This supported the analysis that she compartmentalized her thinking when it came to humans and other animals, that she regarded humans as perfect creations, and that she did not see humans as animals. People were better than animals especially in intelligence. She definitely felt uncomfortable talking in public about this issue and indicated that she did not enjoy the “lab on creationism.” She maintained a quick creationist framework and regarded evolution as a mere adaptation for better fit with the organisms environment. With regards to other animals, she was a gradual creationist because God created these animals and directed their “evolution.”

Her final grade score was a C minus. In the final examination she scored a B minus. For the isolated examination items, she scored 100% for the natural selection items, 100% for the phylogeny items, over 80% for the biogeography items, and over 60% for the allometry/biometry items. It would seem impossible for her to score a pass grade for this course based on her survey and interview information. But she had amassed enough knowledge through rote-learning to pass the course without understanding the most basic concepts. It is obvious she was not learning meaningfully and that her rejection of evolution might have played a role here. She had not changed her opinion about evolution by the end of the semester and summed up her rejection of evolution as follows:

I understand their (evolutionists) argument but I do not believe it.
Nature of science and nature of evolution

There was no evidence of any conceptual change in this fundamental category. As mentioned above, she felt that microevolution was plausible, but that macroevolution was fictitious. She did not understand the mechanism of natural selection at all and how these microevolutionary processes lead eventually to macroevolution. She felt that evolution and creationism should get equal time in school classrooms (in line with current developments in some school districts e.g., Kansas). She therefore felt that there were other theories (possibly creationism) which could tell us more about the history of the natural world. She believed in evolution as a change which occurs in the life time of the organism, which helped it to adapt to its environment.

With regard to the nature of science items, she correctly answered 2 of the 5 items, retaining exactly the same pattern of choices as on the pretest survey. The only two items which she answered correctly are that science cannot provide absolute proof and science is not a solitary pursuit. This might be the influence of the laboratory course where students worked in groups and the instructor was able to stress the nature of science more than he did during lectures.

Human evolution

It became clear that she compartmentalized her thinking when it came to evolution for humans and evolution for other living organisms. She did not regard humans as animals and held a quick creationist conception of human. For other living things she seemed to use a gradual creationist conception (God created them, then directed evolution to better fit them to their environments). But she equated adaptation (the everyday definition is implied) with change and evolution. She further asserted
that she believed in microevolution which she perceived as small changes or adaptations to improve the organism in its environment. She maintained that the "Bible is the justification for origins as it goes step by step." Humans were the most perfect of God's creation.

Evolutionary conceptions

She did not change her conception of natural selection. She seemed to equate natural selection with adaptation and therefore she obviously understood evolution to be operating through adaptation. But her understanding of adaptation was an everyday definition of the word. Therefore this reinforced the conception that the environment directed an influence on the appearance and development of traits. In the biological sense, populations change over many generations through the action of natural selection. She therefore understood evolution to be rapid and of small magnitude, operating to improve the fit of the organism to its environment. She therefore had a number of alternative conceptions with regard to the nature of evolutionary change and which in turn impacted other evolution concepts.

Her response to the adaptive radiation item in the interview also showed that she did not understand variability within a species, and she consequently answered this item in a Lamarckian fashion:

The environment had to play a role here. These might just live in different environments and they evolved around their environment.

She could not define non-random natural selection, nor could she give a scientific conception of mutation or variation:

Natural selection means organisms randomly selected for something; mutation, it can be random too, but it is more so a change in the person to be better suited to the environment and variation, it is like speciation. Both can be dogs,
different types of dogs, maybe they look different because they were put in different environments.

Further probes on natural selection provided more insight into her vague understanding of the mechanism of natural selection. The giraffe neck problem was a sorting task and the participant was asked to arrange the six images so that they explain Darwinian natural selection and Lamarckian inheritance of acquired characteristics. She was able to correctly sort the images, but probably only because she was guided by the captions. When asked to explain the cave salamander probe using the ideas from these images, she was unsure. She discounted the role the environment (the dark) might have played in causing blindness, but she also did not use mutation in her explanation. She felt that:

A different species came and they were blind. They did not gradually become blind. It was probably by chance. I just say that a different species evolved that was different from the sighted ones.

She seemed to be suggesting that they just happened to be blind or that they became (evolved instantly) blind before entering the cave. She might have been suggesting a sudden, drastic speciation event (her conception of a mutation or adaptation) which resulted in the formation of a new species which just happened to be blind. This was connected to her conception of change (evolution) happening to adapt an organism to its environment. It probably stemmed from her vague understanding of adaptation and the use of the everyday meaning of adaptation. She did not understand or apply the biological understanding of adaptation.

The cheetah probe indicated that she understood that Lamarckism and the inheritance of acquired characteristics were not scientifically acceptable. She also showed some understanding of variation. The mechanism operated through survival and
death. It appeared that she understood two of the three essential criteria needed to understand the mechanism of evolution, namely, the origin of mutation and the unit of evolutionary change. She incorrectly understood that the quality of the trait (faster and faster) would improve with each generation. The first section of this quote indicates that she has some understanding of natural selection but the last part is faulty:

Maybe some of them were already fast, some were slow. Maybe the fast cheetahs outlived the slower ones. They were faster and quicker and they could catch food. The slow cheetahs did not survive because they were not eating as much. Over time every generation got faster, this was not immediate. When asked to explain the second part of the probe (“their bones and muscles changed to adapt to this”) she included need in her answer (“they needed to be more equipped to catch their prey”). It appeared that she understood the mechanism of evolution as having these characteristics: (a) Variation (implies this) results from an innate ability, (b) a typological species concept, (c) evolution being a change in the quality of the trait, (d) the death of unfit and the survival of fit ones. She was moving toward understanding that variation is important for natural selection to act on. However, she did not demonstrate that she understood the process of natural selection as being separate from the production of variation (through mutations and sexual recombination) nor that natural selection acted on differential reproduction.

The prediction interviews were intended to further elicit the participants understanding of natural selection. She did not mention natural selection at any time during these interviews. For the antibiotic problem (Appendix H) she selected the human body as the target of the antibiotic. The concern for increased use of antibiotics she understood to mean that human body would become immune to antibiotics. She did not take any medicine herself because she preferred to wait it out (reasoning on non-selection grounds; Brumby, 1984).
The insect probe also showed that she did not understand the role of mutation, and that she did not realize this example involved natural selection. She saw the change that occurred (immunity) as a result of increased immunity and tolerance for the insecticide. She regarded this as an instance of adaptation, which for her is the central concept in her understanding of evolution (adaptation to best fit a particular environment).

The skin problem is also linked to her understanding of evolution operating through adaptation. She did not see that the skin color probe involved genetics. When probed about children born outside of their parents’ environment (e.g., a colder climate like Scotland), she stated that their skin would be slightly lighter than the parents skin. The quality of the trait therefore changed:

They are not gonna change. But maybe their offspring is gonna gradually change and gradually lighter.

When probed about what the children of a light-skinned couple would look like if they were born in a hot climate (e.g., Africa) she said:

I don’t think they’d be dark dark. They would be a shade but not a drastic shade darker that the parent. Maybe a shade or so darker.

From this description it is clear that she did not understand the role mutations might have played and she did not understand that skin color was genetically determined. Evolution therefore operated through adaptation or need.

The alternative conception of natural selection was reinforced by, among others, her failure to separate it from variation, her failure to understand it as a non-random, non-purposeful act, and her inability to understand mutation, and adaptation.

She showed a regression in many of these concepts from one alternative conception to another. Her species concept remained typological. The regression to
and maintenance of alternative conceptions were probably reinforced by her use of the everyday meanings of biological terms (e.g., adaptation, fitness). She also confused some concepts, for example, mutations and adaptations.

Mutations I guess that can be random too but it is more so a change in the person to be better suited to the environment.

Her understanding of taxonomy was vague and she exhibited alternative conceptions here. A duck-billed platypus was a bird (incorrect) which has evolved and now has limbs for better fit with its environment. She used this example to show that microevolution is real and happens in a short period of time:

- a duck billed platypus does not have wings anymore it has limbs to be better suited for the environment. That's just proof right there it's a duck but it has limbs now. You can look at different species and you can see the microevolution occurring.

Conceptual change at the end of the semester

Although she maintained that she was interested in evolution, it became clear that she viewed the topic as directly contradictory to her personal belief system. She also did not understand the natural world in a mechanistic way and she maintained a vague understanding of evolution despite having done both lecture and lab courses. Her framework for evolution was clearly influenced by her religious framework of quick creationism and the issue of human evolution. She was an authority seeker and compartmentalized her knowledge. She reverted to the latter two modes whenever she found that her personal knowledge conflicted with incoming ideas or knowledge. This was especially clear after the pretest interview item which dealt with the issue of humans having a soul.

She did not make many ontological shifts at the end of the semester. She maintained a belief in special creation for humans. However, she showed a shift in
category for animals other than humans. They would change to be adapted to their environment. Nevertheless this is an ontological shift for acknowledging that animals evolve (deletion of old central rule, replacement of central rule; Thagard, 1992). She did not make an ontological shift for variation (equated it with adaptation), for natural selection (it was a purposeful act, purposeful and random), age of the earth (a young earth), and the species concept (static, typological species concept).

Humans were created (quick creationist) and other animals could evolve (gradual creationist) but only because they had to adapt and then the act was guided by God (see cave salamander items). She therefore subscribed to a theistic view of evolution. She experienced what Jackson, Doster, Meadows & Wood (1995) call a conflicted situation with regard to evolution and religion. She regarded learning about evolution as a threat to her personal belief system. She perceived the courses as forcing her to choose between the two fields of knowledge; as expected she chose religion (confrontation; McGrath, 1999).

With regard to fitness she had a dual construction after the pretest survey, but at the end of the semester she did not know how to define it. She maintained the alternative conceptions about the mechanism of evolution as well as the nature of evolution. The latter was a rapid, minor process (she calls this microevolution) and its purpose was to help organisms adapt or improve their fit to their environments (an everyday use of adaptation). At the end of this study, it was clear that her conceptual framework and rejection of evolution were based on subjective, sociological considerations. She did not know enough about evolution and had many alternative conceptions which she was not prepared to address. She would not consider evidence
or new knowledge. They were therefore not intelligible, plausible nor fruitful to her.

The Bible, she said "is the justification for origins as it goes step by step."

Preinstruction Phase
Scientific conceptions
Nature of evolution
Natural Selection does not have a valid scientific foundation.
Evolutionary concepts
Animals undergo change or evolution.
Fitness as a capacity to produce offspring which reach reproductive age.
Human evolution
Human are not derived from apes.
Nature of science
Science does not offer absolute proof.

Alternative conceptions
Nature of evolution
Macroevolution is not valid.
A young earth (much less than 4.5 billion years)
Creationism more important in explaining the history of the natural world.
Organisms do not have common ancestors.
Evolution has purpose and direction.
Evolutionary concepts
Not sure mutations are random.
Mutations and variation are not chance events.
Mutations are beneficial for survival of organism.
Mutations are directed by God.
Natural Selection is a man made way of describing diversity. Change operates through
inheritance of acquired characteristics.
Species are immutable.
Animals are also created.
Typological species concept.
Fitness defined in terms of desirable traits & survivability.
Unit of evolutionary change is the whole population.
Fitness is the ability to adapt to new situations.
Human evolution
Humans were created (biblical literalist).
Humans are not animals.
Humans are not more perfect than other animals.
Nature of science
Scientists all follow a universal general scientific method.
Science and technology are the same.
Acceptance of scientific knowledge is straightforward.

Figure 14: Brianna's Conceptual Inventory Profile and conceptual change
instances

Figure continued
Nature of evolution
Microevolution is a valid scientific theory.
Organisms have common ancestors, back to simple one-celled organisms

Evolutionary concepts
Mutations and variation are chance events.
Mutations as a source of variation.
Fitness as a capacity to produce offspring which reach reproductive age.
Natural selection acts on variation.
Unit of evolutionary change is part of the population.
Inheritance of acquired characteristics is not scientifically valid.

Human evolution
Humans cannot evolve from modern apes, chimps etc.
Animals evolve.

Nature of science
Science is not a solitary pursuit.
Science cannot provide absolute proof.

Alternative conceptions
Nature of evolution
Natural Selection does not have a valid scientific foundation.
There is no proof for macroevolution.
Evolution is not the main theory explaining the history of the natural world.
Evolution does have a purpose and is directional.
A young earth.

Evolutionary concepts
Evolution and mutation as adaptation to environment.
Organisms evolved around their environment.
Mutations are always beneficial.
Fitness is the ability to adapt to new situations.
Typological species concept.
The trait increases and improves over time.

Human evolution
Humans are not classified under animal kingdom.
Humans are on the top of the hierarchy.
Humans are most perfect, especially in intelligence.

Nature of Science
Scientists all follow a universal general scientific method.
Acceptance of scientific knowledge is straightforward.
Science and technology are the same.

Summary of Conceptual Change for the Two Comparison Groups

This section summarizes the conceptual frameworks and conceptual change experienced by students in the two comparison groups. The eight participants were college juniors (2) and seniors (6) who shared a particular interest in evolution, as is
evident in the interviews. They were interested in the topic and in the teaching style of the professor, who had a good reputation among students. Many of the interview participants mentioned that they were interested in the course or courses, or that they were fulfilling a degree requirement by enrolling for the course(s). The following section summarizes conceptual change and conceptual frameworks for the lecture only and lecture-lab groups respectively. Figure 15 summarizes conceptual inventory profiles for the eight interview participants.

**Summary of lecture-only group's conceptual change at semester end**

The participants in the lecture only group were one female and two males. Their frameworks for evolution and patterns of conceptual change are discussed below.

**Ian**

Ian was a model student with a positive scientific orientation and a realist scientific epistemology. His future plans were to enroll in medical school. He accepted evolution as plausible and did not outwardly reject religion, nor did he interpret his personal life through a religious framework. His initial framework for evolution did not show many alternative conceptions. After instruction, he was one of two students who showed typical holistic, wholesale conceptual change for the major conceptions. Conceptual change was linear, logical, and predictable. This phenomenon is linked to his strong scientific epistemology; he operated like a scientist by searching for the most plausible and scientifically appropriate explanation for natural phenomena. As a result of his positive scientific orientation and epistemology, he was able to “think through” (logically) the many alternative conceptions, and consequently he entered the course with a sophisticated, scientific framework for evolution.
At entrance level, the only area he had problems with were the mechanism of evolutionary change, the unit of evolutionary change, and aspects of human evolution. He also had alternative conceptions about the nature of evolution and science. However, his conceptual framework for evolution was mostly in place before instruction and was expanded upon (conceptual change) in a logical and predictable fashion; that is, wholesale conceptual change occurred.

Adrian showed a similar scientific epistemology, future career plans, scientific orientation, and interest in evolution. They differed in their religious orientation; Adrian was a theistic evolutionist, which is described by Moore (2000) as a belief that a deity had intervened in the biological history of humans, and that evolution is God’s plan. This orientation was not as pronounced in the posttest survey and interviews. The student operated by attempting to converge these two very different knowledge frameworks, religion, and evolution.

He, like Ian, valued scientific knowledge, had alternative views with regard to the nature of evolution and the nature of science, and understood the origin of mutation to be use/disuse and need. He believed that evolution was directed by God, and that it is part of His plan. He believed that all organisms were created and that they evolved to their present state. He did not show any real conflict, although he obviously had not separated the two knowledge claims, but he had reached a level of reconciliation by adapting his religious framework around scientific claims. In this regard then, he believed in an old earth, that humans and apes had a common ancestor, and in the evolution of all animals including humans. Humans were different only in the fact that
they were chosen to worship; this did not imply that they were perfect or the most perfect animals. He held a good foundation for evolutionary conceptions at the start of the study. He held scientifically acceptable conceptions for the species concept, but not for the unit of evolutionary change nor the origin of variation. He exhibited dual constructions for these last two major conceptual groups. Linked to this is his inability to understand the significance of variation and the fact that mutations, in his opinion, are not chance events. After instruction, he never revealed the religious aspects of his conceptual ecology; but he showed a blend of the scientific and alternative conception for some important conceptions. These included fitness, the origin of new traits, and the scientific method.

Patricia

She had her future career plans in common with the two males; she wanted to pursue a medical career. Other than that, she differed in many ways from them. She was an African American teenager (19), she reasoned on science and evolution from the perspective that science is treated as dogma to be learned and regurgitated. Her rejection of evolution was based on her religious convictions. She had a positive orientation toward science and she had a pragmatic scientific epistemology. She learned content that would get her through the course. Thereafter she would forget it. This was certainly the impression the researcher got in the interviews.

Patricia also had a very strong religious orientation, coupled with an initial framework for evolution fraught with alternative conceptions. She attributed her reasoning in the survey entirely to learned information. The items on the survey that she did expand on were those associated with her religious framework, such as
conceptions about human evolution. After instruction, she moved even more toward her religious framework. This contributed to her not being able to understand the major conceptual groups, such as the origin of variation (use/disuse and need in her case) and the unit of evolutionary change. She held onto the typological species concept as well.

She was convinced that humans are special, and she did not understand the chance factor in mutations. Therefore she could not understand how new traits (variation) arose or the significance of variation. At best, she underwent conceptual change which can be characterized as fragmented/gradual for the concept of human evolution and their relationship with apes (they have common ancestors; humans could not have evolved from modern apes). However, these are minor conceptions for evolution. Her conception of natural selection acting on variation is an anomaly given the fact that she was unable to understand the major conceptual groupings identified in the research literature (Bishop and Anderson, 1990; Demastes/Southerland et al., 1994). She did not think rationally and logically with regard to the logical assessment of theories she was confronted with. It was evident that she interpreted the natural world and her personal life through her religious framework. She did not have a good enough understanding of the specifics of evolution, she did not have sound, rational reasoning skill and she was unable to take advantage of the opportunities created for conceptual change in the lectures.

Summary of lecture-lab group's conceptual change at semester end

The participants in the lecture-lab group consisted of two males (one white and one Spanish-speaking, and the other three were female (one African American and two white). This represents a diverse group of students.
Martin was a senior student who had enrolled for both courses to meet degree requirements and because he was very interested in the topic. He was the only student bound for graduate studies who had his future field (mycology) and project defined. He had a definite scientific orientation and a realist epistemology. He did not reject religion; he was agnostic by his own admission. He stated that he did not reject anything because he just did not have proof. Science was his philosophy of life.

He entered the course with the most coherent and scientific understanding of evolution among the interviewed. However, he did hold certain prominent alternative conceptions. This included a notion that perfection had a place in biology (bacteria are more perfect); that humans arose from modern apes; that the unit of evolutionary change is the whole population; and scientists all follow a universal scientific method. The last point was most surprising because he worked as a student worker in a Life Sciences department. During discussions in the lab and informal conversations, it became evident that he was logical and rational, basing his beliefs and acceptance of knowledge on evidence or on proof provided, and not on an extra-logical criteria. He was not convinced, however, about the age of the earth, although he did accept the old-earth theory. He underwent conceptual change for the major conceptions; that is wholesale change. In his case, it proceeded as follows: mutations are chance events (thus evolution cannot be directional or have a purpose); therefore, they cannot always be beneficial; mutations cause variation; natural selection acts on variation (therefore the unit of evolutionary change cannot be an individual nor the whole population); this leads to the variable species concept; therefore use/disuse and need as sources of...
variation are not plausible; and it follows that the proportion of organisms with the
favored trait will increase in each generation. After instruction he was able to clear up
his alternative conceptions, and he was the only interviewed student who did not hold
any alternative conceptions which were held in the preinstruction phase. He held the
correct conception that scientists do not all follow a universal scientific method. He
removed the notion of perfection having a role in biology, he was now clear that the
unit of change is part of the population, and he corrected the conception that humans
are apes (they share a common ancestor). This was another example of wholesale
conceptual change.

Mary

This student held many alternative conceptions which were not unexpected if
one considers that she also held a very religious, creationist framework. A prominent
feature of her conceptual ecology for evolution is the fact that she rejected human
evolution and was a biblical literalist in this regard (quick creationist). She experienced
a lot of conflict with incoming scientific knowledge because of her strong religious
orientation. She was very vocal in the interviews, and even in discussions in the lab
course, about her rejection of certain aspects of evolution, for example, her rejection of
macroevolution (large scale change). During the lab discussion sessions, it became
clear that her objections were not based on sound scientific understandings; she mostly
disagreed with alternative conceptions, such as humans evolving from apes and a young
earth. She was unaware of the unscientific claims of these alternative conceptions.
This indicated her acceptance of anti-evolution propaganda. Hence she reasoned
essentially in an extra-logical manner, and her orientation toward biology and evolution
is basically sociological. One of the major conceptions, the variable species concept, however, was in place. She held many alternative conceptions (see figure 11).

After instruction, Mary's conceptions on evolution underwent considerable change: the origin of variation was mutation, mutations are chance events, therefore they can be beneficial or not, or even neutral, and natural selection is the main mechanism of evolutionary change. Since she used both the use/disuse and need as sources of mutation and as mechanisms of evolutionary change, it is clear that she held a dual construction for the mechanism of evolutionary change. Therefore, conceptual change involved cascade change of conceptions related to mutation (action and nature) but led to retaining her alternative conceptions and forming new alternative conceptions. This is seen when she described evolution as mainly microevolution in the last interview. She rejected the idea of large-scale evolution or macroevolution because of its implications for human evolution. She accepted evolution only as far as it fit her description of small or subtle change in groups of organisms but not between groups. This posttest framework is indicative of the conflict between religious and scientific frameworks, her tendency to depend on authority figures (either seeking advice from science or more often, from religious doctrine), her tendency to use dual constructions for certain conceptions. This led to her regression to the typological species concept. This was especially evident when she attributed the evolution of skin color to special creation. Conceptual change therefore did not always follow a logical pattern as proposed by the CCM (Posner et al., 1982) but could be characterized as extra-logical (dual constructions). It was not wholesale change as described by the CCM. Her case serves to inform us also that even though students develop a good
understanding of evolution, this does not necessarily mean that they have given up their religious convictions.

Juan

Juan was a Spanish-speaking senior who had a positive scientific orientation, but could be categorized as having a pragmatic epistemology for science. He was a nominal Christian by his own admission and did not have an overtly deep religious life. His case was unique because he was the only student whose mother language was not English. There was evidence that he partially processed and reasoned about evolution through his religious framework. He held many alternative conceptions including the origin of variation, the unit of evolutionary change, and the typological species concept. The fact that mutations are random and have variation as a possible consequence did not make sense to him. After instruction he understood that mutations did not necessarily equip the organism with a better means of survival; he understood that variation was important, that natural selection acts on variation, and that some organisms have a slight advantage over others (because of variation). Once he understood that variation exists in a population, he concluded that evolution acts on part of the population. His understanding of human evolution was unique as well, considering his theistic evolutionary framework. However, this student did not always use his religious framework to filter information. He admitted conflict between these two knowledge fields.

It appeared therefore that he still held alternative conceptions, but that he also had experienced conceptual change for certain concepts. This resulted in a fragmented conceptual change pattern. The conceptual change observed here is non-traditional but still has elements of rationality.
Rhonda

Rhonda professed to be atheistic and anti-religion from the start of the study. She had a positive scientific orientation and a naive realist epistemology for science. She entered the courses with many alternative conceptions. Her keen interest in anthropology contrasted with her pretest understanding of science as dogma.

After instruction, many of her alternative conceptions for major and minor conceptual groups underwent drastic changes. But at the end of the semester, she held on to the misunderstanding surrounding mutation and the possibility that it might have a neutral effect (cave salamander problem).

Certain important changes included her understanding that mutations can be deleterious and not always beneficial. Following this was the conception that evolution was not directional and did not have a purpose. When she understood that variation existed in the population, she was able to understand the variable species concept and consequently that the unit of evolution was no longer the whole population. She understood that the act of natural selection is separate from the origin of variation.

Conceptual change in this particular string of conceptions was initiated by the understanding that mutations are a source of variation. Her conceptual change can be described as wholesale (cascade) according to the major conceptions, but because she held alternative conceptions in other areas she also can be said to have experienced dual construction for some conceptions. The nature of mutations and the use/disuse conception are examples. Motivation and the shift away from dogmatic understanding of the nature of science facilitated conceptual change. However, her case is informative because it presents a case where the student had accepted evolution as a plausible
theory to explain the natural world before she actually had a good understanding of the content knowledge of evolutionary biology.

**Brianna**

Brianna was the most intriguing participant in the lecture-lab group. In many ways she was like Mary and Patricia, especially with regard to her religious orientation and the many alternative conceptions she held. The alternative conceptions were clearly linked to anti-evolution propaganda. She was a relativist with regard to her scientific epistemology and had a positive scientific orientation. Her religious framework was consistent and was instrumental in her adamant rejection of evolution. She explained animals in terms of evolution in the pretest interviews but humans were definitely not subject to it. The issue of human evolution was a salient feature of her conceptual ecology and had a profound influence on her conceptual framework for evolution. The latter happened in conjunction with her religious convictions and her tendency to appeal to authority. After instruction, she reverted back to all her alternative conceptions including the typological species concept. Her reasoning was not founded on logical thinking but was influenced by extra-logical factors. The acceptance of small, subtle changes within species for better fit to its environment showed that she accepted microevolution (or her account of it) and rejected macroevolution because it threatened her religious convictions and implied that humans evolved. She ended with a progressive creationist framework for evolution. Her religious convictions and the Bible were her authority when it came to her personal life and her understanding of the natural world. Hence species were static, humans were special and on top of the hierarchy, and evolution happened in animals. This student
showed a fragmented conceptual change pattern; only a few concepts changed and were integrated with the alternative conceptions which were still in tact. This example serves to illustrate that students’ understanding of the nature of evolution and very strong religious beliefs are aspects of the conceptual ecology which can affect conceptual change. She also had insufficient content knowledge and inadequate critical thinking skills, and therefore reverted to propaganda hence reversing her understanding of some important concepts.

Summary of participants’ conceptual inventory profiles

Students who had a poor understanding of the nature of evolution were more likely to hold the opinion that evolution has a purpose and direction. Brianna and Patricia held the view that evolution was directed by a supreme being, but that it was not the main theory explaining the history of the natural world.

Those students who did not have a good understanding of the nature of evolution also appeared to have a poor understanding of the nature of science. They held alternative conceptions with regard to the species concept and they held Lamarckian conceptions with regard to evolutionary changes, the nature of mutations, and fitness. Human evolution appeared to be a contentious issue for two lecture-lab students (Mary and Brianna) and one lecture-only student (Patricia). These students voiced their rejection of macroevolution. They “accepted” microevolution.

Students who had a good understanding of the nature of evolution had a good understanding of the nature of science as well. They also held scientific conceptions for the three major conceptual groups, namely, the species concept, the unit of evolutionary change, and the origin of variation. These students were Ian, a lecture-only group
student, and Martin, a lecture-lab student. These students scored an A grade for the theory course and both experienced wholesale conceptual change.

Lecture-only and lecture-lab students who did not have a good understanding of the three major conceptual groups were more than likely not able to solve prediction problems which dealt with natural selection (e.g., Brianna in the lecture-lab group and Patricia in the lecture-only group). The performance of students on the final examination indicates that the whole class experienced a problem with the concept of natural selection (N=80). The problem with this concept include students do not see the significance of variation in the population, and they mistakenly believe that the environment induces the appearance of new traits, and that the quality of the trait improves over successive generations. Interview data indicate that natural selection does not affect the production of new traits; natural selection is a non-random, environmentally-dependent mechanism which affects only the composition of the population. Students generally do not understand that random processes are responsible for the origin of new traits. Students with alternative conceptions about the origin of new traits were unable to see the significance of variation. Without this understanding students selected use/disuse or need as mechanisms for evolutionary change instead of the correct scientific explanation, namely natural selection. Students also had a problem with understanding that which individuals in the population with adaptive traits will be successful in a particular environment.

Figure 15 summarizes students’ conceptual inventory profiles for evolution concepts and nature-of-science concepts. Two students experienced wholesale change, four held dual constructions, and two experienced fragmented conceptual change patterns. Dual constructions were associated with inconsistent conceptual frameworks, fragmented patterns with rote learning styles and poor reasoning skills.
<table>
<thead>
<tr>
<th>Evolution &amp; Nature of Science concepts</th>
<th>1</th>
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<th>5</th>
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<tbody>
<tr>
<td>Scientific conceptions</td>
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<tr>
<td>Natural selection has a valid scientific foundation</td>
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<tr>
<td>Evolution is the main theory explain. history of natural world.</td>
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<tr>
<td>The earth is old (at least 4.5 billion years old).</td>
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<td>Evolution involves gradual change.</td>
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<tr>
<td>Evolution does not have a purpose or direction.</td>
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<td>All life has evolved.</td>
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<td>Humans are animals.</td>
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<td>Humans and modern day apes share a common ancestor.</td>
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<td>Mutations can be advantageous, neutral or detrimental.</td>
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<td>Mutations are chance events.</td>
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<td>*Mutation is a source of variation.</td>
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<tr>
<td>Natural selection acts on this variation.</td>
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<td>*Biological species concept.</td>
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<td>Fitness, a capacity to produce offspring, reproductive age.</td>
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<td>*Unit of evolutionary change proportion of population.</td>
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<td>*The trait not increase over time, proportion of population.</td>
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<tr>
<td>Science is a shared pursuit.</td>
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<td>There is no one scientific method.</td>
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<td>Scientific knowledge is tentative.</td>
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<td>Scientific knowledge does not provide absolute proof.</td>
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<td>Science and technology are not the same.</td>
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<td>*Use/disuse is not a valid explanation for change.</td>
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<td>Natural selection will select disadvantageous traits.</td>
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<tr>
<td>Alternatives conceptions</td>
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<td>*Typological species concept.</td>
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<tr>
<td>Mutations equip organisms for survival.</td>
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<tr>
<td>Macroevolution is a false theory; only microevolution occurs.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humans and other creatures were created.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humans are more perfect life forms.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fitness: number of females, strength, survivability.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Evolution is part of a supreme being’s plan.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Figure 15: Summary of participants’ conceptual inventory profiles (1=Ian; 2=Adrian; 3=Patricia; 4=Martin; 5=Mary; 6=Juan; 7=Rhonda; 8=Brianna) (* indicates a major concept; Demastes/Southerland et al., 1993; Demastes, 1994)
CHAPTER 6: SUMMARY AND CONCLUSIONS

Background

The theory of conceptual change as proposed by Posner et al. (1982) has impacted science educators’ understanding of science learning largely because it has legitimized research into the role of prior knowledge on student learning and has illuminated the importance of students’ conceptual frameworks in learning. The role that the learner’s conceptual ecology plays in conceptual change has also become very important (Strike and Posner, 1990). Traditionally, the conceptual change model has been understood to require that the following conditions be met before accommodation can occur: the learner must experience dissatisfaction with his/her present conception (it cannot solve present anomalies); the learner must find the new conception to be intelligible; the conception must be plausible (it can answer problems previously answered by the previous conception); and the conception must be fruitful.

Conceptual ecology, which includes metaphysical belief, and epistemological commitments, accompanies the learner’s conceptual framework for the particular conceptual field, for example, evolution. It is implicated in controlling and influencing the conceptual changes that can occur. Therefore, in summary, the conceptual change model proposed by Posner et al. (1982) includes wholesale, holistic change eliminating the old (alternative) conception and it is operates in a linear, orderly fashion because it is a rational (logical) process. Its rationality implies that the student reasons by weighing evidence in a logical way and chooses the most valid and overarching concept over the alternative concept to explain a natural phenomenon. The conceptual change of major conceptions is sometimes called accommodation. However, the work of
various researchers in the field of evolution education demonstrates that the conceptual change model of Posner et al. (1982) is not sufficient to explain the conceptual change patterns of major conceptions.

The work of Demastes/Southerland (1994), Demastes/Southerland et al. (1995), and Bishop and Anderson (1990) especially impacted this researcher and was plausible because it caused the researcher to examine what the CCM was really implying. The researcher decided to undertake this project especially since evolution is such an important unifying principle in the biological sciences. The decision to examine the effect of the evolution laboratory on conceptual change was an important part of this study. Many students avoid laboratory courses because of time constraints or because the course is not a degree requirement. Students may mistakenly assume that they would not learn much more than they would by just attending lectures. These were some of the reasons given by the lecture-only participants in this study. Additionally, some of them were excluded because of the limited seats available. The lab course typically would count only one credit and yet involve a lot of work (3 hours per week), about the same time required for the 3-credit lecture course. This discrepancy often downplays the importance of the lab in science, and it makes it easier for students to opt out of taking lab courses.

**Summary of Findings**

This study was in part an attempt to investigate areas suggested for further study (Demastes/Southerland, 1994; Demastes/Southerland et al., 1995). More importantly, it was an attempt to investigate the effects that laboratory teaching and learning can have on conceptual change. With regard to the studies above, the findings
(Demastes/Southerland et al., 1995) suggest that conceptual change patterns include wholesale (holistic and cascade), fragmented (gradual), and dual construction patterns. These patterns are controlled by rational components (logical and extra-logical) and extra-rational components (motivation and affective).

The present study therefore set out to investigate whether other patterns of conceptual change which depart from the Posner et al. (1982) model would occur, and to investigate the effect of the lab on conceptual change. This was investigated for the whole class (research question 2) and individual participants (research question 1). In addition, the relationship between the nature of science and understanding of evolution was investigated (research question 3).

**Conclusions**

The data described and discussed in the results and discussion section of this study led the researcher to important conclusions with regard to the aim of the study. The conclusions most pertinent in answering the research problem and research questions are related to: the alternative conceptions associated with the evolutionary framework, patterns of conceptual change, influences on conceptual change, and the relationship between the nature of science and understanding of evolutionary conceptions.

**Alternative conceptions associated with the evolutionary framework**

Alternative conceptions held by the whole class and interview participants (lecture and lab) were not surprising or even unique to this study. These alternative conceptions for major conceptions included the origin of variation as special creation and mutations caused by a creator/supreme being as part of his design.
Alternative conceptions about other evolution concepts confirmed the findings of previous studies (Demastes/Southerland et al., 1995; Bishop and Anderson, 1990; Brumby, 1984). For example, the collage conception of fitness (Bishop and Anderson, 1990) was well represented among participants in both lecture-only and lecture-lab groups. The alternative conception that mutations are beneficial was very common. Another common alternative conception about mutations was that they cannot be neutral.

Other alternative conceptions for the whole class are included in Appendix K and that of the interview participants are included in the figures 6 through 13 (Conceptual Inventory Profiles for each participant). Alternative conceptions among whole class participants in both comparison groups include the existence of a young earth, humans as exempt from evolution (special creation), that humans do not share a common ancestor with apes, and the rejection of macroevolution. Alternative conceptions for interview participants mirror that of the whole class data.

Conceptual change and patterns of conceptual change

Whole class conceptual change

Primary research question 1:

What does the whole class data reveal about the overall differences in conceptual change between the lecture-only and lecture-laboratory course participants, and the effect of lab learning on their understanding of evolution?

The pre- and posttest surveys were analyzed, and patterns of conceptual change for the major conceptions were discerned. The data analysis showed that for the species concept, both lecture-only and lecture-lab groups experienced wholesale conceptual change. For the unit of evolutionary change, the pattern for the lecture-only group was
wholesale, while for the lecture-only group only 38% experienced wholesale conceptual change, and the rest retained the alternative conception (i.e., the whole population changed). For the origin of variation, in the lecture-only group, some students accepted use/disuse as the origin of variation, others selected mutation, and still others used need as a source of variation. In some instances, the same student used use/disuse, need, and even mutations for different probes on the survey. This indicates that conceptual change followed a dual construction pattern.

In the lecture-lab group, mutation was selected by the majority of students as the source of variation, followed by need and then use/disuse. In the case of this group, conceptual change was mostly wholesale, followed by the dual construction pattern of conceptual change. The latter was observed in the use of use/disuse, need, and mutation as sources of variation on the same survey for a particular student. This was more pronounced in the lecture-only group.

Conceptions of fitness is observed to have undergone a similar pattern of conceptual change as the major conceptions. In the lecture-only group, less than 20% had a dual construction for this concept. In the lecture-lab group, less than 30% held a dual construction for this concept. Further probing by adding a problem-based item on the survey led to the observation that 71% of the lecture-only group had a dual construction for this concept (defined in terms of desirable traits and the number of offspring reaching adulthood), and in the lecture-lab group, only 14% (1/7) held this view. However, the pattern of conceptual change was fragmented and gradual for both groups. This was because the change of conception for fitness was not followed by a cascade of changes in other related conceptions it, for example, natural selection.
Interview participants’ conceptual change

Primary research question 2:

What patterns of conceptual change can be observed in college students and what differences are observed for participants in the lecture-only and lecture-laboratory groups?

Students often used newly acquired conceptions in an incorrect rote-like manner and this seems to indicate that they were experiencing dissatisfaction with their old conceptions but were unsure of how the new one fit into their conceptual framework. The old conception, therefore, is mostly retained and is modified to include newly learned information. The researcher noticed this especially with respondents who reasoned aloud (e.g., Juan). Students who appealed to authority (religious or scientific) instead of logically and rationally weighing the evidence available to them, were more apt to exhibit this phenomenon. It was also apparent that this was tentative and that as the semester progressed, and more knowledge was acquired, the student was able to articulate the correct scientific understanding of the conception. This type of conceptual change is not included in the CCM (Posner, 1982) but has been described by the Demastes/Southerland et al. (1995) study as an incremental pattern (Metz, 1991) or a fragmented/gradual pattern (Nussbaum, 1989).

The fragmented pattern of conceptual change for the “major” conceptions was reported for one student in the lecture-only group, namely, Patricia. In the lecture-lab group, two participants (Juan and Brianna) also exhibited this type of conceptual change for certain concepts. The latter participants held dual constructions too. Conceptual change was not guided by rational, logical thinking; the alternative conceptions about the topic of evolution and the affective, moral implications of the new conceptions...
could have precluded her from trying to integrate the new conception(s). In the case of Patricia, her rejection of human evolution prevented her from dealing with conceptions related to human evolution, and hence she held on to alternative conceptions: human are more perfect and more intelligent than other life forms, they did not evolve, they were not classified as animals, they are not related to apes. She was a biblical literalist for human creation yet accepted the notion of an old earth. She retained all other alternative conceptions even after instruction. In this case, the student made the conscious decision to reject these scientific claims. She did not experience conceptual change for any major conceptions.

Another pattern departing from the Posner et al. (1982) Conceptual Change Model is the dual construction pattern in which the student’s conceptual framework includes two competing conceptions. This was common among the participants in this study. The reasons for the existence of this pattern are varied according to the literature. It could be attributed to poor reasoning skills, insufficient knowledge about the nature of evolution, or the use of extra-logical patterns of concept selection. An example from this study is Patricia’s insistence that everything was created, after which she explained that organisms have common ancestors going back to simple, one-celled organisms. This dual construction pattern represents an inconsistent conceptual framework. The fact that mutations are chance events was not understood by Juan in the preinstruction phase. Later, he understood its random nature, but insisted that they are beneficial to an organism. This was the most common type of conceptual change pattern for the lecture-lab group (four participants) and one of the lecture-only group also experienced this kind of conceptual change pattern. Adrian, Mary and Rhonda
showed dual constructions for some of the major conceptions. Mary ended the semester with dual constructions for the origin of variation (i.e., special creation and mutations). She regressed to the typological species concept.

The other most common type overall was wholesale conceptual change. The two students who underwent this type of conceptual change were Ian and Martin, the former in the lecture-only group and the latter in the lecture-lab group. They had a lot in common; both had a positive scientific orientation, a realist scientific epistemology, very few alternative conceptions about evolution, good understanding of evolution, and acceptance of evolution as a plausible theory to explain the history of the natural world. They reasoned in a scientifically rational and logical way about natural phenomena, and for Martin this was also his philosophy of life. Martin and Ian both experienced wholesale conceptual change for the major conceptual groups (e.g., the species concept), as well as for related conceptions (e.g., fitness). In the researcher’s opinion, although Ian scored higher than Martin on the final objective examination, Martin’s explanations in the interview were less rote-like, included richer examples from nature, and included a better understanding of the nature of science and evolution. He ended up with none of the original alternative conceptions on the posttest survey and interview. He appeared to agree with a scientific method, but his open-ended response refuted this supporting the view that the lab can play a positive role in conceptual change. It was noteworthy that when one conception changed and it was related to another conception, a sequence of conceptual changes occurred. This was especially true for situations where dual constructions were in place. The change in a conception was mulled over, included into the conceptual framework, and when the student had
gained sufficient knowledge, he/she experienced the cascade changes described above over a short period of time (e.g., Mary’s understanding of the major conceptions of evolution). Gaining a good understanding of evolution does not necessarily result in students giving up their religious beliefs (Adrian and Mary).

This researcher noticed a trend in the type of conceptual change pattern experienced at the end of the semester. In the beginning the learner might shift to an understanding of the variable species concept. At this stage the student is said to have a fragmented and gradual conceptual change pattern (because it remained the only changed concept). Then later, when the student had the opportunity to do some lab work (including the natural selection simulation where the concept of chance mutations was brought home) and gained a better understanding of evolution, there was a shift to a scientific understanding of mutation. This would then lead to a cascade of changes for related conceptions. If the student still held alternative conceptions for certain related concepts, this pattern of conceptual change would be categorized as a dual construction pattern. This indicates that perhaps there exists a continuum from fragmented through dual to wholesale conceptual change. Because the stages happen over a short period of time, it is often difficult to detect this continuum.

Factors influencing conceptual change

Conceptual ecology

The influence of aspects of conceptual ecology on conceptual change was clear in this study. Motivational considerations played a role in the case of Juan, a strong religious orientation and moral considerations on the part of Brianna influenced her conceptual change especially with regard to human evolution. A positive scientific
orientation facilitated wholesale conceptual change for Ian and Martin. Brianna, Mary, Patricia, Adrian, and, to a lesser extent, Juan were all influenced by their religious convictions. However, each one “managed” the conflict between evolution and their religious beliefs differently. The issue of human evolution was very controversial for some students (Mary, Brianna, and Patricia). They remained in a conflicted situation in this regard and struggled with the classification of humans as animals. Some students rejected macroevolution and “accepted” microevolution, essentially because of the implications this held for human evolution (Brianna, Mary, and Patricia). Mary did not remain totally in a conflicted situation for evolution. This could have contributed to her movement from away from a confrontation model, to a “selectively” convergent way of thinking about evolution. She represents the student who enters a course with many questions about evolution, and want to see the fields of religion and science “cooperating.” Despite her strong religious views, she was able to understand the basic evolution concepts.

In addition to their rejection of human evolution, Brianna and Patricia shared a very conservative way of thinking. They were closer to six-day (quick) creationists and Mary was closer to the description of the scientific creationist. All three students espoused the views of present-day “young-earth” fundamentalists.

Also showed convergent thinking from the start of this study and ended the study with similar views. According to Adrian, God not only started evolution, he still guides it and evolution is part of his “plan.” However, despite his strong religious views, he was able to articulate his understanding of evolution, and evidence in support of it, intelligently.
Students probably benefitted from the group work in labs because it provided opportunities for addressing their alternative conceptions (e.g., Juan). His religious orientation was not the major influence on his conceptual change. Perhaps because he was still grappling with English as a second language, he was overwhelmed by the terminology he was exposed to in the evolution courses. However, he ended the semester with a better understanding of evolution because he was able to learn more from the lab sessions which included group work, discussions and simulations.

Three students (Ian lecture-only group, Martin lecture-lab group, and Rhonda lecture-lab group) shared the view that evolution and religion are separate, distinct entities. They were able to articulate their understanding of evolution without reference to religion. Ian and Martin had a very good understanding of evolution. Rhonda was an atheistic evolutionist. She supported evolution at the start of this study despite the fact that she held many alternative conceptions. In her case, she ended the semester with a good understanding of evolution as well.

The instructional methods

The instructor's teaching philosophy and instructional methods were also important here. In the lecture, he made explicit through the history of certain concepts how science had arrived at that concept. For example, he explained in detail the various species concepts and where they fit into the history of evolution and biology. This made clear which concepts are unscientific and therefore which are alternative conceptions. The inclusion of history of evolution in the course had an impact on student learning. It allowed students to understand the nature of science and the nature of evolution through the explicit teaching of natural history. The lessons made explicit
the nature of science, and the anecdotes about the instructor’s own experiences as a graduate student were fruitful in this regard. It allowed students to understand important characteristics of the scientific endeavor (National Academy of Sciences, 1998).

In the lab course (Appendix G) students got hands-on practice to develop their understanding of evolutionary conceptions as well as their understanding of the nature of science. The lab course was designed to help students understand that scientists work in a community with other scientists, that they share information, and that there is not one universal general method of doing science. The latter is a common alternative conception among science students. Spiece and Colosi (2000) assert that students fail to understand that science is more complex than they have been taught in introductory biology textbooks; it is not a series of steps scientists follow, and that the method each scientist uses to arrive at his/her theories differs. The lab sessions involved group work and inquiry (e.g., data collection and recording, using computer software to compute statistics, using lab equipment, making inferences from findings, report writing). However, the methods used in the different lab sessions differed, and hence this modeled for students that evolutionists can do controlled experiments or they collect data by means of observations; they do not to follow a single scientific method. The discussion sessions in the lab caused the most conflict in student understanding. In this regard, the sessions on genetic engineering, human evolution, and creationism were most noteworthy. In the posttest survey and interviews, the influence of these labs is clearly noted. The pre-reading articles for this session included Stephen Jay Gould’s *Evolution as Fact and Theory* and the John Moore’s article, *Is “Creation Science”*
Scientific? Both articles examine the claims of Creationism and why it cannot be considered a science. In the posttest survey, all the lab participants rejected the proposal that scientific creationism be given equal time in high school classrooms as an equally valid scientific alternative to evolution. Even students who claimed to be creationists (Mary and Brianna) rejected this on the grounds that scientific creationism was not scientifically valid. Mary was very vocal during this discussion session, but Brianna was very quiet and never participated. In the posttest interview she related to the researcher that she was not in favor of the lab discussion and that it made her extremely uncomfortable. It is noteworthy that she enjoyed the other labs associated with human evolution, but that she used the information there to solidify her belief that humans are more perfect than other life forms. These discussions caused cognitive conflict and were noted by the researcher as critical for effecting conceptual change. Students benefitted from listening to what other students thought about the issues, and perhaps they got answers to some of their questions. These questions included how scientific creationism and evolution differ, the claims of these fields of knowledge, and the essence of genetic engineering. The lecture-only group did not have the benefit of this discussion, and it is noteworthy that there was an increase in the number of those students who felt that scientific creationism should enjoy equal time in high school classrooms.

The lab provided hands-on opportunities for students to develop an understanding of abstract concepts students obtained more examples and were able to build on concepts and knowledge of evolution. The lab might not "help" those who experienced wholesale conceptual change, but it played a big role in conceptual change
of students who experienced other patterns of conceptual change, that is fragmented and dual constructions. The two lecture-lab students who were really able to take advantage of the lab learning were Mary and Rhonda who held dual construction for some concepts but who experienced wholesale conceptual change for other major conceptual groups.

Based on the interview data, the lecture-lab combination differed from the lecture-only course in a number of ways. Labs created opportunities for cognitive conflict. This was noted especially during the discussion sessions. Students were confronted with their own alternative conceptions and were able to consider the scientific conception. Labs promoted understanding of abstract concepts, such as natural selection, by means of hands-on, minds-on activities. Students got practice in using these abstract concepts to explain simulations and were encouraged to relate the simulations to real life. Students also built on concepts and knowledge of evolution and obtained more examples from labs. Therefore labs helped to fill gaps in their knowledge. They promoted student understanding of the nature of science (how science is practiced, as well as how scientific knowledge is arrived at and modified).

Lecture-only participants like Ian would have benefitted from the Natural Selection Lab. He needed more practice understanding the aspects of the theory (e.g., the role of variation, the origin of variation, the unit of evolutionary change), practice afforded students in the lecture-lab group. Other lecture-only students would have benefitted from the discussion sessions. Students like Adrian would have learned more about human evolution. He would also have benefitted from the evolution and scientific creationism discussion; he was not very sure of the controversy. Patricia, the
lecture-only participant, would have benefitted from labs for all of the above reasons. She would also have gained a better understanding of taxonomy and classification systems.

The nature-of-science conceptions

Secondary research question 3:

How does an understanding of the nature of science relate to students’ conceptions of evolutionary concepts (e.g., natural selection, adaptation, variation)?

The study revealed a direct, positive relationship between students’ understandings of evolutionary concepts and understanding of the nature of science (quantitative data analysis and interviews). This study provided insight into how junior and senior college students grapple with the nature of science, nature of evolution, and evolution concepts. Interview results demonstrate that participants who had a good understanding of the nature of science and evolution in this study were more likely to accept evolution as a valid scientific theory and have a good understanding of evolution. This positive relationship was observed for both the lecture-only and lecture-lab groups. This concurs with the findings in the research literature.

Knowledge of evolution can promote student understanding of the nature of science.

In this study it was noteworthy that there was a high frequency of the alternative conception that scientists all follow a general, universal scientific method. This nature-of-science concept appeared resistant to change. It was also noteworthy that whole-class data (final objective examination) indicated that students were not understanding natural selection. They lecture-lab group performed better than the lecture-only for biometry and biogeography questions. This indicates that natural selection is difficult
for students to grasp because it has many abstract subconcepts. The other two areas, biometry and biogeography, involved labs which dealt with more concrete concepts and dealt with topics which were not as controversial.

**Significance of the Study**

Previous studies were conducted with college students and also high school students (Brumby, 1984; Bishop and Anderson, 1990; Demastes/Southerland, 1994; 1995; 1996). The courses used in this study, a theory course and a laboratory course, were in classrooms at a public university in southeastern part of the United States. Student demographics in this study reflected the general population. The interview participants were four males and four females. They were from diverse population groups.

The study is further significant because it expands on the knowledge about how junior and senior college biology majors undergo conceptual change for evolution. Further understanding and verification of other patterns of conceptual change (i.e., fragmented and dual construction patterns) are elaborated on in this study. Furthermore, the impact of the lab on conceptual change for a conceptual field (evolution), which is normally considered to be too abstract for lab work, is also important. The study provides insight into how different lab activities, simulations, and especially discussions can make more explicit alternative conceptions students might hold. The alternative conception is pointed out to students; they are then allowed to weigh the evidence in support of either conception and to make the decision themselves as to which is the most scientifically valid. However, judging from the patterns of conceptual change in this study, it does not always proceed in a clear-cut, logical, and orderly fashion.
New insights into the nature of evolution and the nature of science are provided. Whole class data analysis indicates that participants who had a sound understanding of the nature of science, had a good understanding of the nature of evolution and had the most scientifically coherent and complete conceptual framework for evolution. This pattern was confirmed also for individuals who interview participants.

Students who had very strong religious orientations were able to experience conceptual change and were able to learn new concepts and improve on their previous knowledge. Here Lawson and Worsnop’s (1992) recommendation is valid; learning about evolution does not imply that students have to change their beliefs. They should be taught about how scientists compare hypotheses, their predicted consequences, and the evidence to arrive at their acceptance of a conception. That is, knowledge about the nature of science is instrumental in conceptual change. However, one participant regressed after instruction and after the final examination. Brianna was unable to articulate her understanding of the important concepts of natural selection and mutation, as well as other concepts. She found herself in conflict because evolution posed a threat to her religious beliefs. Macroevolution, and its implications for human evolution, placed her in a situation where she felt that she had to choose. Religion defeated evolution in the case of Brianna.

The mixed-model design implemented in all parts of this study could prove to be a useful way of improving on the design of previous studies which have been limited to paper and pencil data collection, purely statistical studies, or interview-only studies. In this study, mixed-model design enabled the researcher to obtain whole class data and data from representatives in both comparison groups. This enabled the researcher to
gain a better picture of students' alternative conceptions about evolution, as well as patterns of conceptual change for both groups.

Limitations of the study

The surveys and interview probes have a definite zoological bias. Future survey and interview probes should include items on plant and other life forms. Another limitation in this study is the small number of students who participated in the post-test survey; this was unavoidable because of time constraints. The researcher was unable to get students to take the posttest at one sitting, allowing them instead to complete it in their own time. Attrition was also a problem with interview participants as three of the twelve participants withdrew from the study. Therefore data were lost and so were the points of view of these participants. It was not possible to replace these participants with others at the time because the researcher had not had the opportunity to interview them. The study's findings are generalizable to situations which closely match those described in the methods section of the dissertation. The researcher will replicate the study with other relevant student groups to test the generalizability to other situations.

To overcome the possibility of researcher bias, the validity of the findings was established by data triangulation, namely, multiple data collection methods (quantitative and qualitative) and multiple data analysis (t-test, descriptive statistical analysis, content analysis, participant observation, interrater analysis). Thick description of the procedures, methods and participants was implemented to overcome this bias and to facilitate the replication of the study.

Suggestions for further study

The study should be repeated with a larger group of students at the college level. It is suggested that the effect of the lab on conceptual change be further investigated in
other classrooms where evolution is taught. The survey used in this study should be further refined to ensure its reliability and the interview probes should be included on a future survey to gain more understanding of how students solve problems and how conceptual change patterns develop. The instrument was useful in identifying conceptual change patterns for other conceptions as well as possible concepts which control wholesale conceptual change. The survey could include more representative nature of science items; assessment tools for testing nature of science knowledge is needed and researchers have to agree on what exactly the construct means. The concept, nature-of-science still appears to be somewhat of a fuzzy concept which needs to be sorted out by the experts. If the situation is not corrected, teachers and students might incorrectly assume that the topic is too esoteric.

The courses used in this study have been used in previous studies, especially with regard to concept mapping (Trowbridge and Wandersee, 1994; 1996). The researcher would suggest that the lab and lecture courses be the subjects of further study to enable the identification of specific instructional techniques which can facilitate conceptual change for the powerful principle of evolution by natural selection.

This study has confirmed the important relationship between the understanding of the nature of science and domain-specific knowledge, in this case, evolution. The latter is also a central principle of biology, and therefore this relationship has far reaching implications for student understanding of biology. Research at the college level investigating the relationship between nature of science knowledge and domain-specific content knowledge is therefore suggested.

The mixed-model design used in this study was very useful in shedding light on student achievement as well as conceptual change. The researcher recommends that
future studies in laboratory settings and others make of the use the mixed-model philosophy to ensure that research is not based entirely on paper-and-pencil techniques of data collection.

Final thoughts

In our teaching at the college level, we should be aware of the issues which students entering our classes are grappling with. This will allow us to show sensitivity and will enable us to handle situations appropriately. This is especially true for issues which involve the science-religion interface. Furthermore, we need to create situations which can lead to cognitive conflict so that conceptual change and meaningful learning can occur. In order to carry out these tasks, we need to be cognizant of the reform recommendations and also the alternative conceptions students hold, so that we are able to address these in our teaching.

Is it worth it to do labs? The researcher is of the opinion that laboratory work/practical work can help to achieve the goals of evolution education. She makes this statement not simply because of the quantitative and interview results of this study, but also because of her personal experiences. The researcher (as an undergraduate and graduate student) had enrolled in evolution courses which used lectures (with one debate at the end of the semester), seminars, or the lecture-lab format. In this study, the researcher’s role as a participant observer allowed the researcher to participate in the lectures and labs and to observe students. In the researcher’s opinion, the most effective format for teaching evolution is the lecture and lab combination. Lecture-only formats do not allow for very much student-instructor and student-student interaction. Labs allow for these types of interactions and allow time for more feedback to address
student misconceptions. Seminar courses do not allow for hands-on experience; students who learn better by being involved in their learning (to concretize abstract concepts) will not learn effectively in these courses. The researcher has experienced all of the above teaching formats and has come to the conclusion that the lecture-lab format could be very important in a course which aims to promote biological literacy through knowledge of evolution as a unifying principle in biology.

Labs create opportunities for students to grapple with their alternative conceptions and to test their assumptions about evolution. They provide opportunities for students to refine their understanding of abstract evolutionary concepts by providing concrete, hands-on exercises for conceptualization of concepts (McComas, 1997). Labs also provide opportunities for students to use apparatus and develop skills which can be transferred to other lab situations. Finally, lab contributes to student understanding of the nature of science and the nature of evolution. That is, labs help students to develop structural and procedural knowledge about evolutionary biology.

Watson, Priesto, and Dillon (1995) suggest that the “images and episodes” which are established in the memory by means of lab experiences should be used effectively and explicitly to develop concepts. In this study, the researcher observed that lecture-lab participants were not always trying to make this connection. Many came to lab sessions, carried out the assigned activities, and left the lab hurriedly. The researcher would suggest that postlab talks (about 10 minutes) be scheduled into the session time in order for students to grasp the concepts covered. This would also allow them to make the necessary distinctions between lab simulations (e.g., dispersal and vicariance in the biogeography lab) and real-world events (Driver, 1983). The labs
provide a good opportunity for the instructor to gauge student alternative conceptions and an opportunity to monitor their learning. Labs are important to develop a better understanding of the basic evolution concepts. Students who are not able to understand the most basic evolutionary concepts cannot effectively benefit from a biology curriculum at the college level. Evolution is the unifying principle of biology and without this basic knowledge, students cannot reach structural and multidimensional biological literacy, a goal of biology education (BSCS, 1993). At best, many of these students without the basic understanding could reach nominal or functional literacy; this might result in students leaving college with naive theories, alternative conceptions, a limited understanding of biology, and a general lack of interest in biology. This could defeat the noble goals of the reform movements in biology evolution with regard to biological literacy.
REFERENCES


226


228


APPENDIX A: EXAMPLE OF STUDENT RELEASE FORM

Student Release Form

You should be 18 years or older to participate in this study.

Request
My doctoral dissertation focuses on how the biology laboratory course can affect the learning of evolutionary biology concepts. You form part of the focal group for this research project and therefore I am requesting your participation in this important study. The information from this study will be used to improve biology instruction at college level. Participants will remain anonymous in the study and it will not affect your course grade in this class. I will appreciate your participation up to the end of the research project but you do have the right to withdraw when you wish.

Interviews form an important part of my study. I will conduct interviews with selected students. I will meet anytime at your convenience and will be paying you $5.00 per interview (about 30 minutes) to thank you for your time.

Consent
I, ______________________, do hereby give the researcher, Lorna Holtman, permission to use the survey data, interview data (if applicable) and other data sources in the preparation and completion of her doctoral dissertation.

I understand that my participation in her research project is voluntary, and I retain the right to withdraw from the study at any time. By signing this form, I release the said information for her to use with the understanding that it will be kept confidential and at no time will my name be used or connected with any information.

Name of participant:______________________
Contact telephone number:________________
Your email address:______________________
Are you currently enrolled for the Laboratory course (BIOL 3041)_______

__________________________  __________________________
Signature of participant      Date
__________________________  __________________________
Signature of researcher      Date

230

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APPENDIX B: IRB FOR CONDUCTING RESEARCH WITH HUMANS

LSU Office of Sponsored Research/OSR 388-6891; FAX 6792

LSU: HUMAN RESEARCH SUBJECTS

APPLICATION FOR EXEMPTION FROM INSTITUTIONAL OVERSIGHT

Unless they are formally qualified as meeting the criteria for exemption from Institutional Review Board (IRB) oversight, ALL LSU research/projects using living humans as subjects, or samples or data obtained from them, directly or indirectly, with or without their consent, must be approved in advance by the LSU IRB. This Form helps the PI determine if a project may be exempted, and is used to request an exemption.

NOTE: Even when exempted, the researcher is required to exercise prudent practice in protecting the interests of research subjects, obtain informed consent if appropriate, and must conform to the Ethical Principles and Guidelines for the Protection of Human Subjects (Belmont Report) and LSU Guide to Informed Consent; (Available from OSR or http://www.osr.lsu.edu/osr/comply.html).

Instructions: Complete checklist, pp 2-4; if exemption appears possible, follow instructions on p. 4. Otherwise apply to the IRB *

Principal Investigator Lorna Holmman Student? Y/N
Department/Unit Curriculum & Instruction Ph: 344-7572
Project Title The Effects of the laboratory on students' understanding of Evolution
Agency expected to fund project African American Institute (USAID) age
Subject pool (eg. Psychology students) Life Sciences students

Circle any "vulnerable populations" to be used: (children <18; the mentally impaired, pregnant women, the aged, other). Projects with incarcerated persons cannot be exempted: apply directly to IRB.

I certify my responses are accurate and complete. If the project scope or design is later changed I will resubmit for review. I will obtain written approval from the Authorized Representative of all non-LSU institutions in which the study is conducted.

PI Signature __________________ Date ____________

Screening Committee Action: Exempted ___ Not Exempted ___ *

Reviewer __________________ Signature __________________ Date ______

Comments __________________

cc PI (signed face page only); OSR Director (application with protocol) 117 David Boyd Hall, LSU.

* PI: Obtain a current IRB application packet from the IRB office (8-1492; karenb@lsu.edu; 117 David Boyd Hall, LSU).
Students in the lecture group were better prepared with the “correct” scientific terminology for explaining their choices. However, alternative conceptions, especially Lamarckism and teleology, were present even in the better prepared students’ responses. In the group who had not done any college biology, there was a larger proportion of students who identified with Creationist statements. Some used fundamentalist ideas and language to explain their choices. For example: “God could have chosen evolution if he wanted to”; “God created Adam and Eve”. They were also prone to see humans as special (anthropocentrism). Fifty five percent agreed that “Human beings are different from nonliving things because they possess a soul”. One respondent noted that “Jesus died to save humans’ souls”.

One hundred percent of the students in the lab and lecture group agreed with the typological species concept. Twenty five percent of the smaller group identified the role reproduction played in the species concept (variable species concept). “Need” and use/disuse (Lamarckism) alternative conceptions were prevalent among all respondents: 95% of the larger group agreed that ducks “need” webbed feet to swim in water. Seventy five percent of the smaller group also agreed with this statement. Ninety percent agreed that cheetahs’ muscles and bones adapted as they ran faster. This suggests that the traits are passed on to the next generation and that all members change. Seventy five percent of the smaller group also hold this misconception. Twenty percent agreed with the statement that if the tails of cows were cut off, this would be inherited by subsequent generations over time (Lamarckism). Twenty five percent (1 in 4) of the smaller group agreed.

Six items dealt with the Nature of Science. Seventy percent agreed that “Research scientists all follow a general and universal scientific method”. Fifty percent of the smaller group agreed. The smaller group scored higher on the NOS items than the larger group.

The post-test followed three weeks later. Seventeen of the 26 students who sat for the pre-test survey also sat for the post-test survey. 13 from the lab and lecture course completed the post-test survey; the same 4 of the smaller group completed the post-test. Results for the posttest survey are indicated next.

Sixty percent (60%) of respondents (up from 55%) believed that humans have a soul. Ninety percent believed that all cheetahs’ bones and muscles change and adapt as they run faster (Lamarckism). Eighty percent (80%) still understood the development of webbed feet in ducks in teleological terms (need) (down from 95% on the pre-test). Sixty percent (60%) (up from 20%) now agreed with the Lamarckian concept that the tails of cows which are cut off can be inherited from generation to generation (Refer to Figures 3 and 4). With the smaller group, the alternative conceptions of need and use/disuse were still in place. There was no change except that items which were previously left unanswered on the pretest survey, were answered on the posttest survey.

The larger group showed a 5% increase in the alternative conception that humans evolved form apes, and a 30% increase in the belief that evolution affected all
living things except humans and a 5% increase in the belief that human had a soul. The smaller group, which had completed more college biology courses, showed less alternative conceptions. Twenty five percent understood that humans evolved from apes, and there was a 25% drop in the item that humans have a soul.

The larger group showed an increase in all but one Nature of Science item (they moved as a group toward the alternative conceptions). There was a 40% increase in the item which suggests that scientists follow a universal scientific method. The smaller group however, showed a 25% drop in this item after instruction.

Generally, the smaller sample moved slightly toward the scientific conceptions. The larger group was reluctant to change their original views, and one respondent stated that her responses were the same as for the original survey.
APPENDIX D: FINAL VERSION OF PRETEST/POSTTEST SURVEY

Name: __________________________ (Will remain confidential)

Pre-/posttest survey: Conceptual Inventory about Evolution and the Nature of Science.

Directions:

Each question on this survey has two parts. Your response to the first part involves selecting the option that best completes the phrase. These options are indicated as agree or disagree options. Please complete only one option.

Part two requires an explanation for your choice which is to be provided in the space provided. If you need more space, please use the back of the questionnaire making sure to number your responses.

1. The Darwinian theory of Evolution by Natural Selection has a valid scientific foundation.
   Agree ______ disagree ______
   Please explain your choice:------------------------------------------------------------------

2. Mutations and other variations arise by chance only.
   Agree ______ disagree ______
   Please explain your choice:------------------------------------------------------------------

3. Mutations equip the organism with better means of surviving in its environment.
   Agree ______ disagree ______
   Please explain your choice:------------------------------------------------------------------

4. Research scientists all follow a general and universal scientific method.
   Agree ______ disagree ______
   Please explain your choice:------------------------------------------------------------------
5. If the theory of Evolution can be taught in high school classrooms, then Scientific Creationism should be given equal time as both are equally valid scientific alternatives to explaining present life forms.
   Agree _____ disagree _____
   Please explain your choice:-----------------------------------------------
   -----------------------------------------------------------------------

   Agree _____ disagree _____
   Please explain your choice:-----------------------------------------------
   -----------------------------------------------------------------------

7. Human forms are more perfect life forms than lower animals.
   Agree _____ disagree _____
   Please explain your choice:-----------------------------------------------
   -----------------------------------------------------------------------

8. The earth’s present-day life forms have evolved from common ancestors going back to the simplest one-celled organisms.
   Agree _____ disagree _____
   Please explain your choice:-----------------------------------------------
   -----------------------------------------------------------------------

9. Humans and apes share a more recent ancestor than humans and dogs.
   Agree _____ disagree _____
   Please explain your choice:-----------------------------------------------
   -----------------------------------------------------------------------

10. Human beings are different from other living things because they possess a soul.
    Agree _____ disagree _____
    Please explain your choice:-----------------------------------------------
    -----------------------------------------------------------------------

11. Darwinian or genetic fitness refers to an individuals long-term survival, robust health, strength and the number of females in his harem.
12. Below are descriptions of four male lions. According to our understanding of evolution and Darwinian “fitness”, a biologist would say that George is the fittest lion.

<table>
<thead>
<tr>
<th>Name</th>
<th>George</th>
<th>Ben</th>
<th>Spot</th>
<th>Sandy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>10 feet/175 lbs</td>
<td>8.5 feet/160 lbs</td>
<td>9 feet/162 lbs</td>
<td>9 feet/160 lbs</td>
</tr>
<tr>
<td>Number of cubs fathered</td>
<td>19</td>
<td>25</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Age at death</td>
<td>13</td>
<td>16</td>
<td>12</td>
<td>9</td>
</tr>
<tr>
<td>Number of cubs reaching adulthood</td>
<td>15</td>
<td>14</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>Comments</td>
<td>Strongest lion; very large and healthy.</td>
<td>Greatest number of females in harem.</td>
<td>Area in which Spot lived was destroyed by fire. He moved his pride to a new area and changed his feeding habits.</td>
<td>Sandy was killed by an infection resulting from a cut in his foot.</td>
</tr>
</tbody>
</table>

Agree _____ disagree_____
Please explain your choice:-----------------------------------------------

13. Organisms evolve so that they are perfectly suited to their environment.
Agree _____ disagree_____
Please explain your choice:-----------------------------------------------

14. Science and technology are the same.
Agree _____ disagree_____
Please explain your choice:-----------------------------------------------
15. There are alternative theories more useful than evolution in explaining the history of the natural world.

   Agree _____ disagree_____

   Please explain your choice:-------------------------------------

   _______________________________________________________

   _______________________________________________________

16. The eyes of blind cave salamanders are nonfunctional because the salamanders were not using their sight. Blindness first appeared in the cave salamanders by the gradual decrease in sight in all cave salamanders due to living in dark.

   Agree _____ disagree_____

   Please explain your choice:-------------------------------------

   _______________________________________________________

   _______________________________________________________

17. Human beings evolved from apes.

   Agree _____ disagree_____

   Please explain your choice:-------------------------------------

   _______________________________________________________

   _______________________________________________________

18. A species is a group of organisms that have similar traits.

   Agree _____ disagree_____

   Please explain your choice:-------------------------------------

   _______________________________________________________

   _______________________________________________________

19. Biologists believe that ducks evolved from land birds which did not have webbed feet. According to the neo-Darwinian theory, the trait of webbed feet most likely first appeared as a slight webbing in all ducks as the population gradually adapted to the environment.

   Agree _____ disagree_____

   Please explain your choice:-------------------------------------

   _______________________________________________________

   _______________________________________________________

20. According to the neo-Darwinian theory the mechanism which mostly likely caused the trait of webbed feet to become established in the duck population over time are mutations which occurred in many individuals.

   Agree _____ disagree_____

237
21. Cheetahs (large African cats) run faster than 60 miles per hour when chasing prey. Their ancestors ran about 20 miles per hour. Cheetahs therefore gradually ran faster and their bones and muscles changed to adapt to this.

Agree _____ disagree _____

Please explain your choice:-----------------------------------------------

---------------------------------------------------------------------

22. Evolution conflicts with the biblical account of creation.

Agree _____ disagree _____

Please explain your choice:-----------------------------------------------

---------------------------------------------------------------------

23. Evolution is basically the evolution of humans.

Agree _____ disagree _____

Please explain your choice:-----------------------------------------------

---------------------------------------------------------------------

24. Living things look essentially the same today as when life first appeared on the Earth.

Agree _____ disagree _____

Please explain your choice:-----------------------------------------------

---------------------------------------------------------------------

25. Evidence for evolution can be found in the areas of molecular biology and comparative anatomy.

Agree _____ disagree _____

Please explain your choice:-----------------------------------------------

---------------------------------------------------------------------

26. Science is a solitary pursuit.

Agree _____ disagree _____

Please explain your choice:-----------------------------------------------

---------------------------------------------------------------------
27. Acceptance of new scientific knowledge is straightforward.
   Agree ______ disagree______
   Please explain your choice:--------------------------------------
   -----------------------------------------------------------------
   -----------------------------------------------------------------

28. The Earth is billions of years old; at least 4.5 billion years.
   Agree _____ disagree_____ 
   Please explain your choice:--------------------------------------
   -----------------------------------------------------------------
   -----------------------------------------------------------------

29. Evolution affected all living things, except humans because they were created.
   Agree _____ disagree_____ 
   Please explain your choice:--------------------------------------
   -----------------------------------------------------------------
   -----------------------------------------------------------------
Research Questions

1. What do the whole class data reveal about the overall difference in conceptual change between the lecture-only and lecture-laboratory course participants, and the effect of laboratory learning on their understanding of evolution?

2. What patterns of conceptual change can be observed in college students and what differences are observed for participants in the lecture-only and lecture-laboratory groups?

3. How does an understanding of the nature of science relate to students' understanding of evolutionary concepts (e.g., natural selection, adaptation, variation)?

World view
Science is a way of knowing
Evolution is a unifying principle in Biology

Theories
CCM & Revisionist CCM
Biological Evolution
Lab theory
Alternative conceptions
Mixed Model studies
Grounded theory

Practice
Interview techniques are qualitative research techniques
Aspects of evolution theory are natural selection, mutation, variable species concept.

Value Claims
Conceptual Change teaching needs to be investigated in different settings, e.g., labs
Effect of lab on student understanding of evolution

Knowledge Claims
Aspects of conceptual ecology can influence conceptual change

Transformations
Survey data coded and analyzed
Interviews transcribed, coded and analyzed
Pretest-posttest surveys to detect whole class conceptual change
Objective final examination correlated with posttest survey

Events
Students directly encounter evolution concepts in the evolution labs
Participants Observation
Students respond to survey (pre- & posttest)
Students participate in interviews (pre- & posttest)

APPENDIX E: VEE DIAGRAM OF RESEARCH
APPENDIX F: DEMOGRAPHIC INFORMATION REQUEST FORM

Demographic Information for (Name) __________________________(confidential)

Please complete the following information which will help me to better analyze the information you provided in the surveys and/or interviews. The survey on the next page is the same as the one you completed in August. I would like to see if you still hold the same opinions and/or if your understanding of the concepts has changed since then.

1. Your age: ________  2. Your major __________
3. Gender ______________
4. Which science classes have you taken / are you currently enrolled for at college level which dealt with / deals with organic evolution (include lab courses)?

5. Expected graduation date: ______________
6. Number of years in college ______________
7. What are your plans after college?

8. Do you have family who are in science related careers? ______________
9. Do you have any science related hobbies? ______________
10. Do you read science magazines, journals, science fiction or science programs on television in your spare time? (Name them)

11. Why did you enroll for this course?

12. What was your opinion about evolution and science before this course? Has it changed at all?

13. Are you enrolled for the Evolution Laboratory course?
   Yes ________ No ________
   Why have you enrolled/ not enrolled for the Evolution Laboratory course?

Thanks!!!!!!!!!!!!

I want to thank you for participating in my study; without your participation, my study would not have been possible. I wish you all the best for the future.

Sincerely Lorna Holtman (tel./fax 344-____ if you have any questions)
APPENDIX G: SYLLABI FOR BIOL 3040 AND BIOL 3041

Lecture Schedule BIOL 3040

_The Historical Perspective-Required readings:_ Chapters titled _Natural Selection_ and _Recapitulation and Conclusion_ from _The Origin of Species_ (Darwin, 1859); Ridley textbook, Chapters 1 and 3 (read Chapter 2 if you need to review your basic genetics).

Aug. 21 - Organizational meeting and introduction to the concept of evolution

Aug. 24 - Origins of evolutionary thought

Aug. 26 - Early ideas of evolution

Aug. 28 - Charles Darwin and the voyage of the _Beagle_

*Species Concepts and Species Attributes* (Ridley, Chapter 15, pp.398-405)

Sept. 9 - The "Modern Synthesis"

Sept. 11 - The nature of evolutionary units; Species concepts

Sept. 14 - The Biological Species concept

*Mendelian Populations* (Ridley, Chapter 15, pp.405-423)

Sept. 16 - Reproductive isolating mechanisms

Sept. 18 - Models of population growth

Sept. 21 - Variation in natural populations

*Population Genetics I* (Ridley, Chapter 4, pp. 77-86; Chapter 5, 91-100)

Sept. 23 - The causes of evolution; Hardy-Weinberg equilibrium

Sept. 25 - Mutation

Sept. 28 - Gene flow

*Population Genetics II* (Ridley, Chapter 4, pp.69-77; Chapter 6)

Sept. 30 - Genetic drift

Oct. 2 - Nonrandom breeding

Oct. 5 - Natural selection I: Stabilizing, directional, and disruptive selection

*Population Genetics III* (Ridley, Chapter 12)

Oct. 7 - Natural selection II: The general selection model

Oct. 9 - EXAMINATION I (covers material through lecture on nonrandom breeding)

Oct. 12 - Group selection, kin selection, and sociobiology

242
Geographic Variation and Speciation (Ridley, Chapter 9, pp. 222-240)
Oct. 14 - Phenotypic variation; Polygenic traits; Heritability
Oct. 16 - Variation over geography; The "niche" concept
Oct. 19 - Ecogeographic rules; Subspecies concepts
Oct. 21 - Clines and hybrid zones

Speciation and Evolutionary Rates (Ridley, Chapter 16, pp. 425-450; Chapter 20)
Oct. 23 - Modes of speciation I
Oct. 26 - Modes of speciation II
Oct. 28 - A general theory of speciation
Oct. 30 - Fall Holiday

Nov. 2 - Rates of evolutionary change

Building Phylogenetic Trees (Ridley, Chapter 14, pp. 371-387)
Nov. 4 - Tracing ancestor-descendant relationships
Nov. 6 - Phenetics and cladistics I
Nov. 9 - Phenetics and cladistics II
Phyletic Patterns; Macroevo1ution (Ridley, Chapter 14, pp. 387-395)
Nov. 11 - The molecular clock
Nov. 13 - EXAMINATION II (covers material through lecture on the molecular clock)
Nov. 16 - Phyletic patterns and biogeography

Macroevo1utionary Phenomena I (Ridley, Chapter 21, pp. 582-596)
Nov. 18 - Introduction to macroevolution
Nov. 20 - Evolutionary trends and laws
Nov. 23 - Gradualism and punctuated equilibria
Nov. 25 - Adaptation

Macroevo1utionary Phenomena II (Ridley, Chapter 21, pp. 596-607)
Nov. 30 - Ontogeny and phylogeny
Dec. 2 - Evolutionary innovations and the origin of higher taxa
Dec. 4 - Human evolution; diversity of life; the nature of science
Dec. 12 - FINAL EXAMINATION
Laboratory Schedule

August 25 Lab 1 - Organizational meeting. Video: The Evidence for Evolution (30 min.). The use of "concept mapping" as a learning tool in this course.

September 1 No laboratory (MSH in Mexico)

September 8 Lab 2 - Introduction to Biodiversity. The role of systematic collections in science. Measuring biological diversity.

September 15 Lab 3 - Exercises in Taxonomy and Classification. Video: Taxonomy: How Living Organisms Differ (36 min.).

September 22 Lab 4 - Biometry. Rationale, collection of data, statistical analysis, and interpretation. Lab report due next week. Bring a calculator to next week’s lab!!!

September 29 Lab 5 - Protein Electrophoresis and Population Genetics. Techniques, genotype analysis, heterozygosity, polymorphism. Lab report due next week. Bring a calculator to this lab!!!

October 6 Lab 6 - Genetic Drift. The importance of population size in natural populations. Practical introduction to Wright's F-statistics. Lab report due next week. Bring a calculator to this lab!!!

October 13 Lab 7 - Natural Selection. Experiments that simulate the effects of natural selection and adaptation in changing environments. Lab report due next week. Bring a calculator to this lab!!!

October 20 Lab 8 - Biogeography. Experiments that simulate the effects of dispersal and vicariance on organismal distribution. Lab report due next week.

October 27 Lab 9 - Building Phylogenetic Trees. Application of phenetic and cladistic methods to a group of mock "organisms." Lab report due next week. Bring a calculator to this lab!!!

November 3 Lab 10 - Genetic Engineering and Eugenics. Discussion of scientific and moral issues. Video: Genetic Engineering (35 min.). Argumentative essay due at beginning of this lab.

November 10 Lab 11 - Evolution and Creation Science. Discussion of the controversy. What is science? What is a scientific theory? Argumentative essay due at beginning of this lab.

November 17 Lab 12 - The Evolution of Homo sapiens. Discussion of human origins and our relationship to the evolutionary process. Video: Evolution and Human Equality (42 min.).

244

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APPENDIX H: EXAMPLES OF INTERVIEW PROBES

Structured interviews which are adapted from the Bishop and Anderson study (1985) and the Demastes/Southerland study (1994).

Interview about instances
Respondents will be shown graphics and asked to think-aloud and discuss their thoughts as they observed the graphics. The interview will elicit students' understanding of adaptation, the species concept, taxonomy and speciation.
Example of graphic:
1. The Galapagos finches (Darwin's Finches) with the variation in bill structure.
2. Graphic showing three different types of cats: lion, tiger, leopard.

Evolutionary patterns and patterns of evolutionary change
Respondents will be shown graphics of evolutionary patterns and have to select the one (s) that best depict evolution.
(See graphic on the next page)
1. Line drawing depicting evolutionary change:
2. Line drawing of incorrect relationships between certain animal groups, e.g., vertebrate "family tree" (fish, frog, human, snake, bird)

Prediction Interviews
1. Respondents are shown a graphic and are asked to make a prediction based entirely on their initial observation. The second diagram is shown to the respondent and they are asked to make predictions again. The last stage entails an explanation of the difference between their prediction and the outcome of the situation.
   The prediction interview graphics for knowledge of genetics are mice with tails removed who reproduce and have offspring all with tails. Another graphic shows two mice one with and another born without a tail. Some of their offspring had tails and some did not (Demastes, 1994).
2. Prediction questions:
   Antibiotic problem: Scientists have warned doctors of the danger of their increasing use of antibiotics for treating minor infections. What is the reason for their concern?
   Insecticide problem: When they were first sold, aerosol insecticides were highly effective in killing flies and mosquitoes. Today some 20 years later, a much smaller proportion of these insects die when sprayed. Explain why you think this may be so.
   Skin color problem: If we suppose that humans originally arose in one place, say Africa, where some of the oldest human skulls have been found, then how do you account for the different skin colors that exist in the different races around the world today? What would you predict would happen to this couple's skin (dark-skinned) if they went and lived permanently in Scotland? If they had children in Scotland, what would their children's skin look like at birth? What would you predict would happen to the skin of the little girl (very light-skinned), if she went and lived in Africa for the rest of her life? If she married someone of her own race, they lived in Africa, and had

245

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children there, what do you predict their children’s skin would look like at birth (Brumby, 1994)?

**Sorting Task**
Respondents were shown a number of graphics to differentiate between Darwinian natural selection and Lamarckian inheritance of acquired characteristics (Hoagland & Dodson, 1995: p. 215).

**Drawing task**
Respondents were asked to draw a time line which depicted the history of life on earth.

**Examples of open-ended/unstructured interview questions:**
1. What do you think about the Lock Ness monster? How about psychics and tarot cards?
2. What is your opinion about evolution?
3. Can you differentiate between natural selection, variation, mutation, adaptation.

4. How did the labs help with your understanding of evolution.
5. What did you think about the labs on biogeography, natural selection, etc.?
6. Why did you enroll for the course (s) in evolution?
This process was repeated many times until the long necks found in modern giraffes finally developed.

Since variation exists amongst the members of a species, some ancestral giraffes just happened to have slightly longer necks.

Short-necked ancestral giraffes had to stretch their necks in order to reach the leaves of the trees on which they fed.

By natural selection, the longer-necked giraffes survived since they could reach food and the short-necked ones died.

Their offspring inherited these slightly longer necks which they in turn stretched during feeding.

Only those animals with the longest necks survived and produced more long-necked giraffes.

Sorting task graphic: giraffe sorting task
Prediction interview example of graphic: mice graphic
APPENDIX I: EXAMPLES OF THE INSTRUCTOR DEVELOPED ITEMS

Phylogeny:
1. Recent considerations of the relationship between ontogeny and phylogeny reveal that there are two principles means of achieving a paedomorphic descendant through heterochrony. Name these two processes and use a graph to describe each of them. If necessary, also include a short verbal explanation of each process. (10 Points)
2. Which of the following defines “cladogenesis”?
   A. change in a lineage (without branching)
   B. directional change in a lineage (without branching)
   C. branching in a lineage (usually equivalent to speciation) (4 points)

Allometry/biometry:
1. When a structure becomes relatively smaller as overall body size increases in a lineage of organisms, we call this:
   A. allometry
   B. isometry
   C. positive allometry
   D. negative allometry
   E. none of the above (4 points)

Biogeography:
1. Explain what is meant by “vicariance biogeography.” (7 points)
2. Scientists working in the field of “historical biogeography” study:
   A. the distribution of living organisms
   B. the distribution of extinct organisms
   C. the distribution and abundance of organisms at a single point of time.
   D. changes in the distribution and abundance of organisms over time.
   E. none of the above (4 points)

Natural Selection
1. Darwin’s mechanism for evolution (i.e., natural selection) departed from earlier ways of thinking about evolution in that it:
   A. incorporated Mendelian genetics into our evolutionary thinking
   B. sought to explain the “sense of purpose” that drives evolutionary change
   C. revived the early Greek concept of the “eidos”, or ideal form
   E. none of the above (4 points)
2. What is the main idea behind “species selection”? (7 points)
### APPENDIX J: WHOLE-CLASS CONCEPTUAL INVENTORY

<table>
<thead>
<tr>
<th></th>
<th>Lecture</th>
<th>Lect-Lab</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td></td>
<td>% Correct</td>
<td>% Correct</td>
</tr>
<tr>
<td>1. The Darwinian theory of Evolution by Natural Selection has a valid scientific foundation.</td>
<td>94</td>
<td>95</td>
</tr>
<tr>
<td>5. If the theory of Evolution can be taught in high school classrooms, then Scientific Creationism should be given equal time as both are equally valid scientific alternatives to explaining present life forms.</td>
<td>94</td>
<td>76</td>
</tr>
<tr>
<td>8. The earth's present-day life forms have evolved from common ancestors going back to the simplest one-celled organisms.</td>
<td>79</td>
<td>67</td>
</tr>
<tr>
<td>13. Organisms evolve so that they are perfectly suited to their environment.</td>
<td>68</td>
<td>95</td>
</tr>
<tr>
<td>15. There are alternative theories more useful than evolution in explaining the history of the natural world.</td>
<td>72</td>
<td>91</td>
</tr>
<tr>
<td>22. Evolution conflicts with the biblical account of creation.</td>
<td>62</td>
<td>67</td>
</tr>
<tr>
<td>24. Living things look essentially the same today as when life first appeared on the Earth.</td>
<td>94</td>
<td>100</td>
</tr>
<tr>
<td>28. The Earth is billions of years old; at least 4.5 billion years.</td>
<td>94</td>
<td>91</td>
</tr>
</tbody>
</table>

Subtotal: Nature of evolution | 82 | 85 | 73 | 62 |
2. Mutations and other variations arise by chance only.

3. Mutations equip the organism with better means of surviving in its environment.

11. Darwinian or genetic fitness refers to an individual's long-term survival, robust health, strength and the number of females in his harem.

12. Below are descriptions of four male lions. According to our understanding of evolution and Darwinian “fitness”, a biologist would say that George is the fittest lion.

16. The eyes of blind cave salamanders are nonfunctional because the salamanders were not using their sight. Blindness first appeared in the cave salamanders by the gradual decrease in sight in all cave salamanders due to living in dark.

18. A species is a group of organisms that have similar traits.

19. Biologists believe that ducks evolved from land birds which did not have webbed feet. According to the neo-Darwinian theory, the trait of webbed feet most likely first appeared as a slight webbing in all ducks as the population gradually adapted to the environment.

20. According to the neo-Darwinian theory the mechanism which mostly likely caused the trait of webbed feet to become established in the duck population over time are mutations which occurred in many individuals.
21. Cheetahs (large African cats) run faster than 60 miles per hour when chasing prey. Their ancestors ran about 20 miles per hour. Cheetahs therefore gradually ran faster and their bones and muscles changed to adapt to this.

25. Evidence for evolution can be found in the areas of molecular biology and comparative anatomy.

Subtotal: Alternative Conceptions

7. Human forms are more perfect life forms than lower animals.

9. Humans and apes share a more recent ancestor than humans and dogs.

10. Human beings are different from other living things because they possess a soul.

17. Human beings evolved from apes.

23. Evolution is basically the evolution of humans.

29. Evolution affected all living things, except humans because they were created.

Subtotal: Human evolution

4. Research scientists all follow a general and universal scientific method.

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<tr>
<td>14. Science and technology are the same.</td>
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<td>86</td>
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<td>26. Science is a solitary pursuit.</td>
<td>83</td>
<td>81</td>
<td>71</td>
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<td>27. Acceptance of new scientific knowledge is straightforward.</td>
<td>92</td>
<td>91</td>
<td>100</td>
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<td>Subtotal: Nature of science</td>
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<td>79</td>
<td>63</td>
<td>74</td>
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</table>
APPENDIX K: EXAMPLES OF STUDENT RESPONSES

“Major” Concepts:

Species concept:
“We must have similar traits in order to reproduce.”
“A species have similar traits and can interbreed.”
“Just because they are similar doesn’t mean that they are genetically compatible.”
“Species are organisms that can interbreed to successfully produce successful offspring which cannot breed successfully with other species.”
“Yes, species look alike and therefore belong to a group.”

Unit of evolutionary change:
“The mutation probably occurred in one or a few individuals.”
“A single individual would be sufficient.”
“Birds with webbed feet were able to reproduce more successful offspring.”
“The mutation gave all the ducks an advantage.”

Origin of variation:
“Maybe the blind cave salamanders were using their hearing and smell more than their eyes.”
“The cave salamanders did not need eyes, because the cave was dark.”
“The cheetahs needed to run faster in order to keep up with the prey.”
“I think that the film that protects their eyelids (salamanders) grew thicker as it wasn’t moved since they didn’t need to open their eyes.”
“I think that some other trait caused blindness to become prominent in the population.”
“Blindness was no longer a disadvantageous feature so not selected out of the population.”

Other concepts:

Human evolution
“Not only in creation were we made in God’s own image, but in evolution we are more intelligent thus making us more perfect.”
“We possess a soul; although we are not perfect, we are the chosen life to worship in fellowship with Christ and will live eternally with God.”
“We have evolved - look at our technological advances. Evolution from cave man to computer wizards”
“We were created by God, but not as we are today. I believe we evolved to what we are today.”
“I believe that humans have evolved. I believe that God’s Adam and Eve were not exactly like us.”
“Scientifically I believe humans evolved; religiously I don’t (hard to decide.”
Age of earth
"The earth is about 4.5 billion years old, that is what the fossils and geology tell us."
"I don’t know for sure, but older than 1000 years.”
"Yes, it is at least 4.5 billion years old. Change is slow and gradual. Darwin finding shells in mountains of South America, long time for this to happen.”
"Fossil evidence and continental drift influences my opinion.”
"I agree to some extent that the earth is at least 4.5 billion years old, because that is what I have been taught in school. But if creation and evolution were given equal time in school, 4.5 billion years would not be the first age which comes to mind. I would have a choice.”
"I believe in the biblical version for the age of the earth.”
"I disagree that the earth is about 4.5 billion years; I would say it is between 10,000 and 100,000 years old.”

fitness
"I think fitness would select for the number of males in a harem rather than the number of females.”
"Number of surviving offspring.”
"Number of females in the harem.”
"Refers to the individual best able to survive in his/her surroundings (and adapt to it).”
"Fitness refers to health, longevity, number of females and number of offspring.”
"It also has to do with the fitness of the offspring.”
"Fitness is the ability to survive and reproduce successfully.”
"Genetic fitness just means greatest number of viable offspring reaching reproductive maturity.”

Nature of Science
"Scientists follow a scientific method, but they all have different ideas.”
"Scientists all strive to tackle a problem and must do it in the same manner of testing and retesting and hypothesizing”
"Science does not provide absolute proof; I believe that there is a more powerful force guiding us all, through my religious beliefs I feel goes beyond science”
"Theories can be tested and therefore have the possibility of being disproved”
"Science does provide proof; science teaches things that have been proven.”
"In most cases science proof is absolute, but some science is still hypothesis.”
"Science is a method of study/observations and testing; technology only improves our ability to gain info or make it easier.”
"Science can be tested; technology is improvement on things.”
"Science is not a pursuit of a single person - it is a shared pursuit; it demands communication and co-operation.”
"Scientific knowledge should always be questioned.”
"Most new scientific knowledge is based on fact.”
"It should be questioned, reproduced, argued. That way we know it will be correct.”
"Acceptance of science knowledge is not straightforward; people still don’t agree with Darwin’s theory totally.”
APPENDIX L: STUDENT TIMELINES

Beginning of the universe (14 billion years ago)

Formation of the earth (4.5 billion years ago)

nucleic acids (3.5 billion years ago)

Protists cells

eukaryotic cells (true cells) - beginning of life

multicellular organisms

Proliferation of plants and animals (sea to land)

Dinosaurs (Triassic, Jurassic)

Humans (came later)

Ian's time line for major events in the history of life on earth (redrawn from the original)

DINOSAURS (*)
animals on land
& water

Earth Plants Fish Animals of the air humans

Patricia's time line for major events in the history of life on earth (redrawn)

(* she capitalized the word “dinosaurs”)

256
God decided to create world
- Big Bang
- Earth formed
- water & other organic compounds
- create life.
- small scale life.
- Gradually to large scale
- Dinosaurs
- Astroid
- Death of Dinosaurs
  (Much of life too)
- Out of ashes & decay new life
  - Long time
  - Man (ancestral) in Africa
  - Evolve to Homo sapiens
  - 4 A.D.-----------> Jesus
  - 1998-----------> Evolution w/H-----

Adrian’s time line for major events in the history of life on earth

Earth is life - many or not
is formed not sure
how many kinds

| 5 bya | 1 bya | Dinosaurs | Cyanobacter | eukaryotes | (humans) |

Martin’s time line for major events in the history of life on earth
(Redrawn from the original)
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<thead>
<tr>
<th>Earth - 10 000-100,000 s years old</th>
<th>plants</th>
<th>animals</th>
<th>humans</th>
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Mary’s time line for the major events of the history of life on earth (Redrawn from original)

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<thead>
<tr>
<th>Earth</th>
<th>Trees</th>
<th>Bodies of water</th>
<th>Dinosaur</th>
<th>Apes</th>
<th>Man</th>
<th>Women</th>
<th>Animals</th>
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Brianna’s time line for the major events of life on earth (redrawn from original)
Rhonda’s time line for the major events of life on earth (original drawing)
## August 1998

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**Appendix M: Time Frame of Proposed Research**
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<td>* Video Evolution &amp; human equality</td>
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<td><strong>Macroevolution</strong></td>
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<td>* gradualism &amp; punctuated equilibrium</td>
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## December 1998

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</table>
Lorna Holtman (nee Mocke) is a native of District Six, Cape Town, South Africa. She is the proud daughter of Avril and Neville Mocke, and oldest sister to a sister and four brothers. Ms. Holtman and her husband have two children, Jade Aiden and Lisa Erin. They have followed her to Baton Rouge and as a family, consider this to be their second home.

She was educated in public schools and universities on the Cape Flats in South Africa, and obtained her teaching qualifications through distance education at the University of South Africa, Pretoria. Her interest in science was nurtured by the beautiful Cape scenery and wonderful teachers, and her love for teaching fueled her interest in science education. She taught at the University of the Western Cape (UWC) in the Zoology Department since 1988 before coming to the United States as an ATLAS (USAID program) scholar to pursue the doctoral degree in science education in the Fall of 1996. The scholarship enabled her to concentrate on her studies as a full-time student. The people of Baton Rouge, and LSU in particular, will always be a very special part of her memories of the United States.

After completing the degree of doctor of philosophy, Ms. Holtman will return to her homeland to teach at her alma mater, UWC. She looks forward to spending time with her parents and siblings, and the many nephews and nieces who were born in her absence.

265
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Lorna Benita Holtman

Major Field: Curriculum and Instruction

Title of Dissertation: The Effects of the Laboratory on College Students' Understanding of Evolution: Implications for Conceptual Change

Approved:

[Signatures]

Date of Examination:

10 October 2000

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